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King Abdullah Petroleum Studies and Research Center

Future of Fuels in the Aviation Sector

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About KAPSARC

KAPSARC is an advisory think tank within global energy economics and sustainability providing advisory services to entities and authorities in the Saudi energy sector to advance Saudi Arabia's energy sector and inform global policies through evidence-based advice and applied research.

This publication is also available in Arabic.

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Key Points

Aviation is crucial for connecting people and countries worldwide. Although aviation carriers, manufacturers, and governments have all aimed to increase energy efficiency through significant technological advances over recent decades, this transport mode has struggled to find alternatives to fossil-based fuels. However, recent developments in low-carbon aviation fuel (LCAF), sustainable aviation fuel (SAF), hydrogen-based fuel, and electric power have improved the sustainability of the sector. As a result, a better understanding of the current use, future development, and new challenges of energy sources is essential for the future of the aviation industry.

The aviation sector has the second-highest energy demand in the transportation industry after the road sector. Further, demand for aviation has grown steadily over the last decade, despite the COVID-19 pandemic provoking the sharpest demand decline in recent history.

Energy concerns have focused the world's attention on taking active steps toward defining targets and goals in the aviation sector. Although technological advancements are evolving rapidly worldwide, regional disparities are affecting their adoption.

Global energy demand perspectives offer a roadmap for developing new strategies and policies in the short, medium, and long run. The technological pathways for new aviation fuels are diverse, but serious challenges remain to be addressed for them to become commercially available.

International organizations, such as the International Air Transport Association and the International Civil Aviation Organization, are placing pressure on this sector to achieve highly ambitious goals and targets that might be beyond the reach of current technologies. However, technological advancements could make this ambition achievable by 2040 or 2050.

Summary for Policymakers

Energy demand in the aviation industry is driven by its growth. Over recent decades the industry has been increasingly competitive, presenting challenges for carriers. Distinguishing between the types of carriers (e.g., low-cost carriers and full-service carriers) has become difficult. The Global Financial Crisis of 2008 to some extent fostered the industry's consolidation. Hence, worldwide, airline groups are now trying to buy more airlines to control the market and not lose market share. Airlines have therefore become larger than ever. They presently contain a variety of business models, including the provision of essential products and innovative auxiliary services.

While the aviation sector has grown remarkably and been resilient to external events, the COVID-19 pandemic led to the most significant demand decline in recent years. It also underscored the challenge of environmental sustainability for humanity. Nonetheless, aviation sector analysts project that up to 10 billion passengers will fly by 2050 in comparison with 4.5 billion passengers in 2019 (Al Ghailani 2022). In addition to transporting people, aviation plays a significant role in moving cargo, due to the lack of a viable alternative. By 2050, aviation will have additional challenges because of rapid urbanization. Thus, the use of autonomous electric vertical take-off and landing technology will be crucial in cities and will play a role in developing the policy framework for urban air mobility.

The airline industry has traditionally been environmentally conscious. Indeed, although aviation demand has risen significantly in regional, domestic, and international markets, carbon dioxide (CO2) emissions from aviation have remained around 3% globally. The most ambitious global environmental project is the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) introduced by the International Civil Aviation Organization (ICAO). Although participation in CORSIA remains voluntary until 2025, aviation externalities and their internalization for short-, medium-, and long-haul services must recognize the environmental damage of their emissions to the planet.

According to CORSIA, reducing CO2 emissions requires a sensible combination of solutions, including advanced aircraft technologies, operational and infrastructure improvements, and a basket of measures such as offsets, sustainable aviation fuel (SAF), and low-carbon aviation fuel (LCAF), for airline operators to improve efficiency globally. The use of SAF could significantly reduce CO2 emissions. However, it could also raise the related carbon intensities of land use and feedstocks. Therefore, LCAF is a bridge to reaching the maximum potential aviation sector emissions reduction.

Multiple technologies use the different feedstocks available for producing SAF, the majority of which are yet to reach commercial scale. One fully commercial technology, the Hydrotreated Esters and Fatty Acid pathway (HEFA), is the leading supplier of SAF. Other technologies include gasification, the Fisher–Tropsch process, alcohol-to-jet, power-to-liquids, e-fuels, pyrolysis, hydrothermal liquefaction, and thermochemical liquefaction. These are either in the early stages of commercial readiness or rely on facilities currently under construction, and are expected to be three to four times more expensive than the HEFA pathway. Hence, HEFA will remain the leading supplier of SAF over the next decade. Moreover, the production of SAF through co-processing using existing refineries will become significant in regions in which feedstocks are located.

Existing incentive structures and the high cost of SAF are incentivizing its use over diesel. Therefore, cost is the major challenge for SAF when compared with conventional jet fuel. For this reason, international policies could influence the development of SAF in an unprecedented way. For instance, in the European Union, ReFuelEU proposed creating structural demand that could influence the development of new facilities by 2025.

When examining how the aviation sector can reduce carbon emissions, several further issues arise. Its reliance on offsetting as the primary mechanism, because of the cost of the other options relative to fossil fuels, may be a short-lived approach. Indeed, current policies focus on adopting technologies that reduce emissions, improve operational and energy efficiency, alongside new aircraft development. However, those changes will take time to occur: Building new infrastructure and upgrading existing infrastructure require considerable investment.

In conclusion, energy demand in the aviation sector will increase in the medium and long term, with an expected peak in jet fuel demand in 2030. Although policymakers would like SAF to account for a significant proportion of the fuel mix, SAF penetration will be limited by regional policies, high costs, and feedstock availability. Furthermore, as policymakers shift their attention to other technologies such as power-to-liquids and e-fuels, these fuels could increase their share of the fuel mix to help meet CO2 reduction goals.

Background to the Workshop

On June 7, 2022, KAPSARC hosted a webinar on the drivers of rising energy demand in the aviation sector and the future of aviation fuels. Over the past few years, the KAPSARC Transportation and Infrastructure team has been researching the future of energy demand in the aviation sector to provide past, current, and future perspectives on its growth. The sector has been growing steadily over the last decade, reaching 4.5 billion passengers worldwide in 2019, with this figure expected to climb to nearly six billion passengers in 2030. It has previously shown its resilience to external events such as World War II, the 1970s oil crisis, the 9/11 terrorist attacks in 2001, and the Global Financial Crisis in 2008. However, the recent COVID-19 pandemic prompted one of the most extensive demand declines in its history. Nonetheless, the aviation sector remains the second-highest energy-demanding subsector in the transportation industry behind the road sector. Hence, energy-related demand and CO2 emissions from the aviation sector are crucial challenges.

Aviation has been one of the fastest-growing transport sectors in Saudi Arabia over the last decade. Demand for aviation grew at a composite annual growth rate of 9.8% from 2010 to 2019, peaking at more than 103 million passengers per year in 2019, including international and domestic flights. For this reason, the increase in transportation demand is a critical concern from an energy and decarbonization perspective (mainly CO2 emissions).

Taking this into consideration, the following three key themes formed the basis for the workshop:

- The aviation sector's short-, medium-, and long-term prospects, including the impact of the COVID-19 pandemic.
- The barriers, limitations, and opportunities for fossil-based and non-fossil-based fuels in the aviation sector.
- The outlook for energy demand from aviation.

All three themes are expected to impact the global aviation sector's performance and future prospects significantly. In particular, the COVID-19 pandemic has brought about new challenges to the sector's resilience, speed of recovery, and growth prospects. This has created more significant disruptions for international passengers than for domestic passengers.

Although the aviation sector accounts for only around 3% of all greenhouse gas emissions globally, manufacturers, policymakers, and stakeholders are focused on the development and use of alternative fuels (i.e., non-fossil-based fuels) to decrease the overall rise in CO2 emissions. With new technologies and alternative fuels in development, global CO2 emissions are expected to improve significantly in the coming years. However, most alternative fuels are not commercially available because their facilities and costs are substantially higher than those of fossil-based fuels. This has encouraged aviation sector parties such as the International Civil Aviation Organization (ICAO) and the International Air Transport Association (IATA) to define a combination of market basket measures to mitigate a future rise in CO2 emissions.

Many disparities remain between countries' efforts to reduce their CO2 emissions. Although policymakers can play a significant role by offering incentives and imposing mandates, airlines, airports, and manufacturers must take action to make a change. One example is ReFuelEU's proposal for significant abatement mandates by 2050. Global energy demand for aviation is expected to increase, and the efficiency gains and penetration of non-fossil-based fuels and other alternative sources may struggle to keep up the same pace.

Future of the Aviation Sector

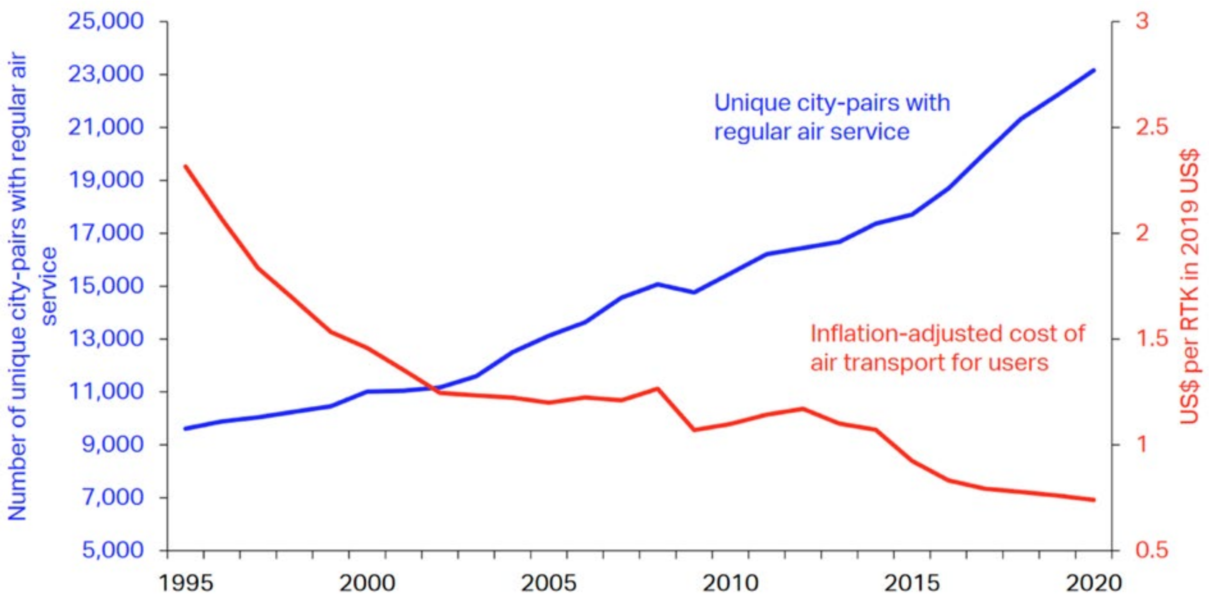
The aviation sector is responsible for transporting goods and people. More than $7 trillion in goods and 4 billion passengers were transported in 2019 (Al Ghailani 2022). Demand for aviation has increased significantly in regional, domestic, and international markets, creating more than 70 million jobs worldwide in aviation and related industries. However, the COVID-19 pandemic provoked the sharpest demand decline in recent decades.

Before the COVID-19 pandemic, the airline industry was characterized by affordable flying for consumers, which increased connectivity by air (Figure 1). Indeed, airlines made impressive efforts to enhance efficiency through the passenger load factor, but this was not the same for cargo (Figure 2). Lower prices for consumers increase efficiency and unit performance (i.e., emissions per passenger-kilometer decrease).

However, it is becoming increasingly challenging for airlines to raise prices to increase revenues because of the highly competitive airline industry, even for routes they monopolize. Further, the potential entrance of new airlines and network structures puts further pressure on carriers. This pressure comes from competing airlines flying to the same destinations, but via alternative routes. As a result, competition in the aviation sector has intensified.

Airline groups are aiming to buy more airlines to control the market and not lose market share, thereby transforming into ever larger organizations that use a variety of business models. However, there are marked differences between airlines in

Figure 1. City-pair connections and actual cost of air transport.



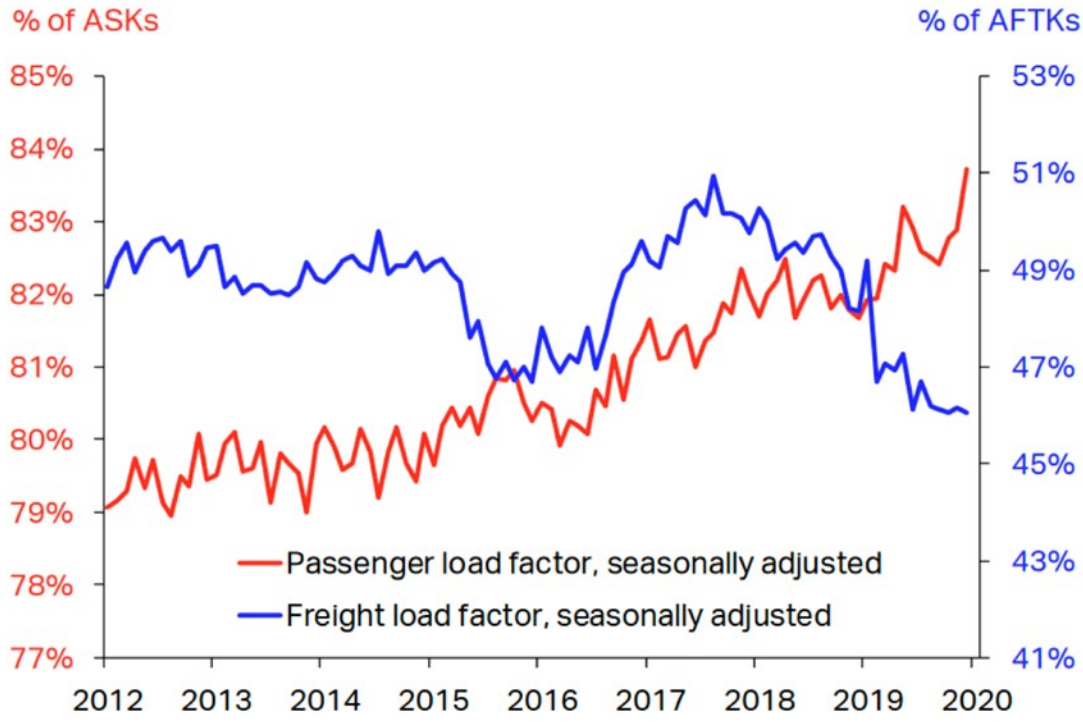
Source: Economic Performance of the Airline Industry (IATA 2019b).

different regions (e.g., the Middle East, the United States, Europe, and Asia-Pacific). Some airlines offer a basic, no-frills product and attempt to generate additional revenue by offering auxiliary services.

In the future, technological development, higher operational efficiency, and the penetration of alternative fuels will play a significant role in creating more efficient aviation systems worldwide. The biggest challenge is that the new technologies needed for this are not yet commercially ready, making their use in aviation a continuing challenge in the coming years. For instance, the development of urban air mobility solutions through autonomous electric vertical take-off and landing technology will depend significantly on the right policy framework being implemented.

As a result, manufacturers and the aviation industry are still working on addressing current challenges associated with an evolving market, new technologies, the use of fossil-based fuels, the penetration of non-fossil-based fuels, and other alternative sources (hydrogen and electric power). However, policies and incentives must play a significant role in supporting aviation's global transition to being more environmentally sustainable.

Figure 2. Load factors (passenger and freight).



Source: Airlines Financial Monitor (IATA 2019a).

Note: ASK = Available-seat-kilometers. AFTK = Available freight tonne kilometers.

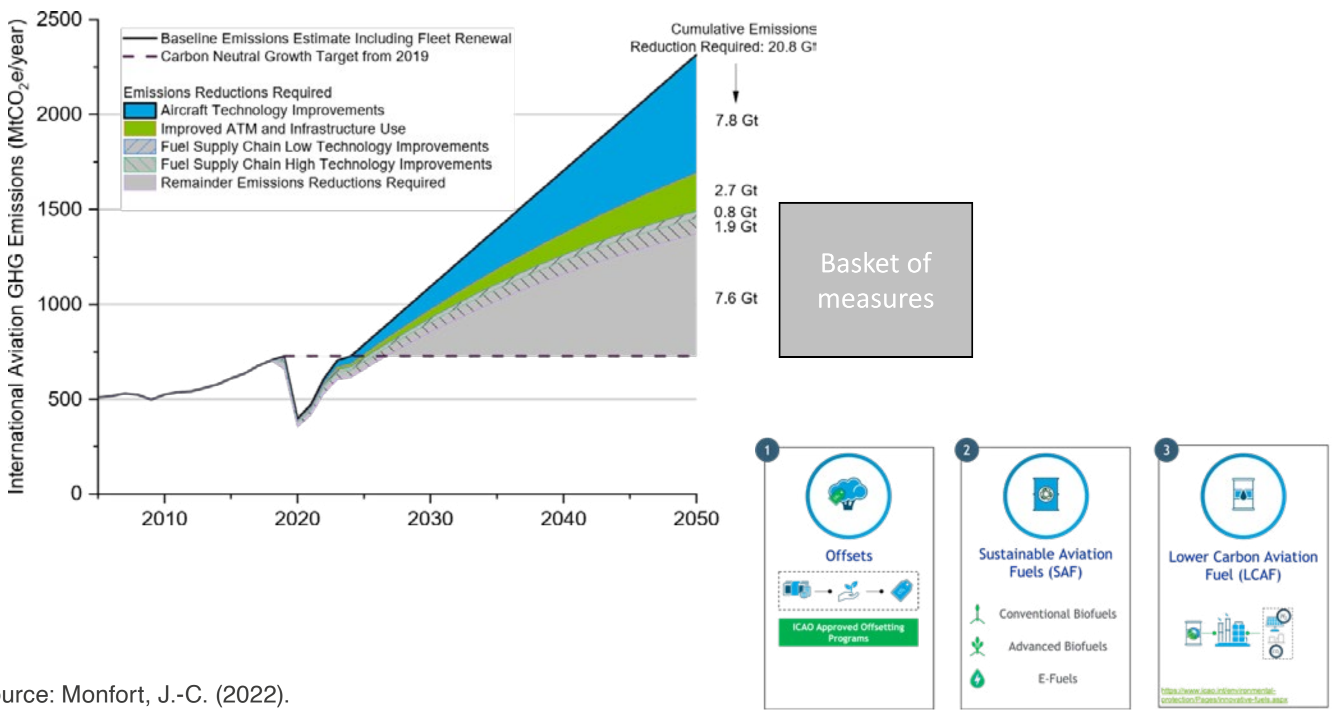
Fossil-Based and Non-Fossil-Based Fuels in the Aviation Sector: Opportunities, Progress, Barriers, and Perspectives

Global energy demand from the aviation sector has traditionally been dominated by fossil fuels. Aviation accounted for nearly 12% of the total energy demand in the transport sector, just behind road transport, which has historically been the most demanding sector worldwide. Traditional fossil-based fuels used in this sector are being replaced by lower-carbon alternatives.

CORSIA, an initiative introduced by the ICAO, sets long-term targets for the airline industry based on developments in aircraft technology, operational and infrastructure improvements, and measures that include offsetting mechanisms, SAF and LCAF, as shown in Figure 3.

If renewable energy is used throughout the LCAF supply chain, it could decrease the LCAF's carbon intensity. This could include the use of renewables in oil fields and refineries, and carbon capture and storage to reduce refinery emissions. Recent studies (Masnadi et al. 2018; Jing et al. 2020) on upstream (9,000 oil fields worldwide) and refining operations (500 refineries worldwide) have shown that carbon intensity could be decreased by (i) formulating policies directed toward innovation, (ii) developing and consuming lower-emission fuels, and (iii) using various technologies to reduce emissions. As a result, LCAF has at least 10% less carbon intensity than commercial jet fuel. Although SAF emissions fall to 25 grams of CO2 equivalent per megajoule (CO2-e/MJ) because, in

Figure 3. CORSIA initiative.



Source: Monfort, J.-C. (2022).

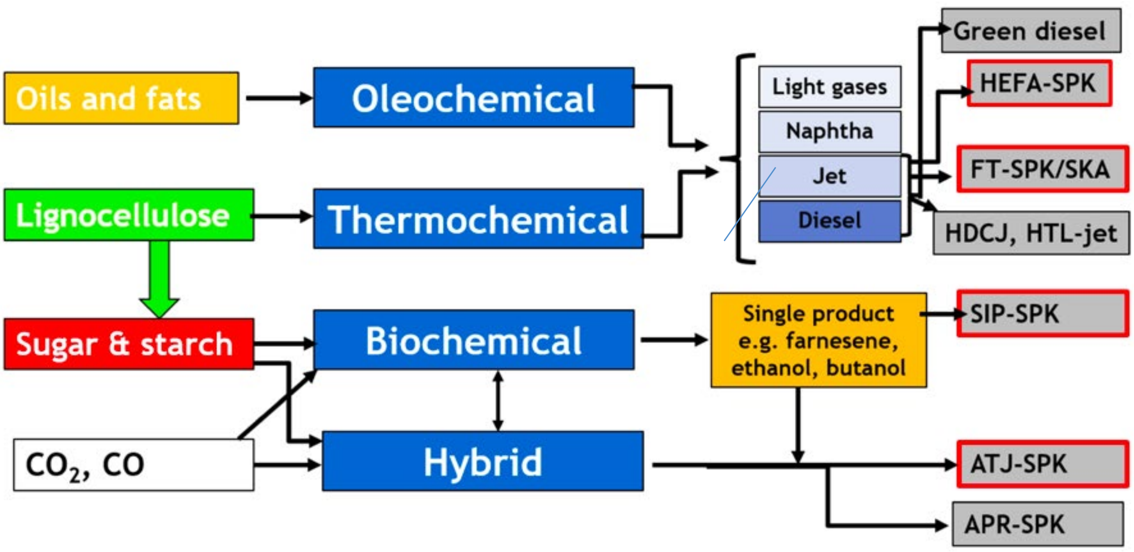
the combustion process, commercial emissions fall to zero, the impact of SAF on land use and feedstocks could cause them to have higher related carbon intensities. The use of cooking oil as an SAF is based on quantities of waste cooking oil, which could have limited availability. Finally, e-fuels have low carbon intensity because commercial emissions fall to zero in the combustion process and they use renewable sources.

There is only one fully commercial SAF technology (Figure 4), known as the HEFA pathway. For this reason, over the next decade, HEFA will remain the leading supplier of SAF. Other technologies rely on facilities either under construction or in the early stage of their commercial readiness. These include gasification, the Fisher–Tropsch process, alcohol-to-jet, power-to-liquids, e-fuels, and thermochemical liquefaction (pyrolysis and hydrothermal liquefaction). However, these fully commercialized technologies are expected to be three to four times more expensive than the HEFA pathway.

The high cost of SAF is the major challenge, and the price gap between SAF and conventional jet fuel is significant. SAF production through co-processing, which is not widely used in existing refineries, will become significant, especially in regions in which the feedstocks are located (Figure 5). In other words, refineries can become involved in SAF production using their infrastructure through co-processing.

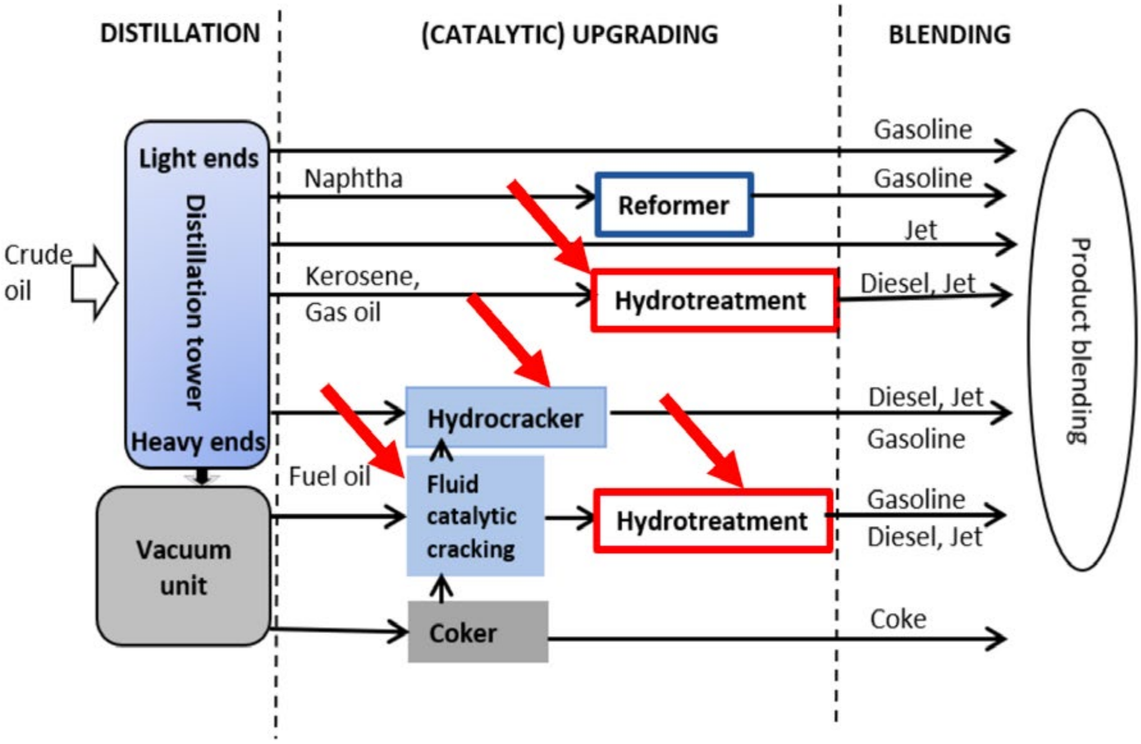
Overall, the aviation sector remains critical systemically, and it is working toward developing technologies to meet its emission goals and targets to ensure a smooth transition. The main limitation of SAF for obtaining real environmental benefits is its mode of production. Therefore, although SAF is the key enabler to meet the industry's emissions mitigation aspirations, LCAF will help it maximize its carbon reduction.

Figure 4. SAF technologies.



Source: Van Dyk (2022).

Figure 5. Co-processing: refinery insertion.



Source: Van Dyk (2022).

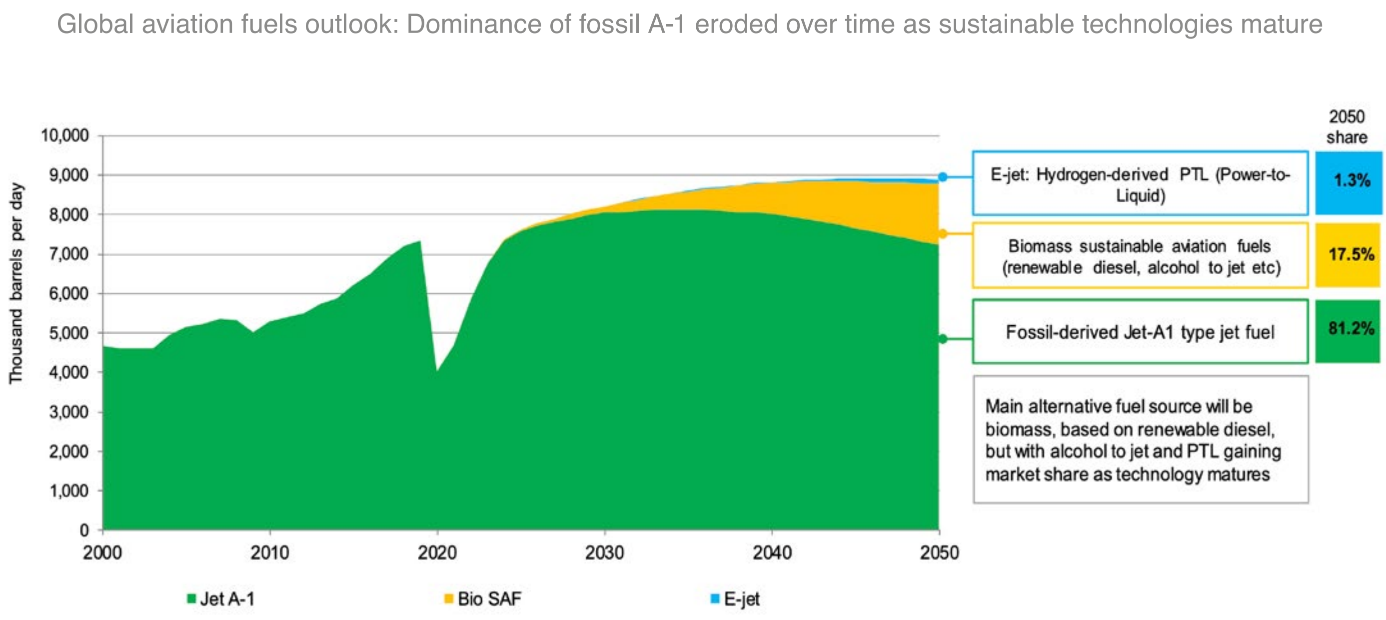
Future Energy Demand in the Aviation Sector

Over the last two to three years, the aviation sector has changed radically. Industry stakeholders have long considered decarbonization to be the main priority for this sector, as it is for many others. However, the aviation sector faces a real challenge to decarbonize because demand for flying is expected to grow significantly and emissions must be reduced. Aircraft manufacturers and airlines have focused on improving efficiency, and aviation sector efficiency has already declined, limiting any potential operational and fuel efficiency gains. Hence, technological advancements are necessary to meet the industry's decarbonization challenges and emission reduction targets.

The industry will rely on offsetting as the primary decarbonization pathway, as all other options are incredibly costly relative to continuing to use fossil-based fuels. However, offsetting will no longer be considered acceptable as the primary mechanism. The main issue is that blending SAF could increase flying costs and dampen demand. In addition, policymakers have begun to incentivize the uptake of technologies that reduce emissions.

Figure 6 shows that, as global energy demand in the aviation sector is expected to increase, demand for flying will outpace efficiency gains. Energy demand from aviation will continue to increase until 2050. SAF penetration will play an increasingly important role in reducing emissions, resulting in a peak in jet fuel demand in 2030. However, SAF penetration will be limited.

Figure 6. Outlook for fuel usage in the global aviation sector.

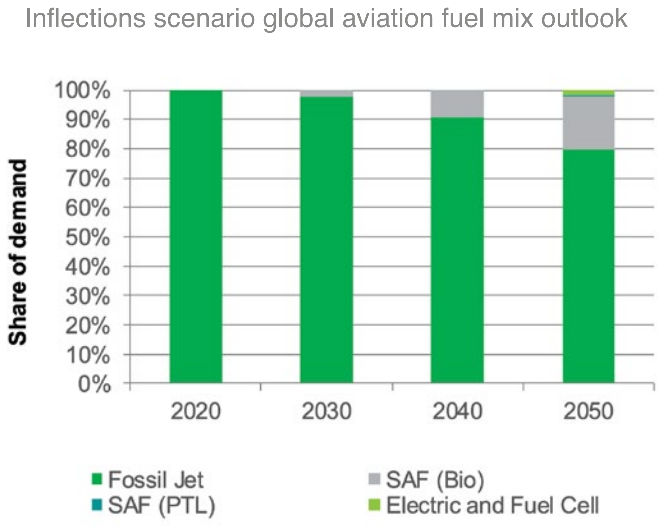


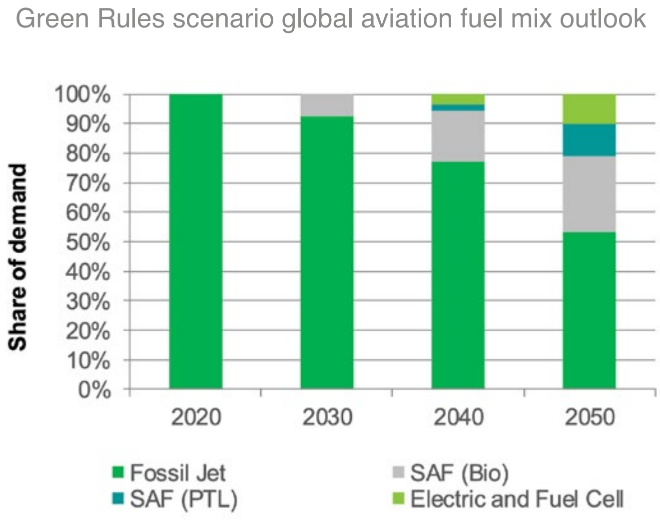
Source: Evans (2022).

The scenarios in Figure 7 (a mixed scenario as a base case and an alternative ‘green rules’ scenario) show that there is a need to go beyond biofuels to meet the deeper decarbonization ambitions of the aviation industry and achieve its emission reduction targets. For example, power-to-liquid technologies and e-fuels with lower carbon intensity must be introduced. Energy demand in the green rules scenario is 27% lower than in the base case scenario by 2050. However, the regionalized policy will lead to a lack of ambition in some regions (see Figure 8), and significant regional disparities will exist irrespective of the scenario. Only some countries, primarily those in Europe and OECD nations in Asia and North America, will have significant SAF penetration.

SAF penetration could also be affected by the competition for it from other end-use sectors (i.e., cars, trucks, and ships). Therefore, it might be attainable only by policymakers offering incentives or imposing mandates. Airlines, airports, and manufacturers must also drive effective change. Electric-powered aircraft will not have a large impact on alternative fuels because customers prefer longer routes on which electric aircraft are incompatible. Hence, electric aircraft will primarily be used on shorter commuter routes in the future.

Figure 7. Global aviation outlook.

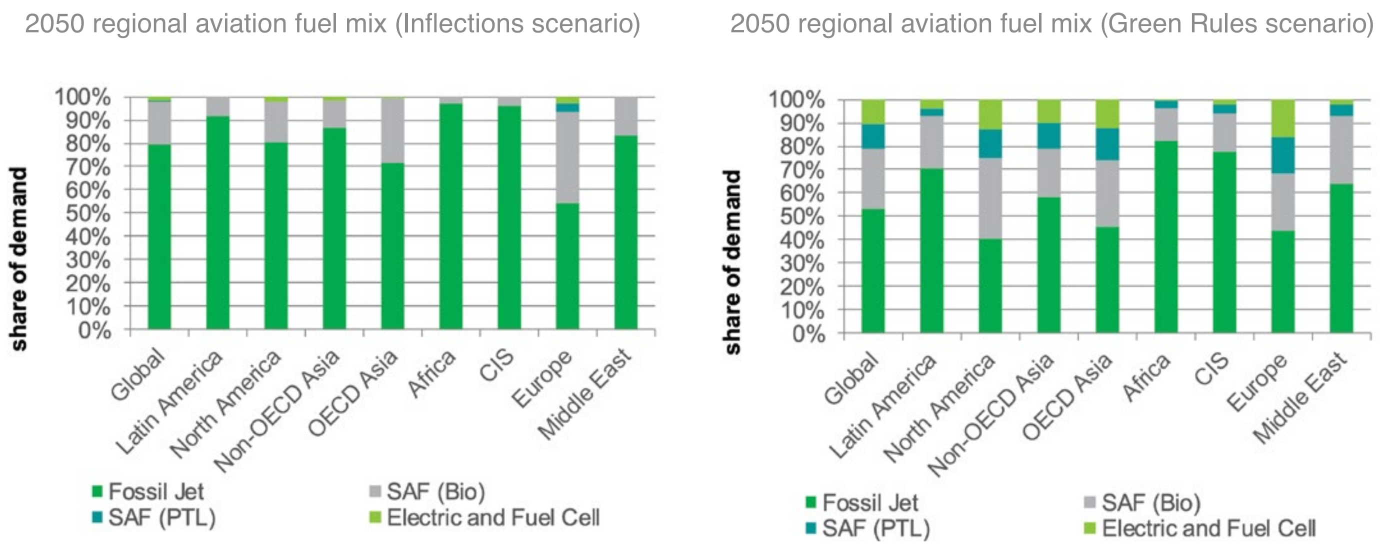




Source: IHS Markit.

Note: SAF = Sustainable aviation fuel. PTL = Power-to-liquids

Figure 8. Regional global aviation outlook.



Source: IHS Markit.

Note: SAF = Sustainable aviation fuel. PTL = Power-to-liquids

Perspectives on the Aviation Sector

The webinar shed light on past and current trends in the industry, which has become a competitive environment worldwide, and whose energy demand has risen significantly. It also gave current and future perspectives on energy demand in this sector by considering the current and future resources available. The webinar aimed to support the discussion on the future of the aviation sector and fuels and provide broader perspectives on the industry. These can be summarized as follows:

Although the aviation sector is responsible for less than 3% of global emissions, it is taking similar actions to other sectors in mitigating them. Not only must the industry and companies take responsibility for exploring all alternatives, consumers must also demand that companies be more responsible and choose the best option to reduce emissions. If one regional market starts sustainable initiatives, others will follow. For instance, in Europe, different types of airlines (not necessarily legacy airlines) and many low-cost carriers have been renewing their fleets to persuade consumers to fly with them due to their greener credentials.

Aircraft manufacturers have reduced fuel consumption by approximately 20% – 25% since 2010. However, it is essential to look at the fuel burn and life cycle. While SAF still emits carbon, the closed-loop system can verify whether these fuel sources are sustainable. In other words, besides reducing fuel consumption, using fuels with lower carbon intensity is essential for reaching the goals and targets set for this sector. SAF will remain expensive because the technologies used to produce them are often immature. Hence, there is limited opportunity to reduce costs. The cost of feedstocks is also a significant constraint.

New fuels such as SAF must not do more harm (e.g., in those places in which it is produced) than the status quo. It will take time to find the best solution using local alternatives to transition to full decarbonization, and the solutions will be context dependent (e.g., urban mobility, short/long haul, or regions where aviation is essential – islands or areas with no other alternatives). LCAF will help in this transition and help the industry recognize the higher cost of SAF relative to the cost of the technology required to produce alternative fuels.

SAF is produced using the HEFA pathway, which is the cheapest option currently and is fully commercial, unlike other technologies, even those with approved technological pathways for production and certified by the American Society for Testing and Materials (ASTM). However, the development of new aviation fuels depends on the feedstocks and resources available in each region. Other technologies could be much more expensive initially because the construction of their production facilities is at least 50% more expensive than facilities exclusively producing fossil fuels. However, the infrastructure costs of these newer technologies are expected to fall by 20% – 25% by 2050. In addition, the cost of electricity is expected to fall substantially, and e-fuels are projected to be 65% cheaper by 2050.

There is significant regional variation in policy implementation (e.g., for intra- and inter-regional flights in the European Union [EU]). Although any airline flying into the EU incurs the same costs as an EU airline, the cost of flying will increase in regions where these policies are imposed, potentially negatively impacting the tourism sector.

The integration of technologies such as direct air capture or removal could increase the competitiveness of traditional jet fuels in the long term, and commercial use could be possible by 2040 or 2050. Products to help meet aspirational targets such as net-zero are required. This remains a challenge.

Prices for passenger aviation have fallen, even though customers have a high willingness to pay for air travel. The European Commission has included aviation in the EU Emissions Trading System to assess the potential price increase of flying due to emissions. At the same time, some airlines have increased their taxes on ticket prices, but only slightly. Consequently, it will be interesting to see how airlines include this charge within their business models as a differentiating factor. If a particular airline is greener than others, it would be more affordable for consumers to pay their fares as they would have a lower carbon cost.

Although SAF and other alternatives are costly, the aviation industry has been able to internalize previous fluctuations in fuel prices or pass them on to consumers. Some airlines may go bankrupt without doing so.

Technological advancements are allowing low-cost carriers to adopt SAF, albeit with some challenges. Some markets are not price-sensitive, such as the business traveler market, where making greener decisions is a large part of being responsible as a business. Some organizations use a considerable amount of corporate travel and are taking steps to offset their emissions or make more sustainable choices when selecting airlines, or even selecting extra legroom.

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About the Workshop

KAPSARC hosted a webinar to discuss the current, short-term, medium-term, and long-term use of fossil-based fuels, the penetration of non-fossil-based fuels in the aviation sector, and the long-term goals of decarbonization and sustainability. The webinar drew more than 210 participants from various backgrounds, including governments, regulatory authorities and entities, international organizations, the aviation industry, and innovation, research, and development organizations. It aimed to provide insights into the future of commercial aviation worldwide from the perspective of energy demand and consumption. The speakers addressed the challenges of energy and sustainability for the aviation industry, given differing regional goals and targets.

Guest Speakers

This webinar was held with participants from academia, the aviation industry, market researchers, and energy producers:

Mohamed Al Ghailani – Regional Lead Global Sustainability Policy and Partnerships, Boeing

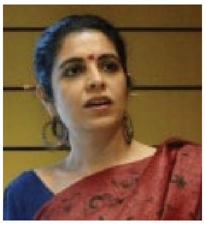
Daniel Evans – Vice President, Global Head of Refining and Marketing, IHS Markit

Edgar Jimenez Perez – Lecturer in Air Transport Management, Centre for Air Transport Management, Cranfield University (United Kingdom)

Jean-Christophe Monfort – Climate Impact Analysis Group Lead, Saudi Aramco

Susan van Dyk – Sustainable Aviation Fuel expert, Biofuels Consultant, IEA Bioenergy Task 39, and Researcher at the University of British Columbia

About the team



Anvita Arora

Anvita is Program Director for Transportation and Infrastructure at KAPSARC. Previously, she was the CEO of Innovative Transport Solutions. Anvita holds a Ph.D. from the Indian Institute of Technology Delhi, India.

Andres Felipe Guzman

Andres Felipe is a Fellow at KAPSARC, working on the future of aviation energy demand. He has previously worked as a professor, researcher, and consultant. His research interests include assessing the economic impact of transport policies/economics, the macroeconomic impact of transport policies, and energy-related decisions.

About the Project

The KAPSARC Aviation Model project's objective is to analyze the main drivers of energy demand in the aviation sector, and assess energy concerns by considering the current and future use of fossil-based and non-fossil-based fuels. Aviation is a key transport mode worldwide because it provides essential travel routes and generates economic growth in many related sectors. Therefore, a better understanding of aviation in countries such as Saudi Arabia is necessary to illustrate how aviation policy decisions are framed so that they continue to be a catalyst for such countries' development. This project explores current and future aviation and energy demand scenarios to generate policy-relevant insights. Issues related to aviation performance, energy demand, and consumption create the need to develop better management tools and methodologies for data, models, and technologies.

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