INSTITUTE OF ENERGY, PEKING UNIVERSITY

# THE PRESENT AND FUTURE OF SUSTAINABLE AVIATION FUELS IN CHINA

北京大学能源研究院
INSTITUTE OF ENERGY

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- Fossil fuel consumption cap;
- Innovation in energy technologies;
- The power sector's transition to a system dominated by renewable energies;
- Promotion of electrification;
- Low-carbon and green development of energy-intensive sectors;
- Sustainable transportation;
- Demonstration and promotion of regional, provincial, and municipal carbon-neutral models;
- Reduction of dispersed coal and plastic consumption;
- Carbon Neutrality, carbon sink, carbon market;
- Energy justice and just transition, etc.

# THE PRESENT AND FUTURE OF SUSTAINABLE AVIATION FUELS IN CHINA

**DING YIRU[1], YANG LEI[1], ZHENG PING[1], WANG QIANYU[1] AND LV JIXING[2]**

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1 Institute of Energy, Peking University

2 Civil Aviation University of China

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# EXECUTIVE SUMMARY

In 2019 before the COVID-19 pandemic broke out, the global aviation sector generated 1.8% of global greenhouse gas (GHG) emissions (equivalent to approximately 1.06 billion tons of carbon emissions). Although the global aviation market shrank significantly in 2020 and 2021 due to the pandemic, its overall business volume is expected to continue to expand in the coming decades, which means that GHG emissions from the sector will represent an increasing share. Without extra reduction efforts, the international aviation business alone will cumulatively produce 7.0% of global carbon emissions during the 2020-2050 period.

Aviation is one of the most difficult of sectors to decarbonize, but the global aviation industry has set an ambitious goal to achieve net zero emissions by 2050. Apart from developing new aircraft technology and improving operational and infrastructure efficiency, developing sustainable aviation fuels (SAF) will also be a crucial measure to achieve net zero. According to a study by the International Air Transport Association, a reduction of 65% in carbon emissions will be achieved through SAF by 2050.

China is the world's second largest aviation market after the US, whose size will continue to expand in view of its potential demand growth. Carbon emissions from aviation only account for about 1% of China's total carbon emissions but given the fact that China has already reached the late stage of industrialization, the carbon emissions caused by the development scale of traditional heavy industries will gradually reach a plateau. It is estimated that carbon emissions from these industries will go down in the next ten years. By contrast, carbon emissions from the ever-growing aviation industry will be something to be reckoned with.

SAF remains a nascent market in China. On the demand side, airlines in mainland China have only conducted four tests of aircraft flying on SAF since 2011, including commercial test flights. To date, there has been no meaningful demand for SAF in China. On the supply side, only two companies are truly capable of producing SAF but remain at the trial production stage, with a designed annual capacity of approximately 150,000 tons. China still lags behind western countries which have been constantly experimenting with SAF over the past 10-plus years, with a momentum increasingly built up over the past several years.

Globally, the SAF industry as a whole remains highly policy-driven, which is a factor that shapes the external environment of the industry. One determining factor that affects consumption is whether SAF blending is mandated or encouraged. Some western governments have either set targets or introduced plans for the uptake of sustainable transport fuels at national or regional levels, and have introduced specific mandates for SAF blending. These policy signals will directly provide a boost to the development of SAF and other biofuels. Globally, SAF consumption increased from 6,000 tons in 2016 to 80,000 tons in 2021, but most of such consumption happened in the West.

In China, the efforts of many industries, including aviation, to reduce carbon emissions are critical to China's goal of peaking carbon emissions and achieving carbon neutrality. According to the 14$^{th}$ Five-Year Plan (FYP) for Green Civil Aviation Development, China aims to increase SAF consumption to 50,000 tons by 2025. This is a positive policy signal, but this amount is not a binding target and there has been no clearly defined pathway towards the goal. Conclusively, participants from across the SAF supply chain in China are still in a stage of capacity building.

Market demand for SAF will certainly be stimulated if the Chinese government sends stronger policy signals in the future to incentivize the aviation industry to reduce carbon emissions. More demand will naturally lead to greater supply. Theoretically, when China's existing and planned production capacity for HVO is retrofitted to produce SAF, it's estimated that the country's total production capacity will reach 2.05 million tons by 2025 when combined with the existing SAF capacity. By then, total SAF supply will account for 4.5% of China's total aviation fuel consumption.

In China, feedstocks that can be used to produce SAF are widespread and available in abundance, which ensures the supply of SAF. However, many uncertainties remain regarding how to strengthen the development of different technical pathways and how to incentivize supply chain collaboration and better designs to make SAF products more affordable.

Generally, the SAF industry faces both challenges and opportunities in China. If internal and external favorable conditions are fully leveraged to unleash the potential of SAF in reducing carbon emissions, the industry will be a strong boost to China's endeavor to reduce carbon emissions from aviation, peak carbon emissions, achieve carbon neutrality and strengthen energy security.

# ABBREVIATIONS & GLOSSARY

| | |
|---|---|
| **ASTM** | American Society for Testing Materials |
| **ATAG** | Air Transport Action Group |
| **CORSIA** | Carbon Offsetting and Reduction Scheme for International Aviation |
| **HVO** | Hydrogenated Vegetable Oil |
| **IATA** | International Air Transport Association |
| **LCA** | Lifecycle Assessment |
| **ICAO** | International Civil Aviation Organization |
| **LCFS** | Low Carbon Fuel Standard |
| **IEA** | International Energy Agency |
| **ISCC** | International Sustainability & Carbon Certification |
| **ISO** | International Organization for Standardization |
| **RED** | Renewable Energy Directive |
| **RFS** | Renewable Fuel Standard |
| **RSB** | Roundtable on Sustainable Biofuels |
| **RTFC** | Renewable Transportation Fuel Certification |
| **RPK** | Revenue Passenger Kilometres |
| **RTK** | Revenue Tonne Kilometres |
| **SAF** | Sustainable Aviation Fuels |
| **UNFCC** | United Nations Framework Convention on Climate Change |
| **WEF** | World Economic Forum |
| **Gt** | Gigatonne (1 billion tonnes) |
| **Mt** | Megatonne (1 million tonnes) |

1

# THE GLOBAL AVIATION INDUSTRY AND CARBON EMISSIONS REDUCTION

Since early 2020, the global aviation industry has been experiencing a difficult period. The COVID-19 pandemic has resulted in an unprecedented decline in passenger traffic. By 2022, the aviation market has started to recover thanks to improved control of the pandemic and relaxed travel restrictions. While struggling to recover, the aviation sector also faces the challenge of controlling its own carbon emissions.

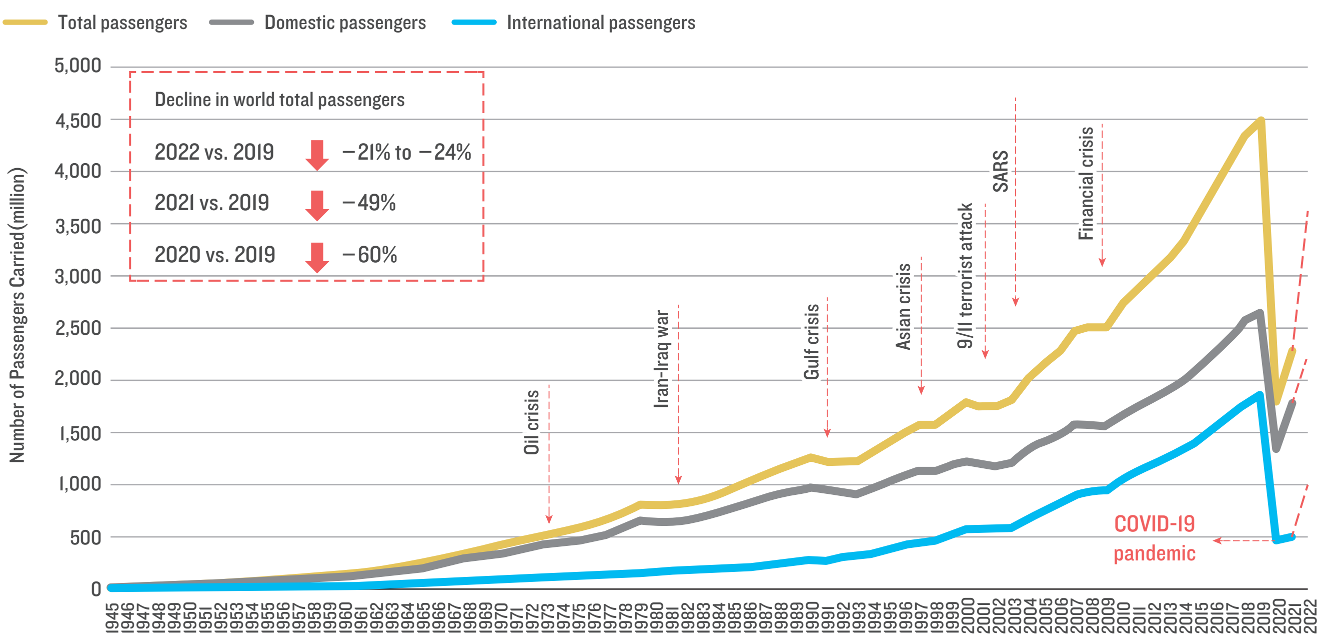


## 1.1 Updates of the aviation industry development

### 1.1.1 A slow recovery from the COVID-19 pandemic worldwide

According to the International Civil Aviation Organization (ICAO)[1,2,3], globally airlines carried 2,300 million passengers in 2021, an overall reduction of 49% from 2019 levels and a modest increase compared with a reduction of 60% in 2020 (Figure 1-1).

**Figure 1-1: World passenger traffic evolution (1945-2022)**




Source: ICAO, June 2022

Compared with 2019 levels, the world respectively reported a USD 324 billion loss and a USD 372 billion loss of gross passenger operating revenues of airlines in 2021 and 2020 (Table 1-1).

**Table 1-1: The COVID-19 impact on world scheduled passenger traffic for year 2020**

| Compared to 2019 levels | 2020 | 2021 | 2022 (estimated) |
|---|---|---|---|
| Seats offered by airlines | 50% | 40% | 15% ~ 18% |
| Reduction of passengers (million, %) | 2,703 (down 60%) | 221 (down 49%) | 921 ~ 1,079 (down 21% ~ 24%) |
| Loss of gross passenger operating revenues of airlines (USD bn) | 372 | 324 | 133 ~ 155 |

Source: ICAO, Effects of Novel Coronavirus on Civil Aviation: Economic Impact Analysis, June 2022

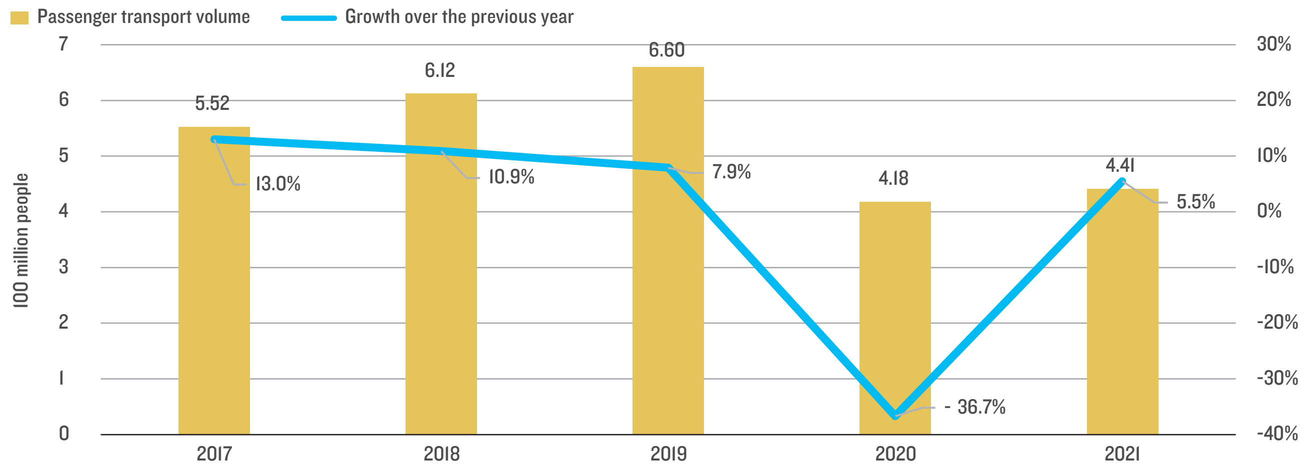
Sluggish business performance and declining revenues have generated adverse impacts on the aviation industry in several areas[4]. It remains uncertain whether airlines will be willing to take further steps to reduce carbon emissions in this economic context. Particularly, the substitution of SAF for fossil fuels is also challenging for airlines, as it will certainly increase their energy costs in the short term.

### 1.1.2 Considerable fluctuations in the Chinese market due to the pandemic

Due to the pandemic, the number of air passengers plummeted in 2019 compared with 2019 levels and slightly increased in 2021. In 2020, the number of passengers carried by airlines totaled 417.7782 million nationwide, a reduction of 36.7% from 2019[5]. In 2021, the figure rose to 440.5574 million, an increase of 5.5% from 2020 (Table 1-2)[6].

In 2020, Chinese airlines reported a cargo transport volume of 79.851 billion ton kilometers (tkm), a decrease of 38.3% compared with 2019--Domestic air cargo traffic dropped by 29.2% and international air cargo traffic plummeted by 54.5%. In 2021, China's cargo transport volume reached 85.675 billion tkm, up 7.3% from 2020, with an increase of 9.1% in domestic air cargo traffic and a growth of 2.3% in international air cargo traffic.

Figure 1-2: Passenger traffic evolution in China (2017-2021)



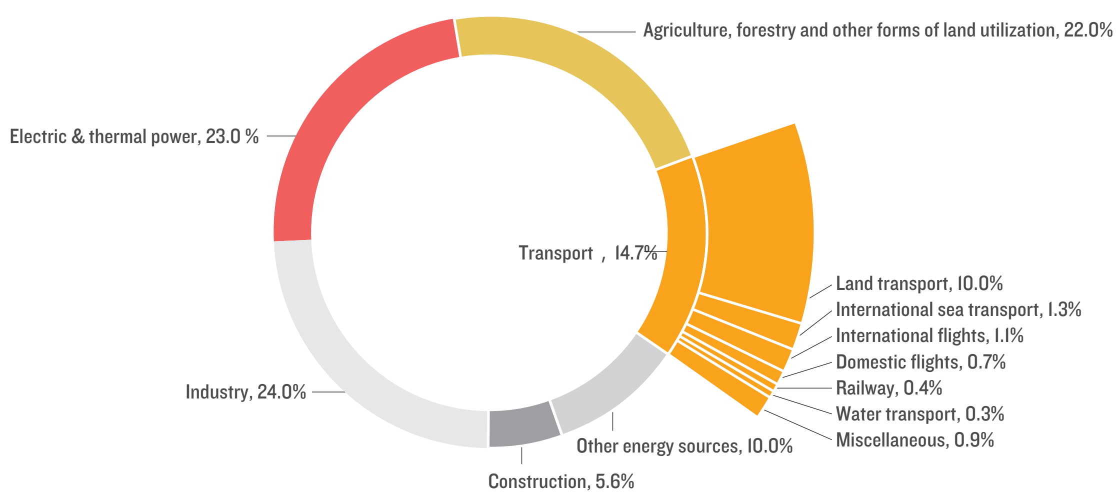

Source: China Statistical Report on Civil Aviation, CAAC, May 2022

## 1.2 Progress of the aviation industry in carbon emissions reduction

### 1.2.1 The aviation industry faces formidable challenges to reduce GHG emissions

The aviation industry generated 1.8% of global GHG emissions (which translates into an equivalent of 1.06 billion tons of $CO_2$ according to 2019 data), including 1.1% from international flights and 0.7% from domestic flights (Figure 1-3)[7].

Figure 1-3: GHG emissions from aviation as % of the world's total




Source: IPCC, Mitigation of Climate Change 2022, April 2022

The continued growth of the aviation sector in the future is expected to result in more GHG emissions that will represent an expanding share. According to the Report on the Feasibility of a Long-term Aspirational Goal (LTAG) [8] for International Civil Aviation $CO_2$ Emissions Reductions that was released by the ICAO Committee on Aviation Environmental Protection in March 2022, cumulative $CO_2$ emissions from international aviation—without extra efforts—will account for 7.0% of the world's total in the context of limiting global warming to 1.5°C. The share can be shrunk to a range between 3.1% and 5.6% if different levels of efforts are made.

China is one of the major aviation markets in the world, with an ever-growing business volume that will also lead to more and more carbon emissions (despite a reduction in carbon emissions due to a business slump caused by the COVID-19 pandemic, see Table 1-2) [9].

Like mature markets such as Europe and North America and other emerging markets, China also faces the challenge of reducing carbon emissions while maintaining business growth in the aviation industry.

**Table 1-2: $CO_2$ emissions from aviation in China (2016-2021)**

| Indicator | Unit | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
|---|---|---|---|---|---|---|---|
| Air cargo traffic | Billion tkm | 96.25 | 108.31 | 120.65 | 129.27 | 79.85 | 85.68 |
| Aviation fuel[10] efficiency | 10,000 tons/100 million tkm | 2.93 | 2.93 | 2.87 | 2.85 | 3.16 | 3.09 |
| Aviation fuel consumption | Thousand tons | 28,200 | 31,730 | 34,630 | 36,840 | 25,230 | 26,470 |
| **$CO_2$ emissions** | **Thousand tons** | **88,830** | **99,960** | **109,070** | **116,050** | **79,480** | **83,390** |

Note: $CO_2$ emissions are calculated based on the aviation fuel consumption that is worked out based on total air cargo traffic and aviation fuel efficiency data disclosed by annual statistical reports of China on civil aviation development (carbon emissions factor: 3.15 kg $CO_2$/kg).

### 1.2.2 The aviation industry has developed aspirational plans to reduce carbon emissions

In view of the effects of aviation on global carbon emissions, the aviation industry has developed a voluntary emissions reduction target. The ICAO Assembly at its 41st Session in October 2022 adopted a collective long-term global aspirational goal (LTAG) of net-zero carbon emissions by 2050[11,12].

As of July 2022, of the 193 ICAO member states, 133 states, representing 98.16% of global RTK, have voluntarily submitted their State Action Plan to ICAO[13]. A number of airlines have also published their carbon neutrality plans, joined by some aircraft manufacturers and parts suppliers that also followed suit to release their own plans in support of the sector's effort to reduce carbon emissions[14].

In 2021, the IATA 77th Annual General Meeting has approved a resolution for the global air transport industry to achieve net-zero carbon emissions by 2050, which is a big stride forward compared with the previous aim of lowering carbon emissions to 50% of 2005 levels by 2050. To be able to serve the needs of the ten billion people expected to fly in 2050, at least 1.8 billion tons of carbon must be abated in that year. Moreover, the net zero commitment implies that a cumulative total of 21.2 billion tons of carbon will be abated between now and 2050[15].

© Photo by Harrison Qi on Unsplash

# 2

# THE ROLE OF SAF IN AVIATION EMISSIONS REDUCTION

## 2.1 Main measures adopted by the aviation industry to reduce emissions

The aviation sector can reduce carbon emissions through a variety of measures, including developing new aircraft technology to enhance fuel efficiency, using electric and hydrogen-powered aircraft, improving operational and infrastructure efficiency, and flying on SAF. For those carbon emissions that cannot be eliminated by itself, the industry can also opt for offsetting plans and carbon capture, utilization, and storage technologies (CCUS) (Table 2-1) [16,17,18,19].

**Table 2-1: Main emissions reduction measures by the aviation sector**

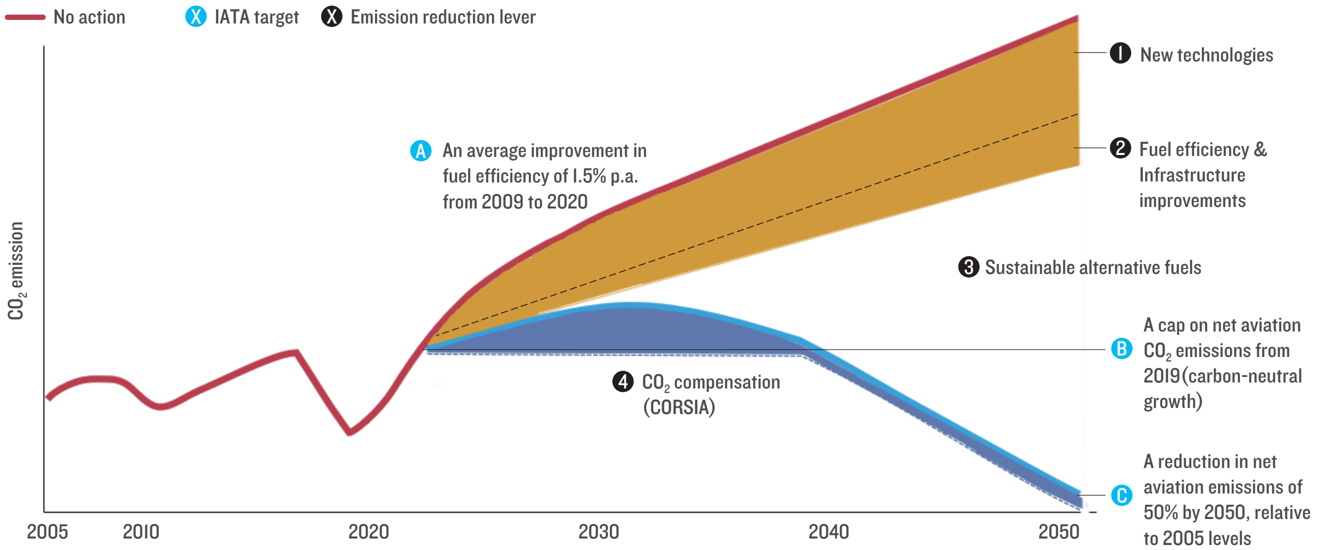
| Measure | Examples of action | Main periods of contribution |
|---|---|---|
| New technologies | • Aircraft and engine manufacturers continue to improve airframe designs and propulsion systems, including optimizing structural designs and using light-weight materials and new combustion chambers;<br>• Develop fully electric, hybrid and hydrogen-powered aircraft, whose commercial or experimental use is envisaged beyond 2030. | 2010-2050 |
| Improved operational and infrastructure efficiency | • Governments and air navigation service providers (ANSP) remove inefficiencies in air traffic management and infrastructure;<br>• Develop more accurate flying plans and shorten flight time to reduce fuel use; keep flights at optimal heights to maximize fuel efficiency;<br>• Airports use low-emission vehicles and install facilities powered by solar and other renewable energy at terminals to further reduce carbon emissions;<br>• The adoption of collaborative decision making (A-CDM) to reduce congestion and delay that will result in more fuel consumption. | 2020-2050 |
| Sustainable aviation fuels (SAF) | • Fuel suppliers provide cost competitive SAF on a large scale;<br>• Certify and approve more technical pathways to producing SAF to accelerate SAF development and uptake;<br>• Airport operators provide needed infrastructure to supply SAF in a more affordable and efficient way. | 2025-2050 |
| Carbon offsetting, capture, utilization, and storage | • Airlines invest in offsetting schemes to offset carbon emissions produced by themselves;<br>• Airlines introduce voluntary offsetting programs for corporate clients to enable them to offset or reduce carbon emissions associated with their business travels;<br>• Airports invest in offsetting schemes like airport carbon accreditation, and build certified green terminals. | 2025-2040 |

Source: IATA, ATAG and ICAO

## 2.2 SAF will be the most important reduction measure

Among these measures, developing new aircraft technology and improving operational and infrastructure efficiency will take time and call for continuous improvement. Over the past 10-plus years, fleet fuel efficiency has been steadily on the rise, but optimization actions in conventional technical fields will only produce limited effects in terms of reducing carbon emissions. In the future, the most important measure for reducing carbon emissions is to expand the use of SAF.

**Figure 2-1: Contributions of different measures to aviation emissions reduction**




Source: IATA, ATAG[20, 21], World Economic Forum[22]

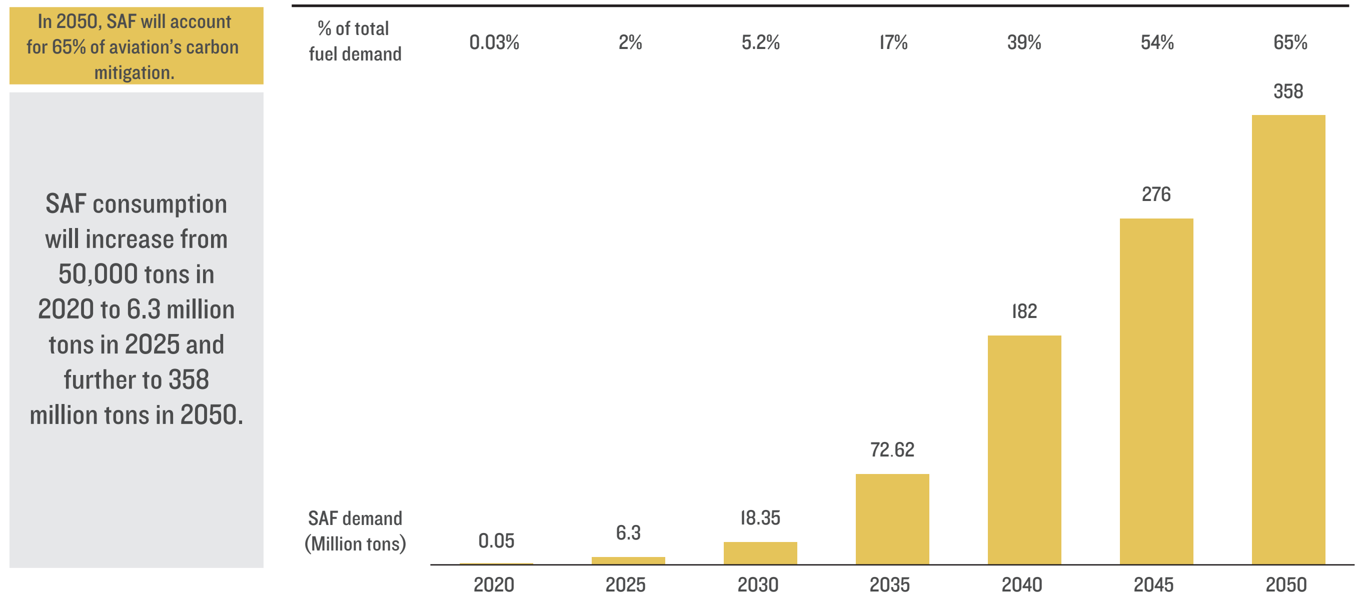
SAF is a liquid fuel that can be used in commercial flights. Compared with the current mainstream aviation fuels (which are mostly petroleum-based), SAF can reduce $CO_2$ emissions by 80% or even more. They can be produced from various feedstocks, including waste oil and fats, agricultural, forestry and municipal wastes, and non-food crops. They can even be produced via synthesizing hydrogen and captured $CO_2$ from the air. SAF are sustainable in that across their lifecycles, carbon emitted by feedstocks during growth and synthesis outweighs carbon emitted from use. Moreover, SAF feedstock does not compete with food crops or water supplies and thus will not contribute to forest degradation or biodiversity loss. To meet sustainability criteria, SAF products are generally required to pass certification by industry-recognized organizations.

In technical and safety terms, SAF products, once certified by relevant standards (like ASTM-D7566), will be deemed as having meet the criteria to blend with the existing petroleum-based aviation fuels without extensive engine and infrastructure modifications. Currently, the maximum SAF blending limit is 50%. However, it is not technically challenging to realize 100% SAF. For example, Boeing once tested a flight using 100% SAF in 2018.

## 2.3 It is critical to dramatically increase SAF production and consumption

To unlock the potential of SAF, it is essential that SAF consumption be dramatically increased from 63 million liters (approximately 50 thousand tons) in 2020 and 100 million liters (approximately 80 thousand tons) in 2021 to nearly 7.9 billion liters (approximately 6.3 million tons) in 2025 and further to 449 billion liters (approximately 358.3 million tons) in 2050[23] (Figure 2-2).

**Figure 2-2: IATA's SAF targets**




Source: IATA, 2021

This pace of growth is challenging for the aviation sector, but it is achievable. The past five years have already witnessed some progress in the utilization of SAF in the sector. Today, SAF is already available at a number of airports, including Oslo Airport in Norway, Stockholm Airport in Sweden, and Los Angeles International Airport and Seattle Airport in the US[24, 25].

3

# TECHNICAL PATHWAYS TO PRODUCING SAF

As of October 2021, a total of nine technical pathways to SAF production have been approved by the ASTM International, including seven pathways approved by ASTM D7566 and two pathways approved by ASTM D1655[26,27,28]. This report will mainly examine three of the nine pathways, including the Hydroprocessed Esters and Fatty Acids (HEFA) process, the Gasification/Fischer-Tropsch (G+FT) process and the Alcohol to Jet (AtJ) process, as well as an unapproved pathway, the Power to Liquid (PtL) process.

These four technical pathways are widely considered by the aviation industry as most promising and are being closely watched by major fuel suppliers worldwide.




## 3.1 The status of production

Currently, Europe and North America remain the major consumers and producers of SAF. The HEFA pathway dominates the existing and new production capacities disclosed by major European producers, despite the fact that G+FT, AtJ and PtL are also adopted in some new production capacities. In the US, most of SAF producers opt for the AtJ pathway.

In Europe, at least eight manufacturing facilities have been built to produce SAF, in addition to more than 20 new or expansion projects that are being planned (including five demonstration projects). By 2025, SAF production will likely reach 7.2 million tons under HEFA, 700 thousand tons under G+FT, 400 thousand tons under AtJ, and 200 thousand tons under PtL (Table 3-1). Theoretically, if stimulated by strong external policy incentives, these capacities can produce up to three million tons of SAF a year. Without clear policy signals, however, these capacities may be mostly utilized to produce biofuels used for road transport[29].

## Table 3-1: Main SAF producers and production in Europe

| | Supplier | Country | Site | Tech. | Start/Expansion | Total fuel capacity (Mt./yr.) |
|---|---|---|---|---|---|---|
| Existing facilities / Expansions | Neste | Finland | Porvoo | HEFA | – | 0.4 |
| | Neste | Netherlands | Rotterdam | HEFA | – | 1.3 |
| | UPM | Finland | Lappeenranta | HEFA | – | 0.1 |
| | Total Energies | France | La Mede | HEFA | – | 0.5 |
| | Cepsa | Spain | San Roque | HEFA | – | 0.1 |
| | Repsol** | Spain | Cartagena | HEFA | 2023 | 0.2 |
| | ENI** | Italy | Venice | HEFA | 2024 | 0.4 |
| | Preem** | Sweden | Gothenburg | HEFA | 2025 | 1.0 |
| New projects | Enerkem* | Netherlands | Rotterdam | G+FT | 2021 | <0.1 |
| | Colabitoil | Sweden | Norssundet | HEFA | 2021 | 0.5 |
| | ENI | Italy | Gela | HEFA | 2021 | 0.5 |
| | ST1 | Sweden | Gothenburg | HEFA | 2022 | 0.2 |
| | Kaidi* | Finland | Kemi | G+FT | 2022 | <0.1 |
| | SkyNRG | Netherlands | DSL01 | HEFA | 2023 | 0.1 |
| | Sunfire* | Norway | Nordic Blue | PtL | 2023 | <0.1 |
| | Caphenia* | Germany | Dresden | PtL | 2023 | <0.1 |
| | TotalEnergies | France | Grandpuits | HEFA | 2024 | 0.2 |
| | SkyNRG / LanzaTech | TBD*** | FLITE | AtJ | 2024 | 0 |
| | Preem | Sweden | Lysekil | HEFA | 2024 | 0.7 |
| | Neste | Netherlands | Rotterdam | HEFA | 2025 | 1.0 |
| | Velocys | UK | Altalto | G+FT | 2025 | 0.1 |
| | LanzaTech | UK | Wales | AtJ | 2025 | 0.4 |
| | UPM | Finland | Kotka | G+FT | 2025 | 0.5 |
| | Fulcrum | UK | Stanlow | G+FT | 2025 | 0.1 |
| | Synkero | Netherlands | Synkero† | PtL | 2027 | 0.1 |
| | Engie* | France | Normandy‡ | PtL | TBD | TBD |

Source: Analysis based on World Economic Forum (2020), "Clean Skies for Tomorrow: Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation" and press releases.
Note: List is not exhaustive. Timelines assume delay for projects announced pre-COVID-19.
*Pilot/demonstration facilities not counted towards future productive capacity estimates.
**Expansion or re-configuration of existing sites. Map does not include co-processing facilities – e.g. ConocoPhillips plant in Cork, Ireland & Galp Energeia in Sines, Portugal.
***Joint venture of the FLITE consortium, led by SkyNRG and Lanzatech, with funding support provided from the EU H2020 programme. The final location of the planned site is yet to be announced.
†Led by Synkero, a project development company, in collaboration with partners SkyNRG, the Port of Amsterdam, Royal Schiphol Group, and KLM. Production is set to commence at low levels after 2025 so is not included in the subsequent figures in the text.
‡Joint venture between Engie, Safran, ADP, Airbus, Sunfire, and Air France-KLM. The year of operation and expected output is yet to be announced.

In the US, the federal government aims produce three billion gallons (approximately 9.06 million tons) of SAF by 2030. According to the pathways disclosed by some major suppliers, AtJ is the most common pathway, followed by G+FT and HEFA. For example, LanzaJet plans to produce one billion gallons (approximately 3.02 million tons) of SAF per year by 2030 by AtJ processing (Table 3-2)[30].

**Table 3-2: Main SAF producers and production in the US**

| Supplier | Tech. | Year | Total fuel capacity | Mt./yr. |
|---|---|---|---|---|
| LanzaJet | AtJ | 2030 | | 3.0 |
| World Energy | HEFA | 2024 | | 0.5 |
| Gevo | AtJ | 2025 | | 0.5 |
| Fulcrum | G+FT | 2022 | | 0.1 |
| Velocys | G+FT | - | | 0.9 |

HEFA G+FT AtJ

Source: The White House

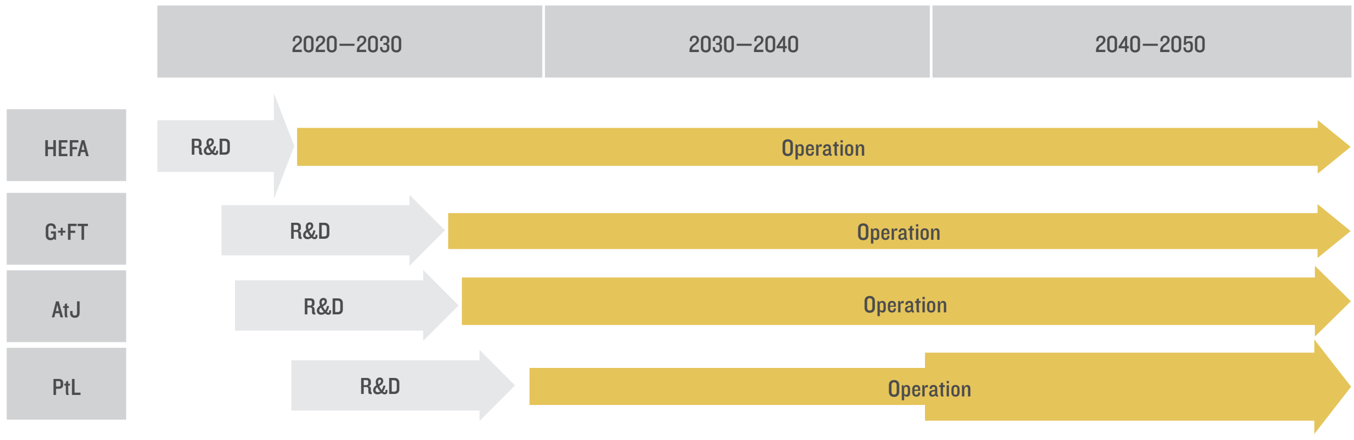
## 3.2 The prospects of development

Among the four pathways, HEFA is currently the most commercially viable process, whereas G+FT and AtJ are supposed to gradually shift from demonstration to commercialization. PtL remains at the nascent and experimental stage.

HEFA is expected to continue to maintain its market dominance before 2030, but its production capacity will not grow rapidly in view of the limited supply of feedstocks. FT and AtJ are expected to enjoy constantly expanding market shares between 2030 and 2050 thanks to their growing technological maturity, declining costs and feedstock diversity (agricultural and forestry waste, municipal solid waste and industrial waste, etc.).

The PtL pathway still has a long way to go before commercialization, but compared with traditional fuels, SAF produced by PtL processing will offer great potential for emissions reduction and producers almost don't have to worry about the availability of feedstocks. Therefore, if backed by favorable policies, larger market shares and technological breakthroughs that will significantly help reduce its costs, PtL would become the predominant route in the medium and long term (Table 3-1).

**Figure 3-1: Expectations of different SAF pathways between 2020 and 2050**




Note: 1) The width of bars in the operation period represents different pathways' level of dominance.
2) The estimation is made based on the research of ATAG, IATA and WEF.

4

# SAF ADMINISTRATION, LAWS, AND POLICIES IN CHINA

## 4.1 Laws and policies

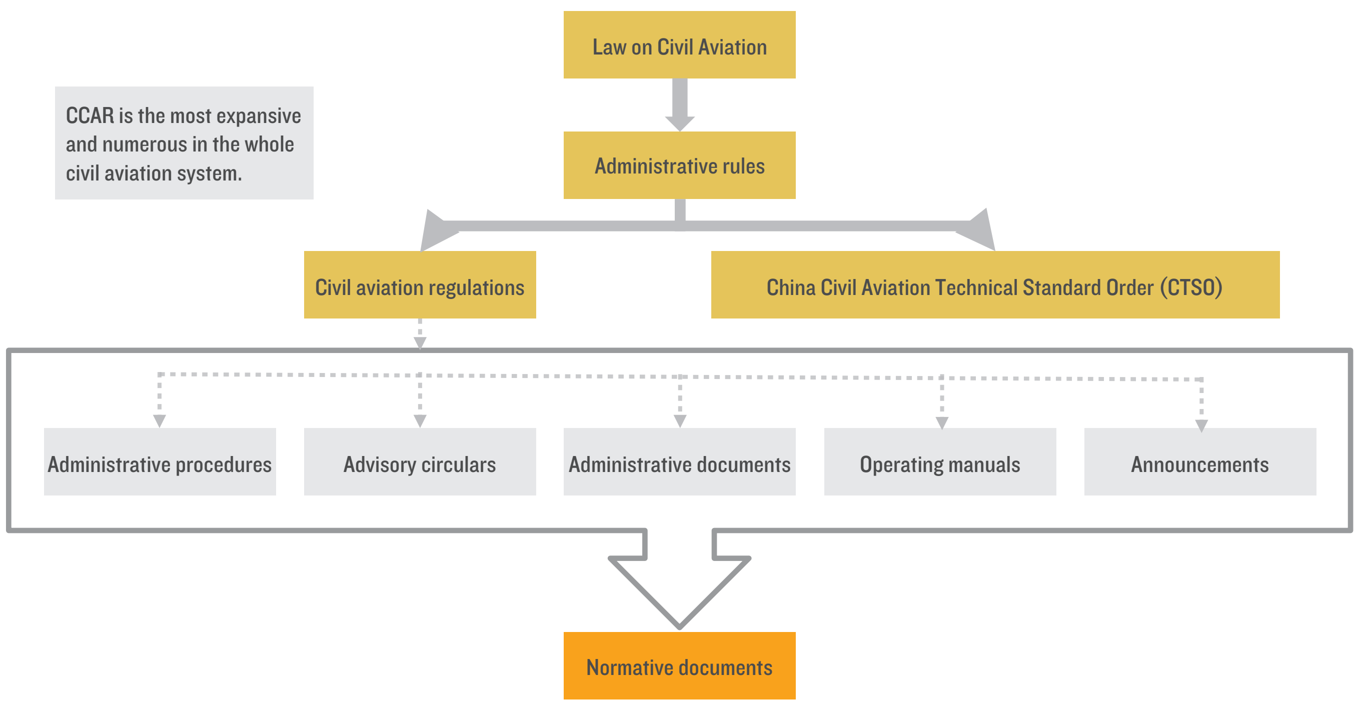
China manages the quality of aviation fuels through administrative licensing. In July 2004, the Decision of the State Council on the Administrative Licensing of Items That Require Administrative Approval set forth that civil aviation fuel suppliers shall obtain airworthiness approval and fuel testing organizations shall also have approval from the Civil Aviation Administration of China (CAAC). In April 2005, CAAC released the Regulations on Airworthiness Management of Civil Aviation Fuels (CAAR-55). From 2006, airworthiness certification authorities for civil aviation started to certify aviation fuel suppliers and testing organizations[31]. In March 2010, the Aviation Fuel/Oil and Aerochemicals Airworthiness Certification Center of CAAC was established.

### 4.1.1 Regulatory system

China's regulatory system for civil aviation is composed of three levels: laws, administrative rules, and civil aviation regulations. The first level is the Law of the People's Republic of China on Civil Aviation, which is the basic law of China governing the organization and implementation of flying activities as well as the basis for the development of directives, rules, regulations, and policies by aviation agencies. The second level is administrative rules, through which aviation fuels are approved through administrative licensing. The third level is civil aviation regulations. CAAC is responsible for introducing the China Civil Aviation Regulations (CCAR). Today, airlines and other aviation companies regulated by CAAC have all established and improved their management systems in accordance with CAAR requirements.

In April 2005, the airworthiness certification department of CAAC released the Regulations on the Airworthiness of Civil Aviation Fuels (CCAR-55), which standardizes the airworthiness management of aviation fuels[32]. The Procedure for Certifying the Airworthiness of Corporate Suppliers of Civil Aviation Fuels (AP-55-01) that was promulgated in February 2007 provided further clarity on the procedure of certifying the airworthiness of aviation fuels.

**Figure 4-1: China's regulatory system for civil aviation**



### 4.1.2 Relevant policies

From 2010, CAAC started to place more emphasis on the R&D and utilization of SAF and has defined SAF as a strategic energy reserve for decarbonizing the aviation industry. Over the past ten years, CAAC has taken a variety of measures for this purpose, including establishing a coordination mechanism, strengthening standards development, supporting domestic airlines to make SAF-powered test and commercial flights, and participating in international cooperation. Some policies recently promulgated by the State Council and CAAC also cover the demonstrative and commercial use of SAF (Table 4-1).

The Chinese government is more encouraging of biodiesel development and has successively introduced nearly 20 laws, plans, as well as industrial, fiscal and tax policies and product standards. The Ministry of Finance (MoF) and the State Administration of Taxation (SAT) have also released a number of official documents to provide tax benefits for biodiesel.

**Table 4-1: Chinese policies related to the promotion and use of SAF**

| Date of issue | Issuer | Policy title | Description |
|---|---|---|---|
| Oct. 2021 | State Council | Action Plan for Peaking Carbon Emissions by 2030 | Push for the substitution of advanced liquid biofuels and SAF for traditional fuels and improve fuel end-use efficiency. |
| Jan. 2022 | CAAC | $14^{th}$ Five-Year Plan (FYP) for Green Civil Aviation Development | Achieve breakthroughs in promoting the commercial use of SAF, with an aim to raise SAF consumption to over 20,000 tons in 2025 and cumulatively to 50,000 tons during the $14^{th}$ FYP period; establish an expected goal for reducing fuel use and reducing carbon emissions—reducing fuel consumption per ton kilometer for air transport fleet to 0.293 kg and $CO_2$ emissions per ton kilometer for air transport to 0.886 kg[33,34]. |
| May 2022 | National Development and Reform Commission (NDRC) | $14^{th}$ FYP for Bioeconomy Development | The Plan points out that areas with good conditions are encouraged to promote and pilot the use of biodiesel and advance the demonstrative use of aviation biofuels[35]. |
| Jun. 2022 | NDRC and National Energy Administration (NEA), etc. | $14^{th}$ FYP for Renewable Energy Development | Scale up efforts to develop non-food liquid biofuels and support the R&D and promotion of advanced technology and equipment for biodiesel and aviation biofuel production. |

Source: compiled based on policies released by the government.

## 4.2 Airworthiness certification

### 4.2.1 Management system

China's airworthiness management system is composed of the CAAC Department of Aircraft Airworthiness Certification (DAAC) and airworthiness certification divisions of regional bureaus, with the support of designated airworthiness representatives, technical centers, certification centers, research institutions and training organizations[36].

China's management system for certifying the airworthiness of aviation fuels is different from that of western countries. As China does not have ASTM-like industry associations, when Sinopec No. 1 Aviation Biofuel was certified, it was characterized as one of the most-often used aircraft parts and the certification was conducted by reference to the certification of parts and in accordance with the CTSOA (Chinese Technical Standard Order Authorization) certification[37]. Moreover, quality management covers the entire continuum of aviation biofuels, from design to production, storage, transportation, and into-plane service.

The milestone event of Sinopec No. 1 Aviation Biofuel has basically resulted in the creation of a SAF airworthiness certification system. In February 2014, Sinopec Zhenhai Refining & Chemical Company (Zhenhai Refining) received the first CTSOA certificate, an airworthiness certificate, from CAAC, signaling the commercial use of a domestically produced aviation biofuel. To grant authorization, DAAC formed a certification board composed of experts from airworthiness, engine, refining, aviation fuel and other technical fields, as well as a review group comprising experts from the Aviation Fuel/Oil and Aerochemicals Airworthiness Certification Center of CAAC (FCCC)[38].

### 4.2.2 Certification process

Airworthiness certification of aviation biofuels includes three parts: design certification, producer certification and post-certification supervision. Design certification refers to the certification of fuel performance, process and other related activities to confirm that the manufacturing process, performance and other technical indicators of the fuel conform to CTSO-2C701 requirements. Producer certification also refers to CTSO-2C701 for a document review and a site conformance assessment. Post-certification supervision means that after the certificate is granted, CAAC will appoint an authorized representative responsible for day-to-day supervision of the certificate-holding organization, within the scope of responsibilities and authority defined by CCAR-183[39].

In China, airworthiness certification is conducted in accordance with regulatory procedures and technical standards. Generally, the producer is required first to submit an application in the AMOS system. After the application is processed by DAAC, FCCC will be authorized to form a review group. If the aviation biofuel passes the certification, the company producing the biofuel will be awarded a CTSOA certificate. The certification of the biofuel company will only apply to a manufacturing process that is capable of mass production and will not cover laboratory R&D or a process that remains at the small-scale stage. Processes are not limited to those approved by ASTM, such as HEFA, FT and AtJ. The time taken to complete certification depends on whether the process is one of the seven pathways approved by ASTM-D7566.

Before CAAC issued the CTSOA certificate to Zhenhai Refining, the aviation biofuel produced by the company has undergone a two-year examination against CTSO-2C701. The examination covered two parts: design and production and the scope of certification included: manufacturing process, quality assurance system, physical and chemical properties, particular properties, material compatibility, engine bench test and flight test validation[40].

### 4.2.3 Relevant standards

Step by step, China has developed its own set of standards and certification system for aviation biofuel manufacturing processes and performance measurement. Currently, aviation biofuel remains characterized as a "part" of aircraft for the purpose of airworthiness certification. China has not developed standards for sustainability. FCCC and some academic institutions are conducting research on standards and methodologies for sustainability certification.

In 2011, Boeing and Air China collaborated to complete the first successful SAF passenger flight test. Before the test, SAF airworthiness was certified by DAAC. Ttransportation, storage and into-plane service were all certified in accordance with the applicable rules of the Airworthiness Management of Civil Aviation Fuel, the 55th part of the China Civil Aviation Regulations (CCAR). Specifically, these activities were carried out according to the Standard of Civil Aircraft Refueling Procedure (MH/T 6005) and the Commercial Aviation Fuel Quality Control & Operating Procedures (MH/T 6020).

In 2013, CAAC developed the Civil Aviation Jet Fuel Containing Synthesized Hydrocarbons (CTSO-2C701)[41]. The standard prescribes that aviation biofuels shall be approved in the form of CTSOA, including biofuels produced by HEFA and G+FT processing. Sinopec No. 1 Aviation Biofuel was certified this way.

In 2018, China amended the No. 3 Jet Fuel (GB6537) and included into it Appendixes B and C that respectively list technical requirements and testing methods for FT-SPK and HEFA-SPK.

In 2022, FCCC assisted DAAC in revising CTSO-2C701. The new CTSO-2C701a includes seven processes listed in ASTM D7566 and draws on the “qualification process” and “fast track” of ASTM D4054.

Currently, any aviation biofuel manufacturer must apply for airworthiness certification through the AMOS system[42]. Certification will be conducted by FCCC in accordance with CTSO-2C701a and a CTSOA certificate will be awarded if the aviation biofuel manufacturing process is approved.

According to current requirements, aviation biofuel must be blended with conventional aviation fuel, with a maximum blend limit of 50% (which applies to HEFA and FT processes). If an aviation fuel pending certification is to be used in China, it shall be blended with a No. 3 jet fuel that conforms to the GB 6537 standard before certification. If it is to be used in other countries, it shall be blended with Jet A-1 that conforms to ASTM D1655 or DEF STAN91-91 before certification.

As for standards on biodiesel, China has introduced national standards B5 Diesel Fuels and Automobile Diesel Fuels (Stage VI)[43]. Moreover, relevant industry standards, such as Hydrotreated Vegetable Oil (HVO) (NB/T 10897-2021) and Feedstock of Biodiesel (NB/T 13007-2021), have also been approved by NEA in December 2021 and started to be enforced on June 22, 2022[44].

**Biodiesel products produced in China that are to be exported to foreign countries will have to obtain sustainability certificates required by destination markets, such as RSB and ISCC certificates.**

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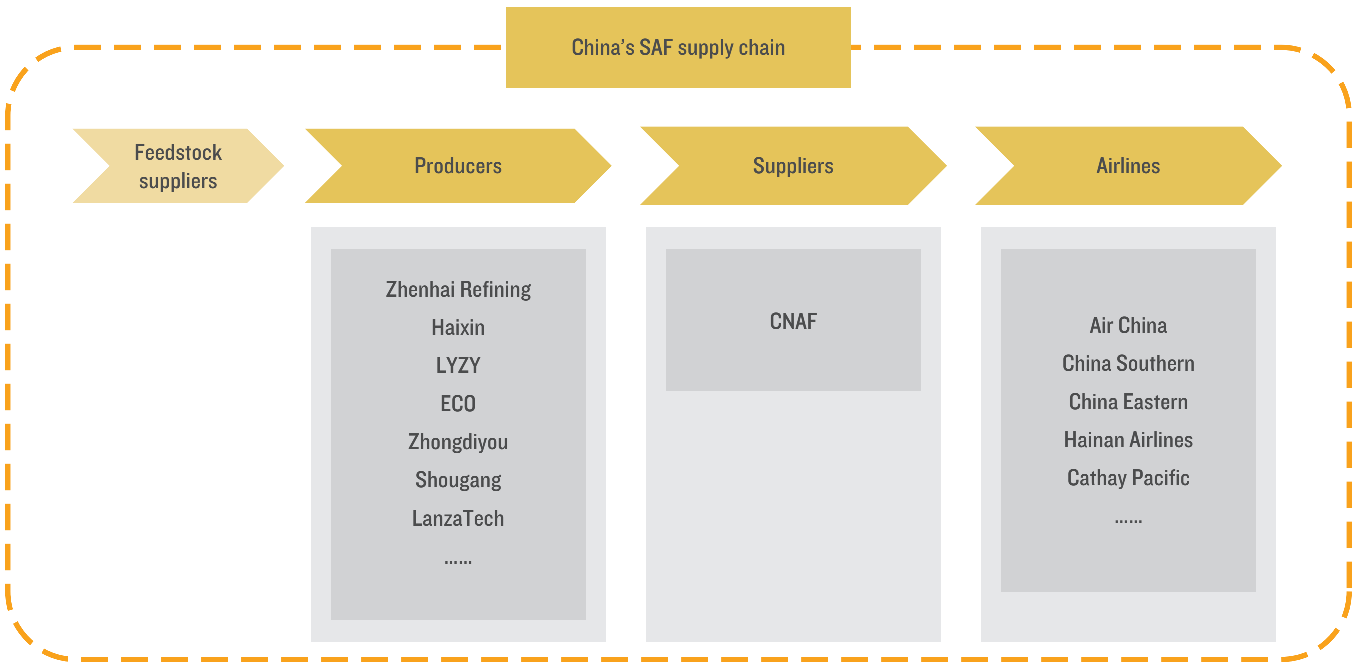
5

# MAIN SAF MARKET PARTICIPANTS IN CHINA

The SAF market is still in its infancy in China and basically operates in a similar way to the conventional aviation fuel market in terms of production, sales, utilization, regulation, and other relevant areas. Compared with conventional fuels, SAF can be produced using a broader variety of feedstocks. Therefore, there are more diverse producers and feedstock suppliers (Figure 5-1).

**Figure 5-1: China's SAF supply chain**




## 5.1 Producers

Today, there is only a limited number of companies capable of producing SAF in China, but like their western counterparts, Chinese companies that produce biodiesel (especially those that produce HVO) are also able to transition to SAF production by retrofitting their production lines to suit market needs[45].

As of June 2022, HVO production capacities that were either in operation or being planned in China totaled 2.35 million tons a year; operational and planned SAF production capacities, hosted by two plants and manufacturing facilities, totaled 150 thousand tons a year.

Today, active players in China's SAF and HVO markets include: Sinopec Zhenhai Refining & Chemical Company (Zhenhai Refining), ECO Environmental Investments Limited (ECO), Beijing Haixin Energy Technology Co., Ltd. (Haixin)[46], Zhongdiyou New Energy (Shandong) Co., Ltd. (Zhongdiyou), Beijing Shougang LanzaTech New Energy Co., Ltd. (Shougang LanzaTech), Longyan Zhuoyue New Energy Co., Ltd. (LYZY) and Shijiazhuang Changyou Bioenergy Co., Ltd. (Changyou). Among them, ECO and Zhenhai Refining have already started a small-scale trial production of SAF. Haixin and Zhongdiyou have developed plans to either build new SAF capacities or repurpose the existing biodiesel capacities for SAF. Shougang LanzaTech is advancing a commercial-scale project of converting CO and $CO_2$ from industrial waste gases into ethanol via bio-fermentation and plans a trial production of biodiesel or SAF using ethanol. Building on its success in producing next-generation biodiesel, LYZY is also planning to build new HVO production capacities. Apart from these companies, Hangzhou Energy Engineering Technology Co., Ltd. and some other companies are also involved in China's early SAF R&D projects. Some research institutes, like the Guangzhou Institute of Energy Conservation of the Chinese Academy of Sciences (CAS), are also exploring how to produce SAF using agricultural and forestry wastes[47].

### 5.1.1 Zhenhai Refining

Zhenhai Refining, a subsidiary of China Petroleum & Chemical Corporation (Sinopec), is the largest company in China that integrates refining and chemicals. As an oil and gas company, Zhenhai Refining offers a good example of a traditional energy company making forays into the SAF market.

Sinopec, as the largest producer of conventional aviation fuels in China, is the first company in the country to systematically initiate R&D (in 2009) and production of SAF. Within Sinopec, Zhenhai Refining not only supplies two million tons of conventional aviation fuels per year (before the COVID-19 pandemic), but also undertakes to develop and produce SAF.

The existing SAF manufacturing facility at Zhenhai Refining can process 100 thousand tons of feedstocks. Trial production started in the middle of 2022. Like large multinational oil companies such as BP and Shell, Sinopec's SAF production remains on a small scale. Whether Sinopec will invest more in the business depends on market demand.

### 5.1.2 ECO

Established in 2000, ECO is a wholly owned subsidiary of The Hong Kong and China Gas Company Limited (Towngas). ECO focuses on the development of new energy projects in China, covering resource exploitation, coal-based chemicals, liquefaction of coalbed methane, vehicular fuels and utilization of biogas from landfills. In Hong Kong, ECO also operates LPG filling stations and a permanent aviation fuel storage facility for the Hong Kong International Airport[48].

ECO is another example of a large traditional energy company tapping into the SAF market. Its parent company, Towngas, focuses on supplying town gas mainly to Hong Kong and Chinese mainland.

In 2021, Towngas supplied three million tons of aviation fuels in Hong Kong and produced approximately 180 thousand tons of HVO that generated a sales revenue of HKD 2.6 billion, much higher than HKD 960 million in 2020. HVO has surpassed water tariffs and sales revenues from fossil fuels such as oil and coal to become the largest stream of income, secondary only to the main gas business (including gas sales, installation, gas appliances, and maintenance)[49, 50].

### 5.1.3 Haixin

Haixin's (formerly named as Beijing Sanju Environmental Protection & New Materials Co., Ltd.), which was established in 1997. The company's major shareholder is the State-owned Assets Supervision and Administration Commission of Haidian District, Beijing[51].

Since 2019, HVO has become an important area of business for Haixin, with an annual production capacity of 350 thousand tons, all of which are exported to Europe. The company plans to increase the capacity to one million tons a year. To date, Haixin has not produced SAF, but depending on market demand, it may build new SAF production capacities or repurpose the existing HVO production capacities for SAF.

### 5.1.4 Zhongdiyou

Zhongdiyou was established in 2020 and is located in the Zhanhua Economic Development Zone in Binzhou, Shandong.

Zhongdiyou focuses on producing biofuels such as liquid paraffin, HVO and SAF, utilizing hydrogenation facilities in the province's outdated refining capacities that have been upgraded through the company's self-developed "plant residue to oil" (PRO) technology. Leveraging opportunities from the transition of the refining industry in Shandong, Zhongdiyou also shares its technology and process with local companies to produce biofuels.

Zhongdiyou produced HVO on a trial basis in August 2021, using palm acid oil (PAO) as the main feedstock. The company currently produces 400 thousand tons of HVO a year according to ISCC standards, all of which are sold to Europe. The company targets an annual production capacity between one and two million tons in the future.

### 5.1.5 LYZY

Established in 2001, LYZY is mainly engaged in the research, development, manufacture and sales of biodiesel and derivative products that are produced from waste oil (such as gutter oil and acid oil), including industrial glycerin, bio-ester plasticizers and water-based alkyd resin[52].

LYZY is another example of a biodiesel company expanding its business operations into HVO. In 2021, the company's production capacity of biodiesel (first-generation) totaled 400 thousand tons a year, with an output of 358 thousand tons, an increase of 54.65% from last year. LYZY plans to increase its annual biodiesel capacity to 750 thousand tons in the next three to five years. Its Meishan manufacturing facility, located in Longyan, Fujian and designed with an annual production capacity of 100 thousand tons of HVO, is still under construction[53, 54].

### 5.1.6 Shougang LanzaTech

Shougang LanzaTech, established in 2011, is a Sino-foreign joint venture controlled by Shougang Group. The company is mainly engaged in using CO and $CO_2$ from industrial waste gases as feedstock for producing ethanol and proteins used for animal farming.

In 2018, Shougang LanzaTech put into operation the first factory to begin commercial-scale production of ethanol and proteins by industrial waste gas fermentation. The operational projects in Caofeidian and Ningxia both have an annual capacity of 45 thousand tons. The company has also built another two new projects respectively in Guizhou and Ningxia, each with an annual capacity of 60 thousand tons. During the $14^{th}$ FYP period, its total ethanol capacity is expected to reach one million tons a year.

In terms of process, the technical pathway from ethanol to SAF has been cleared, but there has been no case of such production on an industrial scale. The company's US partner, LanzaTech, has already completed pilot production under the pathway. Currently, a demonstration plant is being built in the US that will convert ethanol to SAF at a scale of 30 thousand tons per year. The plant is expected to be fully operational in the second half of 2023. Shougang LanzaTech has recently planned to introduce this technology to China to build industrial projects. From a process perspective, the technical pathway will be AtJ or G+FT. If the technology is finally brought into China, it will accelerate China's progress in SAF development under such pathways.

## 5.2 Suppliers

China National Aviation Fuel Group Limited (CNAF) is currently the largest aviation fuel supplier in China that integrates the purchase, transportation, storage, quality management, sales, and into-plan service[55], supplying more than 95% of domestic aviation fuels in the country. It is expected to remain the major player in such areas as SAF purchase, sales, and into-plane service in the future.

When it comes to purchase, domestic airlines mostly buy aviation fuels from the following three companies: China National Petroleum Corporation (CNPC), China Petrochemical Corporation (Sinopec), and China National Offshore Oil Corporation (CNOOC). International flights (including flights of domestic airlines originating from China but bound for foreign countries) mainly rely on imported fuels (bonded fuels). China Aviation Oil (Singapore) Corporation Ltd. (CAO) is responsible for the business of importing aviation fuels.

In mainland China, SAF has not been used by airlines on a commercial scale. So far, SAF purchase, and into-plane service have not been established as a routine business at CNAF, but the company was fully involved in the supply of SAF for four test and commercial flights in China (the fifth flight test used biofuel when China Southern Airlines took delivery of a new plane from France[56]. Particularly, in 2011 CNAF went out of its way to build SAF receiving, storage, blending and dispensing facilities at the Beijing Capital International Airport for the purpose of the first flight test conducted by Air China.

Moreover, CNAF is also involved in relevant SAF R&D projects. In 2019, 2020 and 2021, CNAF partnered with the CAS Guangzhou Institute of Energy Conversion and the Second Research Institute of CAAC for national-, provincial- and ministerial-level aviation biofuel R&D projects, but much remains to be done before their products can be used commercially.

Apart from CNAF, a very few foreign companies are also supplying aviation fuels and providing into-plane service in China, like Air BP, the aviation division of BP. Through its four joint ventures formed with CNAF, Air BP provides aviation fuel-related services in Guangdong, Guangxi, Hunan, Hubei, Henan, Sichuan, Guizhou, and Chongqing.

Today, Air BP supplies SAF at 20 locations in seven countries globally. Air BP has not started any SAF business or project in China, but in view of the significance of the country's aviation market, Air BP has started SAF research in China since 2021 to promote SAF development in the second largest economy.

Globally, Air BP has invested in three SAF projects—the Fulcrum project in North America that produces SAF by G+FT processing; BP's refinery in Castellon, Spain; and a collaborative project under which Air BP will purchase SAF from Neste.

Shell, another global aviation fuel supplier, is supplying SAF to a number of airports worldwide, including the Amsterdam Schiphol Airport and the Los Angeles International Airport. In Asia, Shell will first supply SAF to Hong Kong and Singapore[57].

Worldwide, Shell has also made a number of investments and initiated cooperative projects related to SAF. In October 2020, Shell entered into an agreement with Red Rock Biofuels, whereby Shell will distribute SAF to Red Rock's existing airline customers. In the same month, Shell signed a cooperation agreement with Neste to expand SAF supply. In January 2021, ECG Group Paraguay and Shell signed a five-year contract that will provide more than 500 million liters of renewable diesel and SAF per year to Shell, starting from 2024[58, 59].

In addition, Shell has announced its intention to produce two million tons of SAF by 2025. To this end, Shell has made investments to the renovation of refineries to SAF plants. For example, it has built a SAF and biodiesel factory in Rotterdam, Netherlands that is expected to be operational in 2024, with an annual capacity of 820 thousand tons. The company has also announced an investment in Singapore to build a manufacturing facility with annual capacity of 550 thousand tons of SAF[60].

## 5.3 Users

Most of Chinese airlines are state-owned companies. Generally, they will not carry out SAF-related work until instructed by relevant policies and plans of the central government. Currently, Chinese airlines as a whole stay in stage of capacity building and have not introduced clear plans for commercial flights using SAF.

In terms of flight test, Air China, China Easter Airlines and Hainan Airlines respectively conducted SAF flight tests in 2011, 2013, 2015 and 2017 (Table 5-1). However, after the tests, Chinese airlines didn't strike the iron while it's hot to promote commercial use. As a result, while international airlines are actively involved in the promotion of SAF, their Chinese counterparts remain in their infancy in terms of SAF use.

**Table 5-1: Chinese airlines' flights using SAF**

| Date | Airline | SAF feedstock | Blending ratio | Producer | Flight description |
|---|---|---|---|---|---|
| Oct. 28, 2011 | Air China | Jatropha curcas seed oil | 50% | CNPC | A test flight from Beijing Capital International Airport |
| Apr. 24, 2013 | China Eastern | Palm oil & waste cooking oil | - | Sinopec | A 1.5-hour test flight from Shanghai Hongqiao International Airport |
| Mar. 21, 2015 | Hainan Airlines | Waste cooking oil | 50% | Sinopec | A flight from Shanghai to Beijing, the first passenger flight in China using SAF |
| May 28, 2016 | Cathay Pacific | Sugarcane | 10% | Total/ Amyris | A flight from Toulouse to HK (for delivery of a new plane) |
| Nov. 22, 2017 | Hainan Airlines | Waste cooking oil | 15% | Sinopec | A flight from Beijing to Chicago, the first intercontinental SAF passenger flight in China |
| Feb. 28, 2019 | China Southern | Sugarcane | 10% | Total | A flight from Toulouse to Guangzhou (for delivery of a new plane) |

By contrast, foreign airlines demonstrate more enthusiasm about SAF than their Chinese counterparts[61, 62] (Table 5-2).

- 2008-2011: Global airlines are still at a stage of technically conducting SAF flight tests.
- 2011-2015: A total of 22 airlines have made approximately 2,500 commercial passenger flights using SAF.
- 2011-July 2022: The number of commercial SAF flights reaches more than 430 thousand and over 45 airlines have gained experience in flying on SAF.

**Table 5-2: Number of SAF flights made by global airlines**

| Date | No. of commercial SAF flights | No. of airlines with experience in SAF flight |
|---|---|---|
| 2008-2011 | Lots of test flights globally | |
| 2011-2015 | >2,500 | 22 |
| 2011-07/2022 | >430,000 | >45 |

Source: IATA, Aviation Benefits Beyond Borders

To date, large airlines in Chinese mainland have not specified any plan, goal or pathway regarding SAF use. Local airlines are expected to in a stage of capacity building before relevant policies or specific requirements are introduced by the Chinese government.

Hong Kong-based carrier Cathay Pacific is a more active user of SAF. Since 2016 when Cathay Pacific took delivery, using SAF, of a new plane from Toulouse, where Airbus is headquartered, the company has cumulatively consumed more than 200 tons of SAF. It has also committed—to purchasing 1.1 million tons of SAF over the next 10 years, to using SAF for 2% of its total fuel consumption by 2025 and further to 10% by 2030, and to reaching net-zero carbon emissions by 2050. In April 2022, Cathay Pacific launched the Corporate Sustainable Aviation Fuel Program to express its demand for SAF to relevant suppliers, to which CNCP and Shell will supply fuels[63].

6

# OUTLOOK FOR SAF DEVELOPMENT IN CHINA

Generally, the SAF industry is still in its infancy in China and has a bright future ahead, but currently the industry faces many challenges. At the national level, China lacks systematic top-down designs and clear policy signals, as a result of which key market players remain staying in the stage of preparation with no clear development plans. There also exist barriers and bottlenecks in terms of production capacity, technological readiness, feedstock supply and cost. However, China's SAF industry also enjoys certain opportunities and advantages. If making full use of internal and external favorable conditions to unleash the potential of SAF in reducing carbon emissions, the industry will provide a boost to the country's efforts to reduce carbon emissions from aviation, peak carbon emissions, achieve carbon neutrality and strengthen energy security.

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## 6.1 Technical pathways

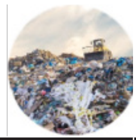
Currently, the industry is mainly interested in four technical pathways to producing SAF, including Hydroprocessed Esters and Fatty Acids (HEFA), Gasification/Fischer-Tropsch (G+FT), Alcohol to Jet (AtJ) and Power to Liquid (PtL) (Table 6-1).

HEFA is the only pathway that has been adopted by China in its SAF and HVO production and demonstration projects. Backed by more mature technology and process, the pathway is followed by both ECO and Zhenhai Refining in their SAF projects, so do Haixin and Zhongdiyou, which also adopt HEFA in their current HVO projects (LYZY also plans to use HEFA processing in its HVO project that is soon to be operational).

Western countries have already launched demonstration projects of G+FT and AtJ, but China has not started to explore the two areas. Some demonstration projects producing ethanol fuel and related chemicals adopt the two pathways. For example, some companies in northeast China are producing ethanol from straws and stalks. Shougang LanzaTech is also converting industrial waste gases into ethanol in Hebei and Ningxia. However, no project in China is capable of directly converting alcohols into fuels at an industrial scale.

As in western countries, the PtL pathway remains a “concept” in China, but there have arisen demonstration projects of producing methanol from green hydrogen. In 2020, a technical team from the Chinese Academy of Sciences (CAS) successfully completed trial production in a demonstration project in Lanzhou, Gansu that can produce methanol from green hydrogen at a scale of one thousand tons a year. Presently, the team is working on an industrialization project with a capacity of 100 thousand tons[64].

**Figure 6-1: Opportunities and challenges for different SAF pathways in China**

| | HEFA | AtJ[1]<br>G+FT | PtL |
|---|---|---|---|
| Opportunity description | Safe, proven, and scalable technology | Potential in the mid-term, however significant techno-economical uncertainty | Proof of concept 2025+, primarily where cheap high-volume electricity is available |
| Technology maturity | Mature | Commercial pilot | In development |
| Feedstock | • Waste and residue lipids, purposely grown oil energy plant[2]<br>• Transportable and with existing supply chains<br>• Potential to cover 5%-10% of total jet fuel demand | • Agricultural and forestry residues, municipal solid waste[4], purposely grown cellulosic energy crops[5]<br>• High availability of cheap feedstock, but fragmented collection | • $CO_2$ and green electricity Unlimited potential via direct air capture<br>• Point source capture as bridging technology |
| % LCA GHG reduction vs. fossil jet | 73%-84%[3] | 85%-94%[6] | 99%[7] |
| Opportunities in the Chinese market | • Rich in raw materials.<br>• With good industrial foundation. | Rich in raw materials | • Development basis of renewable energy industry.<br>• Have better exploration. |
| Challenges in the Chinese market | The distribution of raw materials is scattered and the cost of collection is high. | Lack of technical reserve and R&D foundation | Lack of technical reserve and high cost. |

Note: 1. Ethanol route; 2. Oilseed bearing trees on low-ILUC degraded land or as rotational oil cover crops; 3. Excluding all edible oil crops; 4. Mainly used for gas./FT; 5. As rotational cover crops; 6. Excluding all edible sugars; 7. Up to 100% with a fully decarbonized supply chain

Source: World Economic Forum, Clean Skies for Tomorrow: Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation, 2021; research by Chinese experts.

Under the HEFA pathway adopted in China, companies universally opt for waste oil instead of non-food crops, which is a more sustainable practice that benefits carbon emissions reduction. Moreover, China is industrially better positioned in this field, which is foundational for the expansion of SAF production capacity in the future.

In terms of technological readiness, there remains much to be done for Chinese companies when it comes to G+FT and AtJ processing. Sino-foreign collaboration in R&D may help accelerate the adoption of these two pathways in China, where they will have enormous potential in view of the widespread availability of feedstocks for the two pathways.

The world holds high expectations of PtL as a medium- and long-term technical pathway, so does China, which hosts an abundance of resources for solar and wind power generation that is backed by explicit policy support. This will help drive the development of green hydrogen, which in turn will help give rise to PtL demonstration projects around 2025.

## 6.2 Production capacity

China's current SAF production capacity (under the HEFA pathway) amounts to 150 thousand tons a year. For now, not explicit plans have been announced to initiate new production projects[65].

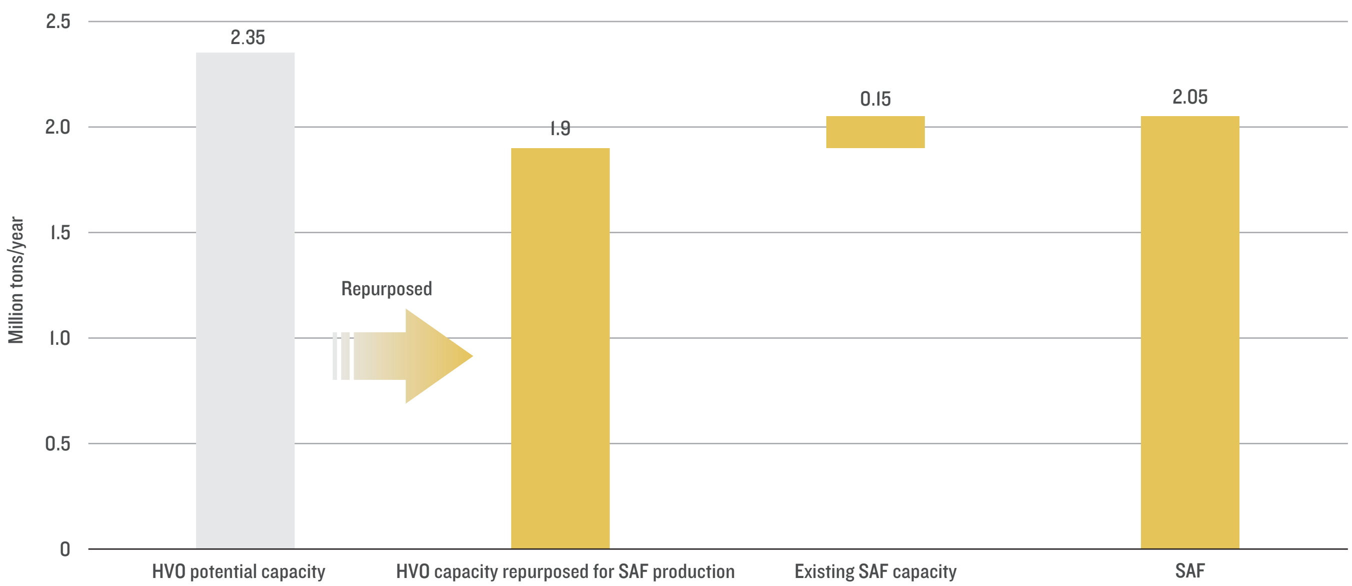
Because of a high positive correlation between SAF production capacity and user demand, China's SAF production capacity may be expanded in response to growing demand. In view of more mature processes for the HEFA pathway, SAF producers will find it more practical and efficient if they want to build new SAF production facilities or repurpose their existing HVO capacities using the pathway.

The HEFA pathways requires a hydrogenation facility (and a hydrogen production facility if there is no supply of the substance), which is the most time- and cost-consuming component of production expansion. Practically, in China it usually takes two to three years to build a new SAF production facility with an annual capacity of 100 thousand tons. The time can be shortened to months or approximately one year if an existing HVO facility or a refining facility with hydrogenation and hydrogen production systems is transformed.

However, it is less practical and less cost efficient to repurpose first-generation biodiesel production capacity for SAF production due to the former's significant difference from HVO and SAF production in terms of manufacturing process and facility.

Before 2025, if we assume that there is no additional SAF or HVO production capacity and China expands or repurposes currently operational SAF/HVO capacities and those to be completed before 2025 to maximize production, total SAF production will reach an estimated 2.05 million tons in 2025[66] (Figure 6-2).

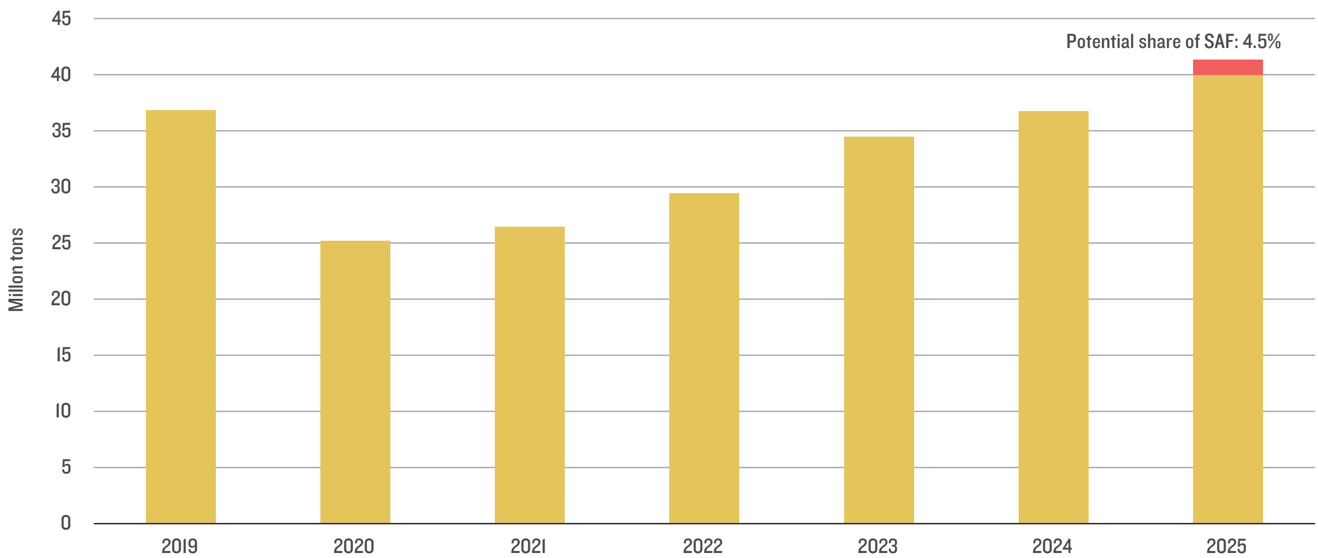
**Figure 6-2: China's theoretical SAF production capacity by 2025**




Note: 1) It is assumed that no new capacities will be added to the already announced SAF or HVO capacities before 2025; 2) another assumption is that both currently operational and SAF/HVO production capacities to be completed by 2025 will be either expanded or repurposed to maximize SAF production and that 80% of HVO production capacities will be repurposed for SAF production.

On the demand side, China consumed 36.84 million tons of aviation fuels in 2019. Due to declines in traffic caused by the COVID-19 pandemic, aviation fuel consumption dropped to 25.23 million tons in 2020 and recovered slightly to 26.47 million tons in 2021. If we assume that the business volume of China's aviation sector recovers to pre-COVID levels in 2024 and continues to increase slightly in 2025, China's aviation fuel consumption will reach 41.2 million tons. If the above-mentioned 2.05 million-ton-capacity can supply 1.85 million tons of SAF to the market, SAF will account for 4.5% of China's total aviation fuel consumption (Figure 6-3).

**Figure 6-3: Estimated aviation fuel consumption in China and theoretical SAF share by 2025**




Note: It is assumed that China will increase its total SAF production capacity to 2.05 million tons and is able to supply 1.85 million tons of SAF by 2025.

## 6.3 Availability of feedstocks

Feedstocks that can be used to produce SAF are widespread in abundance in China, including waste cooking oil, agricultural and forestry wastes, municipal organic solid wastes, industrial fumes, energy crops, and green hydrogen[67].

Waste cooking oil (WCO, commonly known as "gutter oil") is the major source of feedstock for producing biodiesel in China and is expected to be the major feedstock for SAF production at least in the next decade. WCO supply is sparsely distributed in China and the recyclable amount is estimated at 3.4 million tons (2019)[68]. Most of it is processed domestically to produce biodiesel or exported to Europe, with a minority of it reused to produce soaps, plasticizers, and pesticide emulsions. When there is more market demand for SAF, WCO can also be used to produce SAF.

Agricultural wastes generally include straws and stalks as well as leftovers from the primary processing of agricultural products, such as rice husks, corn cobs, peanut shells, and sugarcane bagasse. They are mostly abundantly available in major agricultural producing areas, including northeast, north and the lower and middle reaches of the Yangtze River. China can provide a total of 207 million tons of agricultural wastes for energy production, including 145 million tons of straws and stalks and 62 million tons of leftovers from the primary processing of agricultural products[69].

Forestry wastes include leftovers from tree felling, wood processing, clearing, and trimming. These wastes are mostly found in areas like northeast and southwest. An estimated 195 million tons are available for energy production[70].

Of municipal solid wastes (MSW), organic wastes represent 20% to 35%, which if well processed, can also be used to produce SAF. Nationwide, a total of 235 million tons of MSW were removed (in 2020) [71]. If 10% of them can be recycled for energy production, that will translate into 23.5 million tons of feedstock.

China also generates considerable amounts of industrial waste gas that can be utilized to produce ethanol to the tune of five million or even ten million tons a year. Then ethanol can be used to make SAF.

China possesses sizeable swathes of marginal land[72] (like saline and alkaline land), which can be used to grow energy crops, but in view of China's limited land reserves and water supply, high uncertainty exists with regards to the use of energy crops for production of fuels like SAF. For now, this report will not factor in the available amount of energy crops.

The available amounts of above-mentioned feedstocks are listed in the table below. Although WCO is the most mature feedstock for SAF production, its availability is limited. The supply of agricultural and forestry wastes is bountiful with enormous potential, but in the future China will need to coordinate their use for multiple purposes (such as return-to-field, heat supply, power generation and liquid fuel development).

**Table 6-1: Potential availability of SAF feedstocks in China**

| Feedstock | Availability (million tons/year) | SAF output ratio | SAF production (million tons/year) |
|---|---|---|---|
| Waste cooking oil | 3.4 | 40% (HEFA) | 1.36 |
| Agricultural waste | 207 | 10% (AtJ/G+FT) | 20.7 |
| Forestry waste | 195 | 10% (AtJ/G+FT) | 19.5 |
| Municipal organic solid waste | 23.5 | 10% (AtJ/G+FT) | 2.35 |
| Industrial waste gas-based ethanol | 5 | 50% (AtJ/G+FT) | 2.5 |
| **Total** | **433.9** | - | **46.41** |

Note: 1) The use of different feedstocks and processes for SAF production will also result in the production of different percentages of biodiesel, gasoline, and naphtha. Output ratios can be adjusted to maximize SAF production, but this will also result in more low-value byproducts like naphtha. Therefore, given current technological readiness and cost efficiency, the output ratios listed in the table are overall SAF output ratios under optimal conditions. With technological progress, these ratios may be further improved; 2) Output ratios for using agricultural and forestry wastes or municipal solid wastes to produce SAF fluctuate between 10% and 15%. A standard 10% ratio is used in the table; 3) The output ratio for using industrial waste gas to make SAF is set at 50%. 4) The estimation on feedstocks for PtL pathway is not listed above, since theoretically potential raw materials for PtL, namely CO2 and renewable electricity, are endless.
Source: Data on feedstock availability comes from Tian Yishui and other experts as well as from the Ministry of Housing and Urban-Rural Development; output ratios come from McKinsey Global Energy Practice, ICCT, International Renewable Energy Agency (IRENA) and Chinese industry experts.

## 6.4 Standards development

As a sustainable fuel, SAF must meet process and performance criteria required for aviation fuel safety and quality and satisfy sustainability standards. Currently, countries mainly certify the airworthiness of SAF produced under approved processes via standards such as GB 6537, ASTM D7566 and DEF STAN 91-091. SAF sustainability is certified against standards such as RSB and ISCC. Western countries are leading the world in standards development in view of their status as major producers and consumers of biofuels.

Over the past 10-plus years, China only used a very small amount of SAF, mostly for test flights by some airlines and for only two commercial passenger flights. During this stage, SAF use mainly followed conventional aviation fuel standards for transportation, storage, and into-plane service.

Today, China has preliminarily established a set of standards on aviation biofuel process and performance and is currently conducting research on sustainability standards.

Most of biofuels (mainly biodiesel) produced in China are sold to Europe. For SAF to be produced in the future, western standards and certification systems will apply if they still target the European market.

Airlines and potential SAF producers have high expectations about Chinese authorities' move to develop and improve the country's SAF standards and their coordination and alignment with foreign counterparts. Considering the fact that China has already established its own standards system on aviation biofuels, which is highly consistent with international standards like ASTM, issues associated with standards will not become obstacles to SAF development. In the future, both foreign and domestic standards will be constantly fleshed out and enhanced in response to expanding SAF production and use.

7

# POLICY SUPPORT HOLDS THE KEY TO SAF DEVELOPMENT

## 7.1 Government directives are critical for breakthroughs

Currently, the SAF industry remains highly policy-driven and therefore policy targets constitute an important component of the external environment for the industry's development. The most crucial factor is whether the government will establish mandatory or recommended SAF blending shares.

In European and US markets, governments have introduced goals for the use of sustainable transport fuels and specific blending requirements at both national and regional levels.

Directive (EU) 2018/2001 of the European Parliament (RED II) and of the Council establishes a binding Union target of raising the share of renewable energy to at least 32% of EU's energy consumption, including a sub-target of requiring fuel suppliers to supply a minimum of 14% (with advanced biofuels accounting for 3.5%) of the energy consumption in road and rail transport by 2030[73,74]. As for the aviation sector, the ReFuel EU Aviation Initiative, part of EU's "Fit for 55" package, proposes to gradually phase out free emission allowances for the aviation sector and align the proposal with the global Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). For the first time, the European Council also agreed to include maritime shipping emissions within the scope of the EU Emissions Trading System (ETS). At the same time, aviation fuel suppliers are required to blend more and more SAF in its fuels supplied to European aircraft[75]. To encourage the development of PtL processing, EU also plans to set a quantitative target for the share of SAF produced under the pathway. Currently, these proposals for regulations are pending approval.

**Table 7-1: EU's proposed SAF blending shares**

| SAF blending share | PtL as % | Year |
|---|---|---|
| 2% | - | From 2025 |
| 5% | At least 0.7% | From 2030 |
| 20% | At least 5% | From 2035 |
| 32% | At least 8% | From 2040 |
| 38% | At least 11% | By 2045 |
| 63% | At least 28% | By 2050 |

Source: compiled based on information from EU websites.

Similarly, the Energy Independence and Security Act of the US (EISA) [76,77] has established annual targets for all kinds of biofuels and authorizes the Environmental Protection Agency (EPA) to establish and adjust annual biofuel quotas depending on market supply and demand. EPA requires all obligated biofuel blenders (including refineries) to sell prescribed quotas of biofuels each year or buy corresponding quotas from the trading market.

Driven by these policy requirements, all participants across the supply chain of SAF in western countries are actively pushing for SAF development, which has in turn resulted in its steady growth. Global annual SAF consumption soared from eight million liters (approximately 6,400 tons) in 2016 to 100 million liters (approximately 80 thousand tons) in 2021[78], but most of it happened in Europe and North America.

In China, the 14th FYP for Green Civil Aviation Development proposes to increase annual SAF consumption to 50 thousand tons (approximately 63 million liters) by 2025. This is a positive policy signal, but the target of 50 thousand tons is not a binding one and the pathway towards the target has yet to be clarified. Generally, all players across the supply chain are still in a stage of capacity building.

Airlines, aviation fuel producers, and distributors in China are predominantly state-owned enterprises. Under this system. the absence of top-down designs at the central government level will create a high level of uncertainty for the industry's development. Participants from all parts of the supply chain will remain hesitant, waiting for explicit policy signals from the government, which will result in the lack of coordinated and collective actions among them.

First, in terms of market demand, without a mandatory SAF target, airlines will not take it as an urgent priority to promote SAF use and therefore have not introduced any further plans in this field except for the few flight tests between 2011 and 2017. Despite the global emissions reduction target set by CORSIA for the aviation sector, airlines are still waiting for the progress in negotiations at the national level, without any action plans.

Second, in terms of investment, large fuel suppliers such as Sinopec and CNPC will find it difficult to establish medium- and long-term strategies for SAF production due to the tiny SAF market and the lack of clear policy signals. The SAF facility of Zhenhai Refining is still a demonstration project by nature. As for small and medium-sized suppliers, they will also find it difficult to make investment decisions when SAF involves hefty investments but without policy clarity and market demand.

## 7.2 Supportive measures are essential

The lack of systematic top-down designs for SAF in China has also contributed to the absence of relevant policy incentives and self-driven market mechanisms that can stimulate the development of the SAF industry. In the biodiesel industry that is closely related to SAF, China exempts biodiesel that conforms to national standards from consumption taxes and grants a refund of 70% of value-added tax. When such preferential tax treatment is piloted in some provinces and cities, some local governments have also introduced corresponding fiscal and price policies[79] that are encouraging to biodiesel producers. Another example is the electric vehicle sector under the mobility industry, which has also enjoyed considerable government support throughout the past decade of its infancy.

By contrast, no targeted supportive measures have been instituted in SAF industry. Due to the nascency of the SAF market and the disconnect between SAF standards and certification systems and relevant policies, at best SAF products can only be characterized as a sub-category of the biodiesel category to seek fiscal and tax support before new policies are implemented.

High cost is a weakness of SAF when compared with conventional aviation fuels and it is also a significant impediment to its widespread adoption. Due to the adverse effects of the COVID-19 pandemic, airlines are increasingly conservative about internal cost control and external investment. Using SAF that is multiple times more expensive than conventual fuels will be an extra financial burden for airlines.

SAF will stand a chance of becoming more cost competitive if the government, SAF users and suppliers, aircraft manufacturers and airports make collective efforts and design incentive mechanisms to promote technological progress and wider application.

In this regard, the US has made encouraging attempts. In September 2021, the Biden administration released a cross-departmental action plan, the Sustainable Aviation Fuel Grand Challenge[80,81]. It is a commitment made by the Department of Energy, the Department of Transportation, the Department of Energy and the Federal Aviation Administration in collaboration with the SAF industry to invest up to USD 4.3 billion to produce SAF on a commercial scale, increase the production of SAF to three billion gallons (approximately 9.06 million tons) per year by 2030, and supply sufficient SAF to meet 100% of aviation fuel demand (approximately 35 billion gallons per year) by 2050. Relevant government departments and major industry participants have all made commitments or developed plans.

## 7.3 Multistakeholder collaboration is critical for implementation

SAF use involves all parts of the supply chain. In markets with explicit policy signals, multistakeholder collaboration is a necessary safeguard of implementation. In markets without clear policies (like China), such collaboration is even more critical when the SAF market remains in its early stage, as this will help solve the question "which came first, the chicken or the egg?" Multistakeholder cooperation can not only help early movers become resilient against risks and accumulate valuable experience but will also help inform policy making and improvement. Moreover, successful experience will also enhance policy makers' confidence in promoting SAF.

In western countries, the SAF market is usually activated by the key stakeholder, like airports, from the supply chain in collaboration with airlines, SAF producers and aviation service buyers. This practice has produced encouraging results and offers illuminating insights for the Chinese market. The appendix of this report offers cases of western countries making collective efforts across the supply chain to promote SAF use.

## 7.4 Chinese policies will be shaped by a variety of factors

The Chinese government plans to scale up SAF consumption to 50 thousand tons by 2025, but this is not a mandatory target and pales in comparison with conventional aviation fuel consumption that amounts to 30 to 40 million tons per year (2018-2019). It can hardly bolster the confidence of airlines and producers in making more SAF investments.

As in other countries, whether the Chinese government will institute stricter policies or set more ambitious goals about SAF not only depends on the progress of the global aviation industry in reducing carbon emissions, but also on what potential contributions SAF can make to China's climate change response, environmental protection, energy security, and industrial development. When we examine current and historical policies on carbon emissions control, we can see that these factors are often potential drivers of policy making in a particular sector.

Therefore, whether China will provide further policy clarity on SAF partly depends on how much SAF can contribute in relevant areas.

**Table 7-2: Some drivers of Chinese policies on carbon emissions reduction**

| Sector | Selected polies | Reduce carbon emi-ssions | Reduce conven-tional pollu-tants | Streng-then energy security | Enhance indus-trial competi-tiveness |
|---|---|---|---|---|---|
| Energy-intensive sectors | • Guiding Opinions on Accelerating the Establishment and Improvement of a Green, Low-carbon, and Circular Economic System<br>• 14th Five-Year Comprehensive Work Plan for Energy Conservation and Emissions Reduction<br>• Implementation Guide for the Transformation and Upgrading of Energy-Intensive Sectors to Save Energy and Reduce Carbon Emissions (2022) | V | V | | |
| Renewable energy | • Guiding Opinions on Accelerating the Establishment and Improvement of a Green, Low-carbon, and Circular Economic System<br>• Strategic Action Plan for Energy Development (2014-2020)<br>• 14th FYP for Renewable Energy Development<br>• 14th Comprehensive Work Plan for Energy Conservation and Emissions Reduction | V | V | V | V |
| Electric vehicles | • Mid- and Long-term Development Plan for the Automobile Industry<br>• Development Plan for Energy Conservation and New Energy Vehicles (2012-2020)<br>• Development Plan for the New Energy Vehicles Industry (2021-2035)<br>• The Circular of the Ministry of Finance, the Ministry of Industry and Information Technology, the Ministry of Science and Technology and the National Development and Reform Commission Concerning the Promotion of New Energy Vehicles Through the Further Improvement of Fiscal Subsidies (Caijian 2020 No. 593)<br>• Green Travel Action Plan | V | V | V | V |
| Dispersed coal control | • Action Plan for Air Pollution Prevention and Control<br>• Clean Winter Heating Plan in North China (2017-2021)<br>• Three-Year Action Plan for Winning the Blue Sky War<br>• Strategic Plan for Rural Rejuvenation (2018-2022) | V | V | | |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8

# POLICY RECOMMENDATIONS

## 8.1 Further clarify policy direction

The utilization and promotion of SAF are associated with the overall emissions reduction of the aviation sector as well as with the energy transition and technological change of the supply chain. Currently, ICAO, IATA, aircraft and engine manufacturers, airlines, conventional and new oil companies, and western governments are all actively promoting the uptake of SAF with an aim to become standard setters and leaders in such areas as industry, technology, and trade.

Carbon emissions from aviation will grow in China in anticipation of the sector's fast growth. Aviation fuel is a major cause of carbon emissions as well as a breakthrough in emissions reduction. If China moves early to industrialize SAF production and releases explicit policy signals, it will not only help complete its SAF supply chain and accelerate the post-COVID green recovery of its aviation industry, but will also help itself gain more initiative when participating in the development and improvement of rules on carbon emissions reduction by the global aviation sector.

China has set a short-term goal of cumulatively consuming 50 thousand tons of SAF by 2025, but the country has not developed any action plan, remains vague about its medium- and long-term policy direction, and has not provided enough policy support.

The government is advised to develop explicit plans and favorable policies for the industry's development and to leverage fiscal funding to channel private-sector capital into SAF-related industries. The government can also make it clear to include SAF within carbon emissions trading and incorporate emissions reduction into the measurement of airlines' carbon emissions intensity. Regulatory agencies, including civil aviation, energy, industry & commerce, and quality inspection, can work in collaboration and coordination with each other to strengthen regulation, track the industry on an ongoing basis, regularly analyze the progress in SAF production and promotion, and introduce measures and solutions based on critical issues that have been identified.

## 8.2 Establish a cross-ministerial working group and develop action plans

To strengthen organization and leadership, China is advised to establish a cross-ministerial coordination mechanism to solve major issues arising from SAF development and develop supporting policies to advance progress in a coordinated manner. It is recommended that the formulation of the development and action plans for the SAF industry be dominated by the government and involve industry associations and platform organizations as the organizer, as well as other stakeholders from across the SAF supply chain, including airlines, refineries, aviation fuel suppliers, aircraft manufacturers, airports, and research institutes. China may also adopt these measures, such as—creating and improving monitoring, reporting, audit, and management systems for GHG emissions from aviation and SAF-related sectors; creating needed certification systems; and actively involving itself in the development and implementation of international rules within the framework of CORSIA.

## 8.3 Strengthen the basic information assessment and cost effectiveness analysis of feedstock

China is also advised to strengthen collection and update of basic information on various feedstocks used under different technical pathways to find out their distribution and availability, so as to facilitate better allocation of resources for the industry. Cost effectiveness analysis should also be made based on the levels of difficulty of collecting different feedstocks, technological readiness levels and cost curves to promote the development of financial support policies by the government.

## 8.4 Guide collective actions across the supply chain

Communication and exchanges between participants from across the supply chain should be facilitated to enable coordination between fuel users and suppliers. The government is also advised to support collaborative innovation in SAF among various kinds of entities, and encourage oil refineries, air transport companies and aviation manufacturers to make joint investments in SAF projects that reward investors with returns in a market-based manner, so as to promote SAF use on a regular and industrial scale.

## 8.5 Support technological innovation

On this front, China can adopt the following measures—supporting the establishment of a SAF technology R&D system; promoting the diversified development of different SAF pathways, such as oil-based, cellulose-based, and green hydrogen-based technologies; guiding companies and research institutes to accelerate technological innovation and launch industrial-scale demonstration projects; and supporting SAF producers with proprietary intellectual property rights to expand their production capacity and global competitiveness.

China has a solid industrial foundation in the domain of oil-based aviation fuels, but the presence of Chinese companies in the fields of cellulose-based and green hydrogen-based aviation fuels is minimal. The country needs to expand R&D spending, industry-wide partnership, and international cooperation in these fields.

## 8.6 Actively promote the pilot use of SAF

Based on its industrial strategy, China can pilot the use of SAF produced from different feedstocks and under different technical pathways, taking account of the characteristics of into-plane service. Building on its successful pilot experience and in view of the availability of feedstocks in different places, SAF production infrastructure and regional levels of air transport development, the country can broaden its support to SAF on the demand side by making SAF available at more airports. For air transport companies that voluntarily use SAF with a relatively high share, a holistic approach may be adopted to management policies on fleet, investment, pricing, credit, and tendering. A market-driven approach should also be upheld to encourage healthy competition, to lower SAF costs, to produce replicable and scalable practices and ultimately to create a virtuous cycle for SAF development across the entire supply chain.

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46 Beijing Haixin Energy Technology Co., Ltd. was previously called "Beijing Sanju Environmental Protection & New Materials Co., Ltd." and was renamed on July 15, 2022.

47 Companies and organizations listed here do not cover all SAF and HVO-related organizations. For example, there are media reports that some other companies have also developed SAF plans, but they are not included because their projects have not been verified to exist.

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64 Some companies have been reported to plan new SAF production capacities, but without specifics, so these companies are not covered in this report in view of high uncertainty.

65 Some companies have been reported to plan new SAF production capacities, but without specifics, so these companies are not covered in this report in view of high uncertainty.

66 In addition to production capacities under the HEFA pathway, capacities under the AtJ or FT pathway may also appear before 2025, but this is highly uncertain. Therefore, they are not covered in this report.

67 China still has a long way to go before it can adopt the technical pathway of using green hydrogen to produce SAF on a commercial scale. The prospects of producing SAF from energy crops are relatively uncertain, so energy crops as SAF feedstocks are not covered in this report.

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**Institute of Energy, Peking University**

Add.: Rm.438 Peking University Yanyuan Building, No.5 Yiheyuan Road, Haidian District, Beijing, China

Z.C.: 100871

Email: genergy@pku.edu.cn

Tel: +86-10-62751150

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