ORGANIZATION OF ARAB
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COUNTRIES (OAPEC)

# SUSTAINABLE AND LOW CARBON AVIATION FUEL:
## CHALLENGES AND OPPORTUNITIES

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# Introduction

The aviation sector seeks to encourage the use of alternative aviation fuel led by the International Civil Aviation Organization (ICAO), through its initiative called the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). This initiative aims to reduce carbon emissions resulting from the use of petroleum-based aviation fuel. Among the alternative fuels proposed in this initiative is Low Carbon Aviation Fuel (LCAF), which is a fossil-based fuel with emissions throughout its life cycle at least 10% lower compared to conventional petroleum-based fuel.

This study aims to introduce the technologies for producing sustainable and low carbon aviation fuel and the costs of its production compared to petroleum-based aviation fuel. This is achieved through carbon intensity reduction technologies that can be applied at all stages of the product's life cycle, starting from oil production in the fields, through refining processes, transportation, to distribution centers, and finally consumption.

The study also addresses the difference between low carbon aviation fuel produced from oil and Sustainable Aviation Fuel (SAF) produced from renewable sources, highlighting the challenges facing the production and spread of these types in global markets, and the possible solutions to overcome these challenges.

The study is divided into five main chapters. The first chapter defines the types of low carbon and sustainable aviation fuels and the importance of emission reduction in the aviation sector. The second chapter discusses the available technology and pathways for producing sustainable and low carbon aviation fuel. The third chapter reviews the main challenges facing the production of sustainable and low carbon aviation fuel, opportunities to enhance its spread, and encourage its production and consumption worldwide. The fourth chapter provides an overview of the developments in sustainable aviation fuel in different regions of the world and in Arab countries. The fifth chapter summarizes the conclusions and recommendations of the study, including:

- The main obstacle to producing sustainable aviation fuel is the cost, which ranges from about two to eight times the price of conventional aviation fuel.

- Investing in sustainable and low carbon aviation fuel supports the industry's transition towards sustainability and drives progress in other green technologies.
- Stimulating the production of sustainable aviation fuel requires significant political incentives to bridge the price gap between conventional and sustainable aviation fuel.
- To reduce investment risks in sustainable fuel projects, cooperation between the public and private sectors, the aviation sector, fuel producers, universities, and research centers must be strengthened.
- Co-processing has proven to be an effective way to enhance the production of low carbon aviation fuel.
- To achieve the goal of net-zero emissions, all available pathways for producing sustainable and low carbon aviation fuel must be utilized.
- Funding and supporting research and development institutions is crucial to finding technologies that improve the production of low carbon aviation fuel at acceptable prices.
- Given the need for all possible options for decarbonization, the option of using fossil fuel must be considered in the energy mix equation, especially low carbon aviation fuel (LCAF).
- Despite most Arab countries having large reserves of oil and gas, many of these countries are leading the way in diversifying the energy mix and reducing carbon emissions. They have valuable opportunities to be leaders in the production and export of sustainable and low carbon aviation fuel, with their infrastructure and financial resources for renewable energy projects, and a variety of feedstocks suitable for producing sustainable fuel, such as algae that can be grown in saltwater, and some drought-resistant plants like Jatropha, and other plants that tolerate high salt levels in the soil.

The General Secretariat hopes that specialists will find in this study some ideas that will help them choose suitable solutions to meet global trends towards producing sustainable and low carbon aviation fuel.

Secretary General

Jamal Issa Al-Loughani

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# Executive Summary

The aviation sector is one of the main consumers of fossil fuels. Achieving net-zero carbon emissions in this sector by 2050 faces several challenges, the most significant being that most of the current aircraft fleet will remain in operation until after 2040-2050, making it impossible to modify aircraft engines during this period, and thus difficult to change the type of fuel used. (Royal Society, 2023)

## Classification of Aviation Fuels

The International Civil Aviation Organization (ICAO) classifies aviation fuels according to the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) into two groups: the first group is conventional aviation fuel (CAF) based on fossil fuels, which includes fuel produced from oil refining, such as kerosene and aviation gasoline. The second group is alternative aviation fuel, which consists of sustainable aviation fuel (SAF), low-carbon aviation fuel (LCAF), hydrogen, and liquefied natural gas.

### Petroleum Aviation Fuel

Petroleum aviation fuel is produced from the refining of crude oil at a refinery and is called aviation kerosene. It has several types depending on the field of use, with the most used type being Jet-A1 fuel.

### Low-Carbon Aviation Fuel (LCAF)

Low-carbon aviation fuel (LCAF) differs from sustainable aviation fuel (SAF) in that the former contributes to reducing carbon emissions from the fuel manufacturing process, while the latter contributes to reducing emissions from burning and consumption.

## Sustainable Aviation Fuel (SAF)

Sustainable aviation fuel (SAF) is known by several names that carry the same meaning, such as biojet fuel, renewable aviation fuel, renewable jet fuel, and alternative aviation fuel. (ATAG, 2017)

## Benefits of Sustainable Aviation Fuel

Sustainable fuel emits much lower greenhouse gases than conventional fuel, and CO2 emissions can be reduced by 80% over the life cycle of the product, improve air quality, and thus improve compliance with carbon emission reduction legislation requirements, and enhance energy security by securing an additional source of aviation fuel from renewable and alternative sources, especially for countries that do not have petroleum resources, as it helps them reduce their dependence on oil and obtain fuel from sustainable raw materials such as used cooking oils and agricultural waste, which contributes to supporting the national economy and maximizing the benefit from the existing infrastructure for producing and storing conventional aviation fuel.

## Sustainable and Low-Carbon Aviation Fuel Production Technologies

Sustainable aviation fuel production pathways are classified into three main groups, the first of which is based on the Fischer-Tropsch process, which was approved in 2009, followed by the Hydroprocessed Esters and Fatty Acids process, which was approved in 2011 and is the most widespread in the world, and the Alcohol to Jet Fuel (ATJ) process, which was approved in 2018. All these technologies contribute to reducing the emissions that can be released over the life cycle of aviation fuel by high rates of up to 90% compared to petroleum aviation fuel. The following table shows examples of sustainable aviation fuel production pathways approved by ASTM. (Royal Society, 2023)

Examples of sustainable aviation fuel production pathways approved by ASTM

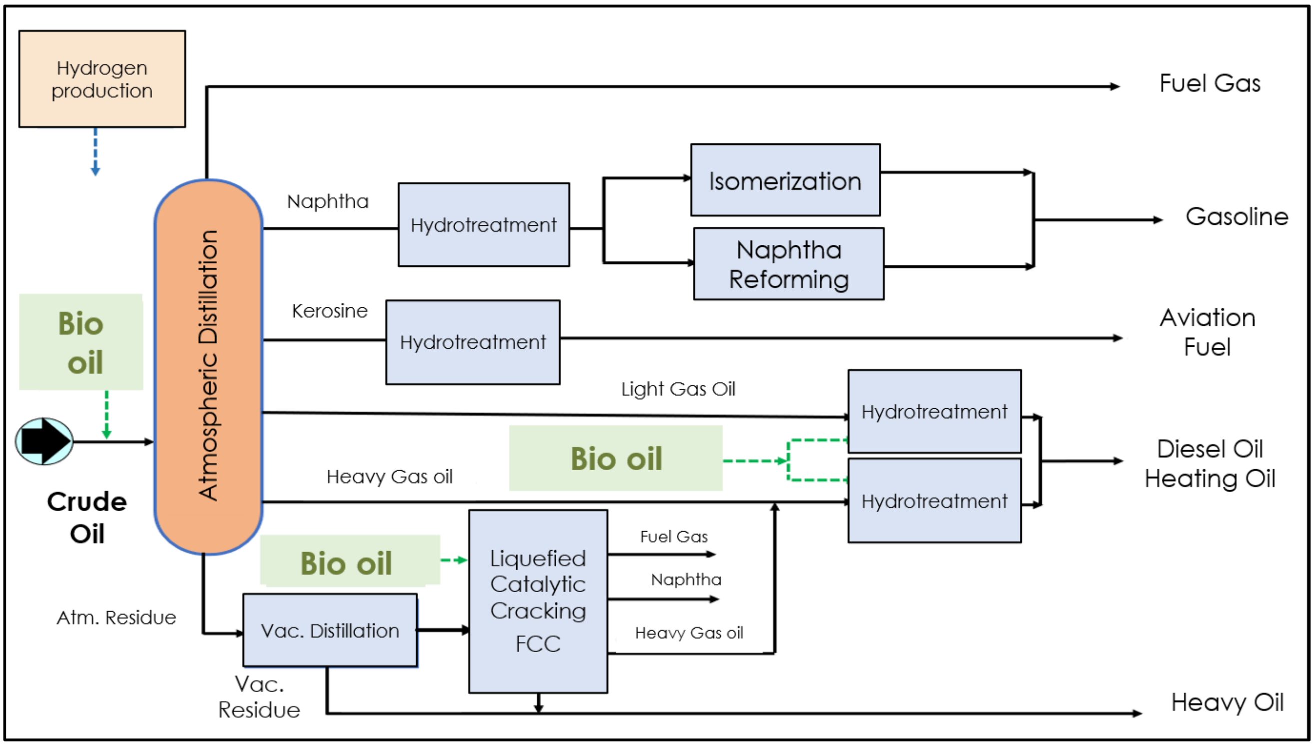
| Process | Feedstock Options | Description | Blending Limit (%) | Technology Readiness Level (TRL) |
|---|---|---|---|---|
| **Hydroprocessed Esters and Fatty Acids (HEFA-KSP)** | Fatty acids and fatty acid esters derived from plant and animal sources, such as used cooking oil and animal fats. | Hydrogenation of fatty acids and esters to produce synthetic paraffinic kerosene (PSK). | 50% | 8 |
| **Fischer-Tropsch Biomass Gasification (FT-SPK)** | Biomass (e.g., forest residues, municipal solid waste). | Conversion of syngas produced via Fischer-Tropsch process into synthetic paraffinic kerosene. | 50% | 5-6 |
| **Synthetic Iso-Paraffinic Aviation Fuel Production (HFS-SIP)** | Sugars directly extracted from sugar plants (e.g., sugarcane, sugar beet) or indirectly from C5 and C6 sugars derived from cellulose. | Hydrogenation of sugars produced via fermentation to convert them into synthetic iso-paraffins. | 10% | (7-8 for conventional sugars) |
| **Alcohol-to-Jet Synthetic Paraffinic Kerosene (ATJ-SPK)** | Agricultural residues, forest residues, energy crops, and corn grain. | Conversion of alcohols (e.g., iso-butanol or ethanol) into synthetic paraffinic kerosene. | 50% | 5-6 |

Source: (Royal Society, 2023)

Oil refineries can play an important role in the production of low-carbon aviation fuel, by applying co-processing technology for renewable raw materials in oil refining operations such as fluid catalytic cracking (FCC) units, hydrotreating units, or crude oil distillation units. Some refineries that have excess capacity in hydrotreating units may modify some equipment in these units so that they are able to process only renewable raw materials or establish integrated biorefineries with oil refineries so that they benefit from the services available in the refinery such as warehouses, pipelines, blending and preparation stations for final products, in addition to other services such as electricity, water, steam, hydrogen, industrial wastewater treatment units, etc. Thus, investment costs for biofuel production can be reduced and risks can be reduced. There are many successful experiments in Europe and the United States of America. (Herbertson, J., & Wheeler, D., 2022)

Given the need for all possible options for decarbonization, fossil fuel options must be considered in the energy mix equation, especially low carbon aviation fuel (LCAF). The following figure shows the options for refining bio-oils in an oil refinery.

Options for refining bio-oils in an oil refinery



## Carbon Intensity Reduction Techniques in Low-Carbon Aviation Fuel Production

The production of low-carbon aviation fuel requires the application of carbon intensity reduction techniques at all stages of the fuel production life cycle, starting from the oil production stage in the fields, through its transportation to refineries, then refining and production operations in refineries, and transporting the product to distribution stations until the consumption stage. In the oil production field stage, they are (1) using renewable energy, (2) managing flare burning and reducing the leakage of volatile hydrocarbon gases, and (3) capturing carbon.

In the oil refining stage, many technologies can be adopted, the most important of which are: (1) carbon capture, utilization and storage (CCUS), (2) production and use of green hydrogen, (3) using heat and power from renewable energy sources in the refinery, (4) rationalizing energy consumption and improving its efficiency, (5) refining sustainable biomass, and (6) refining low-carbon crude oil.

## Challenges of sustainable aviation fuel production and consumption

Sustainable aviation fuel production operations face many difficulties and challenges. Despite the great support provided by governments in many countries around the world, the production of sustainable aviation fuel did not exceed 600 million liters, or 0.2% of the total global demand for aviation fuel in 2023.

High production costs represent the biggest obstacle to the spread of sustainable aviation fuel, as they reach 2.5-5 times the cost of conventional aviation fuel (Barbara, L., & Galea, C., 2024) Jet A-1, but the gap between the costs of the two types is expected to narrow gradually in the future, especially after the implementation of the Emissions Trading System (ETS). (Soone, J., 2020)

Some technologies are characterized by high investment costs that represent 50 to 70% of the total production costs, such as the Fischer-Tropsch technology, while the costs of raw materials constitute 10-35%. Production costs in Fischer-Tropsch technology can be reduced by taking advantage of the economy of scale, but operating this technology at a high production capacity creates difficulties related to transporting and securing sufficient raw materials for the project.

On the other hand, renewable fuel requires expensive infrastructure, in addition to high energy consumption rates, and difficulty in disposing of waste resulting from the process. The production of sustainable aviation fuel also requires a highly efficient process to convert raw materials into usable fuel, in addition to the lack of a global consensus on unified standards for sustainability requirements, which leads to the hesitation of sustainable fuel producers and the inability to choose the appropriate manufacturing technology, and the difference in the general framework of sustainability policies and plans from one country to another, as well as differences in the method and percentage of incentives they provide, which leads to investors retreating from venturing into the production of sustainable aviation fuel. Other challenges facing the production of sustainable aviation fuel include the volatility of the prices of raw materials needed to manufacture sustainable fuel due to competition to purchase them, in addition to the environmental impacts associated with the use of agricultural land that was used to produce food, the damage caused by the use of pesticides, and the subsequent impact on biodiversity, thus keeping investors away from entering into unstable projects.

To facilitate the widespread deployment of sustainable and low-carbon fuels, it is necessary to implement policy and regulatory measures, stimulate demand, and enable the link between supply and demand.

Carbon emission reduction measures related to changing the type of fuel are focused on four paths: hydrogen, ammonia, biofuel, and electric fuel (e-fuel). (Sustainable Aviation, 2022)

## Developments in encouraging the spread of sustainable aviation fuel in the world and Arab countries

The past few years have witnessed many countries moving towards accelerating the procedures for developing legislation and standards for sustainable aviation fuel after demands issued by environmental bodies to increase interest in sustainable aviation fuel compared to other types of renewable fuel used in land transportation. The aviation industry has developed several initiatives to combat climate change, in cooperation and coordination with the International Civil Aviation Organization (ICAO). These initiatives are led by the International Air Transport Association (IATA) and the Air Transport Action Group (ATAG).

The International Civil Aviation Organization (ICAO) has adopted a plan that includes several measures to reduce carbon emissions to zero in the aviation sector by 2050, the most important of which are improving aircraft technologies, developing operating processes, and using sustainable and low-carbon fuel, in addition to carbon trading procedures. The European Union has also issued a set of measures and is working on preparing several legislations related to decarbonization in the aviation sector. The United States has announced the possibility of reducing carbon emissions by 20% by 2030, and to zero by 2050, by removing carbon from the atmosphere elsewhere in quantities equivalent to the quantities produced by aviation fuel. (Royal Society, 2023)

The Arab region's engagement with Sustainable Aviation Fuel is accelerating, marked by pioneering test flights, collaborative research, and ambitious plans for production plants. The UAE has led with concrete demonstrations (like Etihad's halophyte-based fuel flight and Emirates' 100% SAF engine test), showcasing what is possible. Saudi Arabia is integrating SAF into its grand energy transition vision, leveraging NEOM's green hydrogen to position itself as a future supplier of synthetic jet fuel. Qatar is aligning with global alliances and exploring how to utilize its unique gas-to-liquids expertise in a sustainable way. Egypt, propelled by the momentum of hosting COP27, is crafting policies and projects to ensure it isn't left behind in the SAF movement, potentially leading Africa in this domain. Other states like Oman, Bahrain, and Morocco, though early in the journey, recognize the strategic importance of SAF and are laying groundwork through studies and international partnerships.

Although most Arab countries have large reserves of oil and gas, they have valuable opportunities to be among the leading countries in the production and export of sustainable and low-carbon aviation fuel, with their infrastructure and financing resources for renewable energy projects, and a diverse list suitable for producing sustainable fuel, such as algae that can be grown in salt water, and some drought-resistant plants such as Jatropha and Salicornia, which tolerate high levels of salts in the soil.

To maximize the capacity to produce sustainable and low-carbon fuels, Arab countries need to implement some measures, the most important of which are: enhancing cooperation between the energy industry and the aviation sector, issuing supportive legislation and policies, and improving the operational performance of oil refineries to enable them to apply co-processing technology that relies on refining renewable raw materials alongside crude oil in order to reduce the carbon footprint of refinery products and produce low-carbon aviation fuel (LCAF), as co-processing is a cost-effective and short-term solution to expand the scope of sustainable fuel production in the region.

It is worth noting that the Arab Civil Aviation Organization (ACAO) announced in 2024 its intention to adopt an Arab initiative to encourage the development and production of sustainable, low-carbon aviation fuels and other clean energy sources for aviation purposes. This initiative is based on studying the establishment of a joint Arab regional team with the Organization of Arab Petroleum Exporting Countries (OAPEC) to prepare technical feasibility studies on the potential of Arab countries to develop and produce sustainable aviation fuels. (ACAO, 2024)

# Chapter One

## Aviation Fuel and Its Role in the Energy Transition Plan

Air transport emissions are estimated to account for 2-3% of global CO2 emissions and demand for aviation fuel is expected to increase by 50% by 2050 compared to 2019 levels (Barbarà, L., & Galea, C., 2024). Aviation emissions also contain other gases besides CO2, namely nitrogen oxides (NOx), water vapor, fine particulate matter, carbon monoxide (CO), unburned hydrocarbons, and sulfur oxides. These gases have a climate change impact 2-3 times greater than CO2. Statistics indicate that the number of aircraft in the world reached about 28 thousand aircraft in 2020 and is expected to reach 38 thousand by 2032. The rate of aviation fuel consumption reached about 6.7 million barrels/day, and the International Civil Aviation Organization expects the rate of aviation fuel consumption to increase by 2.2 to 3.1 times by 2045 compared to the base year 2015. (Jing, L., et al., 2022)

Although the aviation sector is not directly included in the Paris Agreement on Climate Change, the sector has developed plans to reduce emissions. In 2009, it announced three goals to reduce greenhouse gases: the first is to improve fuel efficiency by an annual rate of 1.5%, the second is to start implementing the carbon neutrality system starting in 2020, and the third is to reduce emissions by half by 2050 compared to the 2005 level.

In October 2022, the International Civil Aviation Organization (ICAO) announced an initiative to reduce aviation emissions to zero by 2050, mirroring what the

International Air Transport Association (IATA) announced in 2021. To achieve this goal, measures must be taken, including improving airport efficiency and shortening aircraft flight distances, developing aircraft engine technologies, using sustainable and low-carbon fuels, and implementing trade measures such as carbon pricing and trading. (ICAO, 2023)

## 1-1: Classification of aviation fuel types

The International Civil Aviation Organization classifies aviation fuel types according to the CORSIA Carbon Offsetting and Reduction Scheme for International Aviation into two groups, the first is the Conventional Aviation Fuel (CAF) group, which is fossil-based, and the second is the aviation fuel group approved to reduce carbon emissions or alternative fuel, as follows: (Chiaramonti, D., et al., 2021)

• Conventional Aviation Fuel- CAF group, which is the fuel produced from oil refining, and consists of aviation kerosene and aviation gasoline.

• Alternative aviation fuel group, which consists of the following types:

  o Sustainable Aviation Fuel (SAF)

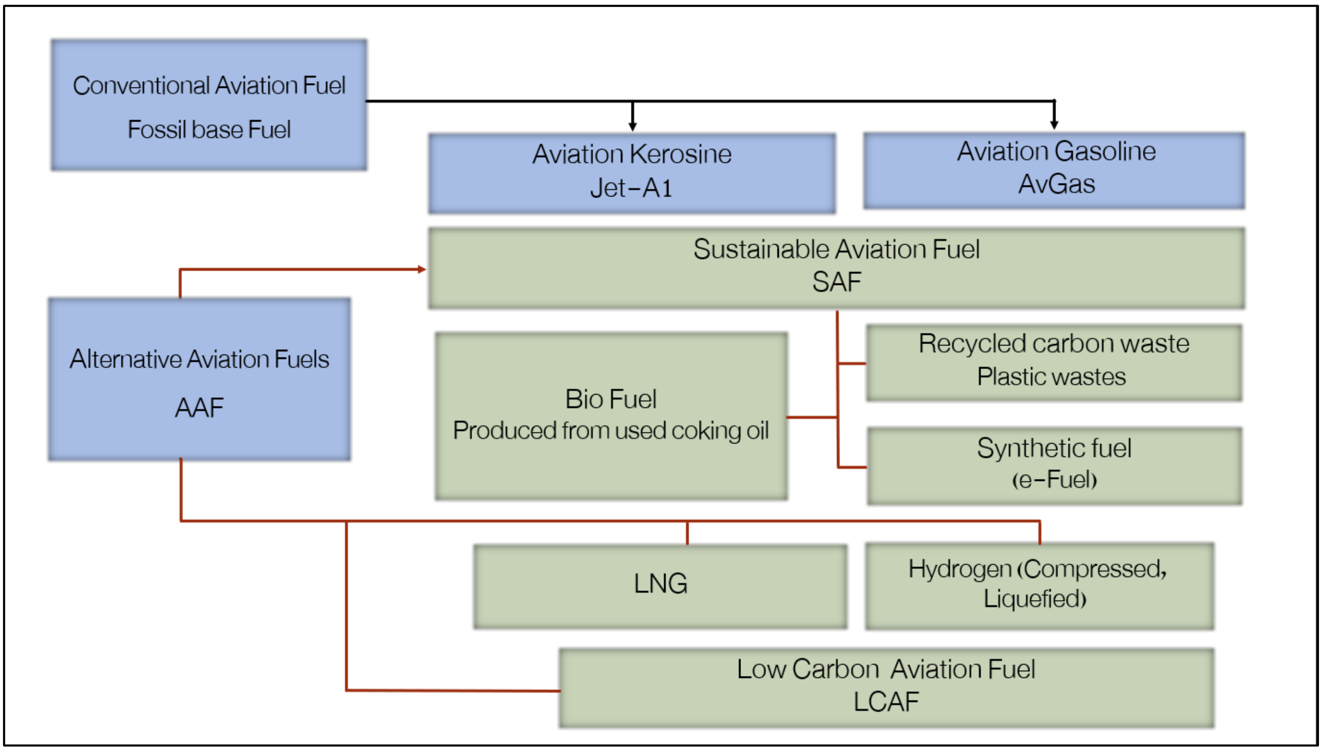
  o Low Carbon Aviation Fuel (LCAF)

  o Hydrogen

  o Liquefied Natural Gas

Figure (1-1) shows the classification of aviation fuel types according to the International Civil Aviation Organization (ICAO) in the CORSIA Carbon Offsetting and Reduction Scheme for International Aviation

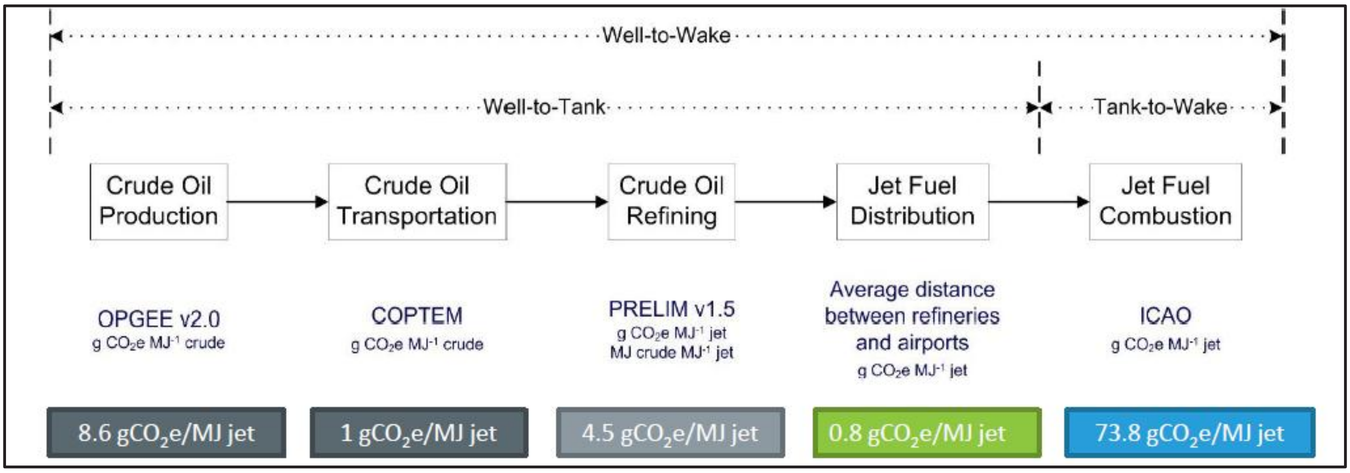
Figure (1-1): Classification of aviation fuel




Source: (Chiaramonti, D., et al., 2021)

The International Civil Aviation Organization has also developed a method for classifying aviation fuel according to the amount of emissions produced by the fuel during its life cycle and comparing it with the amount of emissions released by conventional petroleum fuel, which is called the "carbon intensity". The carbon intensity of fossil aviation fuel expresses the total amount of greenhouse gases emitted during the fuel's life cycle, which is divided into several stages: oil production and transportation to the refinery gate (Well to Refinery), then the refining stage and transportation of aviation fuel to consumption centers (Refinery to Tank), and finally the consumption stage in aircraft (Combustion). Figure (1-2) shows the carbon intensity during the life cycle of petroleum aviation fuel.

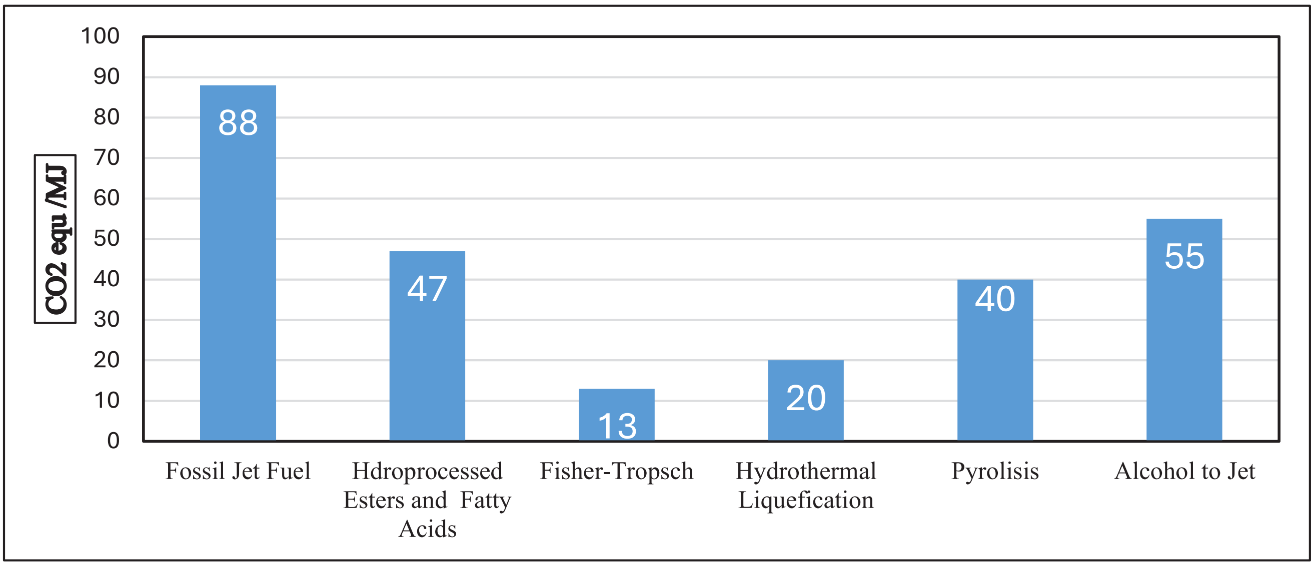
Figure (1-2): Carbon Intensity During the Life Cycle of Petroleum Aviation Fuel




Source: (ICAO, 2023)

The carbon intensity of aviation kerosene varies from one region to another depending on many factors. For example, the carbon intensity resulting from the process of transporting and distributing aviation fuel from the refinery to the consumption center ranges from 0.1 to 5.2 g CO2 equivalent at the country level, while the global average is 0.8 g CO2 equivalent, depending on the distance between the refinery and the location of the airports in the country, as it reaches 2 g CO2 equivalent in Australia, Canada and Mexico due to the distance between refineries and airports, while it does not exceed 1 g CO2 equivalent in countries where fuel can be transported via pipelines or when the distance between them is close. This value increases when the country imports fuel from abroad. The type of refined crude oil also plays a role in reducing the carbon intensity of the aviation fuel produced, as some types of oil are characterized by lower carbon intensity compared to others. (Jing, L., et al., 2022) The carbon intensity of aviation fuel varies according to its type and production process. The carbon intensity of petroleum fuel ranges from 81.1 to 94.8 g CO2 equivalent/MJ, with an average of 88.7 g CO2 equivalent/MJ, as the value changes depending on many factors such as the type of refined crude oil, carbon reduction measures in the refining and transportation stages, etc., while it decreases in fuel produced by the Fischer-Tropsch process to about 13 g CO2 equivalent/MJ. Figure (1-3) shows a comparison of the carbon intensity of petroleum and renewable aviation fuels.

Figure (1-3): Comparison of the carbon intensity of petroleum and renewable aviation fuels




Source: (Jing, L., et al., 2022)

### 1-1-1: Conventional aviation fuel (petroleum)

Petroleum aviation fuel is produced from the process of refining crude oil in the refinery and is called aviation kerosene and has many types according to the field of use, and the most used type is Jet-A1.

In addition to $CO_2$, the use of petroleum aviation fuel produces emissions that have an impact on climate change, including nitrogen oxides $NO_X$, which contribute to increasing the concentration of greenhouse gases, ozone and methane in the atmosphere, in addition to water vapor and carbon soot, which cause the formation of foggy clouds behind the exhaust of aircraft engines. (Royal Society, 2023)

Most of the carbon dioxide emissions produced during the life cycle of petroleum aviation fuel are released in the combustion stage in the engine and the percentage reaches 84% of the total emissions, while the remaining 16% is produced from the production stage that starts from the oil well to the aviation fuel distribution tank.

### 1-1-2: Low-carbon aviation fuel (LCAF)

Low-carbon aviation fuel is defined as a fuel produced from crude oil in oil refineries with the application of carbon dioxide capture technologies and the use of green hydrogen in refining processes, renewable energy sources in electricity generation and heating processes, and other possible technologies for producing low-carbon aviation fuel in oil refinery units using vegetable oils. (Chiaramonti, D., et al., 2021)

The International Civil Aviation Organization also defines low-carbon aviation fuel, according to the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), as a fossil-based fuel that produces lower carbon emissions compared to conventional fossil fuels, and is consistent with the sustainability requirements specified in the Carbon Offsetting and Reduction Scheme for International Aviation. The European Renewable Energy Regulation II (RED II) also specifies that for a low-carbon aviation fuel to be considered low-carbon, it must contribute to a minimum 65% reduction in emissions over its entire life cycle compared to the GHG emissions of conventional fuels, estimated at around 89 g CO2e/MJ, a value that symbolizes the fuel's carbon intensity (CI). (POST, 2020) The International Civil Aviation Organization (ICAO) also considers low-carbon aviation fuels to be the type that can be relied upon to play a key role in the aviation sector's emissions reduction program. This is in line with what was adopted during the 12th meeting of the Committee on Aviation Environmental Protection (CAEP12) in February 2022, where low-carbon aviation fuels were considered one of the complementary measures to the role of sustainable aviation fuels in reducing GHG emissions from the aviation sector. (Herbertson, J., & Wheeler, D., 2022)

Low-carbon aviation fuel (LCAF) differs from sustainable aviation fuel (SAF) in that the former contributes to reducing carbon emissions resulting from the fuel manufacturing process, while the latter contributes to reducing emissions resulting from combustion and consumption. For example, five billion liters of aviation fuel with a carbon intensity of 80 grams $CO_2$-equivalent/megajoule contributes to reducing the amount of greenhouse gas equivalent to only one billion liters of sustainable fuel with a carbon intensity of 45 grams $CO_2$-equivalent/megajoule. Low-carbon petroleum aviation fuel is also characterized by its rapid entry into the markets and the possibility of developing it due to the availability of the infrastructure for its production, storage, and distribution. (Herbertson, J., & Wheeler, D., 2022)

Since conventional fuel is produced from refining crude oil, its composition varies according to the type of refined oil, as it consists of paraffins, isoparaffins, naphthenes, and aromatics in relatively similar proportions. Biofuels are produced from a variety of feedstocks, so the composition and properties are different, making meeting ASTM standards an expensive process.

### 1-1-3: Sustainable Aviation Fuel (SAF)

Sustainable aviation fuel is fuel produced from renewable sources such as biomass, or sources derived from waste such as used vegetable oils, agricultural waste, or from energy conversion to liquids, such as low-carbon synthetic fuels produced from carbon dioxide and green hydrogen. These types are required to meet the minimum sustainability requirements set by CORSIA and can be used directly in aircraft without the need to change or modify the aircraft engine, and it is also required that the source of the biomaterials from which the fuel is made is not produced in lands with a high carbon stock. (Chiaramonti, D., et al., 2021)

Sustainable aviation fuel has several names that carry the same meaning, such as Biojet, Renewable Aviation Fuel, Renewable Jet Fuel, and Alternative Aviation Fuel. (ATAG, 2017)

## 1-2: Benefits of Sustainable Aviation Fuel

Despite the difficulties facing the manufacture of sustainable and low-carbon aviation fuel, it has many benefits compared to conventional fuel, the most important of which are:

### 1-2-1: Reducing greenhouse gas emissions

Sustainable and low-carbon fuel is characterized by releasing greenhouse gases at a much lower rate than conventional fuel, and CO2 emissions can be reduced by 80% on a product life cycle basis. This contributes to reducing the phenomenon of global warming and enabling countries to achieve global goals to reduce emissions that cause climate change.

### 1-2-2: Improving air quality

The consumption of sustainable and low-carbon aviation fuel results in the emission of less fine particles compared to conventional fuel, which contributes to improving air quality in areas adjacent to airports, thus reducing health risks resulting from air pollution.

### 1-2-3: Enhancing Energy Security

Sustainable and low-carbon aviation fuel contributes to securing an additional source of aviation fuel from renewable and alternative sources, especially for countries that do not have petroleum resources, as it helps them reduce their dependence on oil and obtain fuel from sustainable raw materials such as used cooking oils, agricultural waste, or energy crops. This in turn enhances energy security and stabilizes fuel prices in global markets.

### 1-2-4: Supporting the national economy

The production of sustainable and low-carbon aviation fuel can contribute to strengthening the economy by developing new industries that open the way to creating new job opportunities, through the cultivation, manufacture and distribution of sustainable raw materials, as well as the establishment and operation of sustainable fuel manufacturing facilities. It can also support the growth of the green economy and attract investment in sustainable and low-carbon aviation fuel technologies.

### 1-2-5: Maximizing the benefit of existing infrastructure

The ability to blend sustainable aviation fuel with conventional fuel and the possibility of using the blend in aircraft engines without the need for any modifications contributes to enhancing the integration of sustainable fuel with conventional aviation fuel infrastructure, maximizing its use efficiency and raising the return on investment rate for this equipment.

### 1-2-6: Improving compliance with carbon emission reduction legislation requirements

The combined efforts of fuel production facilities, distribution stations, airports and airlines in the field of promoting sustainable fuel demonstrates the extent of these bodies' interest in reducing their carbon footprint and improves their image in the eyes of society and environmental conservation bodies.

# CHAPTER TWO

## Techniques for Producing Sustainable and Low-Carbon Aviation Fuel

The process of producing sustainable aviation fuel derived from renewable sources consists of three main stages. The first stage is the preliminary processing of renewable raw materials, followed by the conversion and manufacturing stage, and finally, the refining stage. (Wormslev, E., et al., 2016)

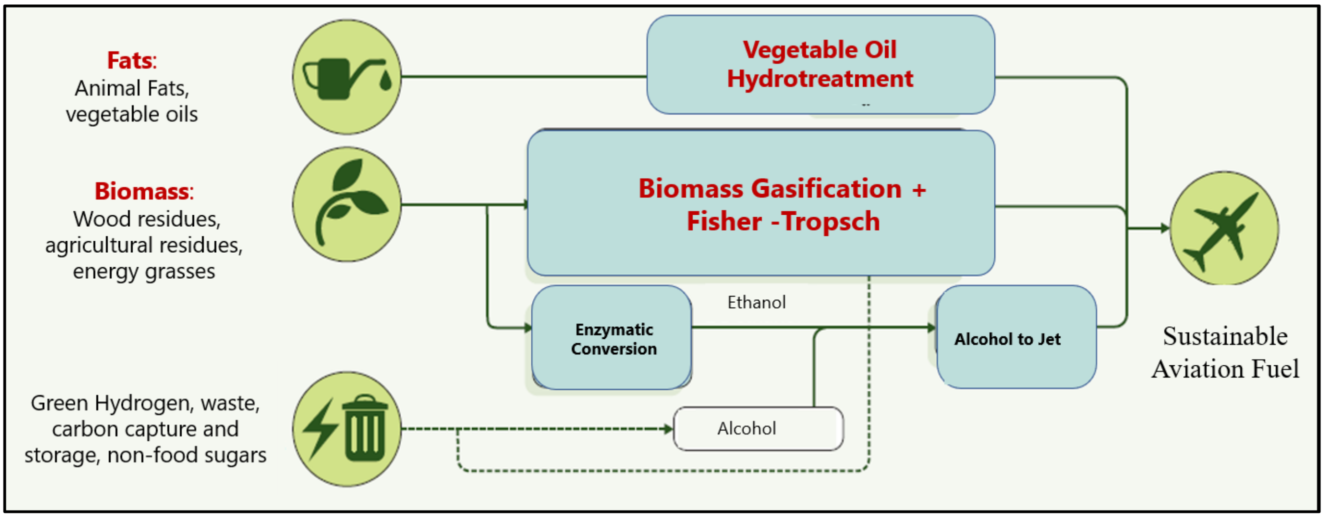
In the preliminary processing stage, the raw materials are prepared to be suitable for the sustainable fuel manufacturing process. This is done through processes such as drying, cutting, or other procedures depending on the type and source of the materials, such as pressing plant seeds to extract oils. Preliminary processing may also include a gasification process if the goal is to convert the renewable raw materials into a gaseous state.

In the second stage, intermediate materials (such as sugars, fats, and gases) are converted into hydrocarbons. The conversion process may involve fermentation to turn sugars into alcohol, hydrogenation to improve the properties of fats, or the conversion of gases into liquids.

In the third stage, the hydrocarbons produced in the second stage are refined to separate sustainable aviation fuel from other secondary products. Impurities are removed from the hydrocarbons in this stage, and hydrocarbon chains are cracked into shorter lengths suitable for producing sustainable aviation fuel.

The pathways for producing sustainable aviation fuel can be classified into three main groups: the first relies on the Fischer-Tropsch technology, which was adopted in 2009, followed by the Hydroprocessed Esters and Fatty Acids (HEFA) technology, which was adopted in 2011 and is the most widespread globally, and the Alcohol-to-Jet (ATJ) technology, which was adopted in 2018. All these technologies help reduce emissions over the life cycle of aviation fuel by high percentages, reaching up to 90% compared to conventional aviation fuel. Figure (2-1) illustrates the classification of sustainable aviation fuel production pathways.

Figure (2-1): Classification of Sustainable Aviation Fuel Production Pathways




Source: (Bernard, Y., et al., 2023)

Currently, several sustainable aviation fuel production pathways are approved by the American Society for Testing and Materials (ASTM). Table (2-1) presents examples of ASTM-approved sustainable aviation fuel production pathways.

Table (2-1): Examples of ASTM-Approved Sustainable Aviation Fuel Production Pathways

| Process Name | Feedstock Options | Description | Blend Percentage (%) | Technology Maturity Level |
|---|---|---|---|---|
| HEFA-KSP (Hydroprocessed Esters and Fatty Acids) | Fatty acids and esters, generally derived from plant and animal fats, such as used cooking oil and animal fats | Hydrogenation process of fatty acids and esters to produce synthetic paraffinic kerosene (PSK) | 50 | 8 |
| Fischer-Tropsch Biomass Gasification FT-SPK | Biomass (forest residues, municipal solid waste) | Conversion of synthetic gas produced via FT to synthetic paraffinic kerosene | 50 | 5-6 |
| Synthetic Iso-Paraffin Aviation Fuel HFS-SIP | Sugars extracted from sugar crops (e.g., beetroot, sugarcane) or indirectly (C5 and C6 sugars from cellulose) | Hydrogenation of fermentation-derived sugars into synthetic iso-paraffins | 10 | (7-8 for normal sugars) (5 for cellulose sugars) |
| Alcohol-to-Jet (ATJ-SPK) | Agricultural residues, forest residues, energy plants, corn grains | Conversion of alcohols (iso-butanol or ethanol) into paraffinic kerosene | 50 | 5-6 |

Source: (Royal Society, 2023)

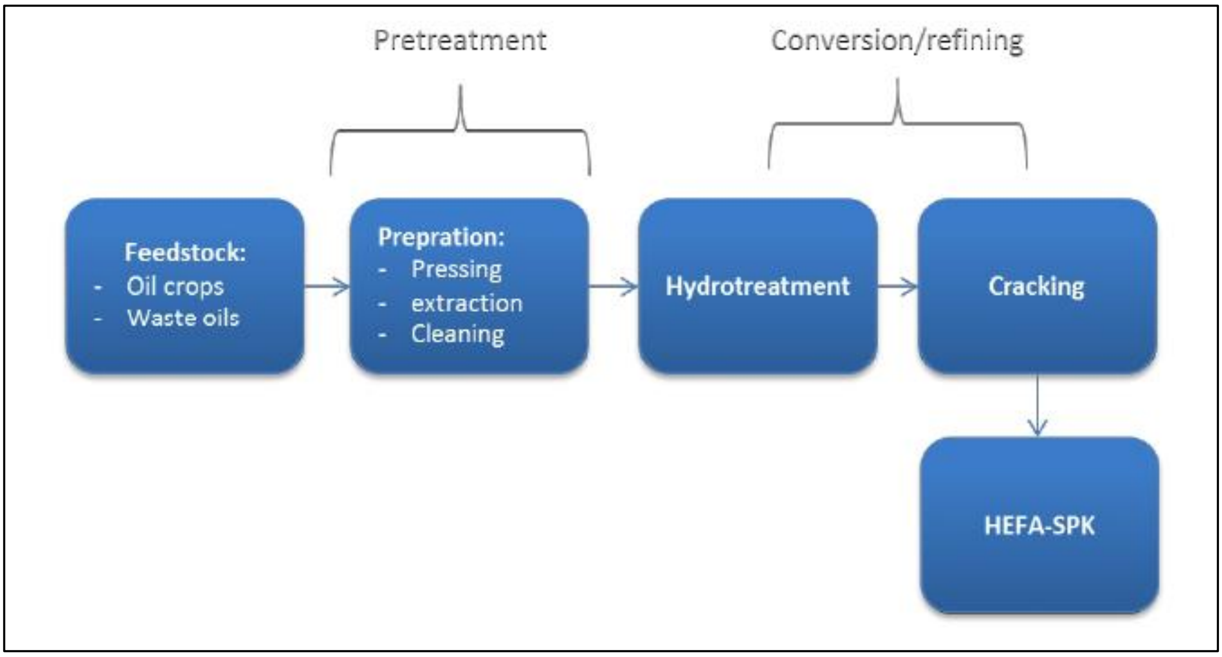
## 2-1: HEFA Pathway

Biojet fuel is produced from the chemical reaction of glycerides found in vegetable oils, where oxygen is removed through hydrogenation in the presence of a catalyst. Before introducing glycerides into the hydrogenation process, they undergo preliminary processing to remove impurities that could damage the catalyst. Additionally, the products of the hydrogenation process need further processing to be ready for use as aviation fuel. (Royal Society, 2023)

The HEFA pathway is characterized by its flexibility in using various oilseed crops or animal fat waste as feedstock to convert them into sustainable aviation fuel or biodiesel. This is done through the following main stages: (Starck, L., et al., 2016)

- **Preliminary Processing Stage:** This involves pressing oilseeds to extract oil or washing animal fats to remove impurities, making them suitable for the hydrogenation stage.
- **Hydrogenation Processing Stage:** This removes oxygen and impurities from vegetable oils and fats in the presence of hydrogen to produce linear paraffins. This stage also involves cracking long hydrocarbon chains, along with hydroisomerization to convert linear paraffins into intermediate bio-distillates that can be blended with petroleum products. The operating conditions in this stage can be adjusted to produce sustainable aviation fuel or biodiesel at varying proportions, ranging from zero to one hundred. Figure (2-2) illustrates the stages of the HEFA ester and fatty acid hydrogenation process

Figure (2-2): Stages of the HEFA Ester and Fatty Acid Hydrogenation Process




Source: (Wormslev, E., et al., 2016)

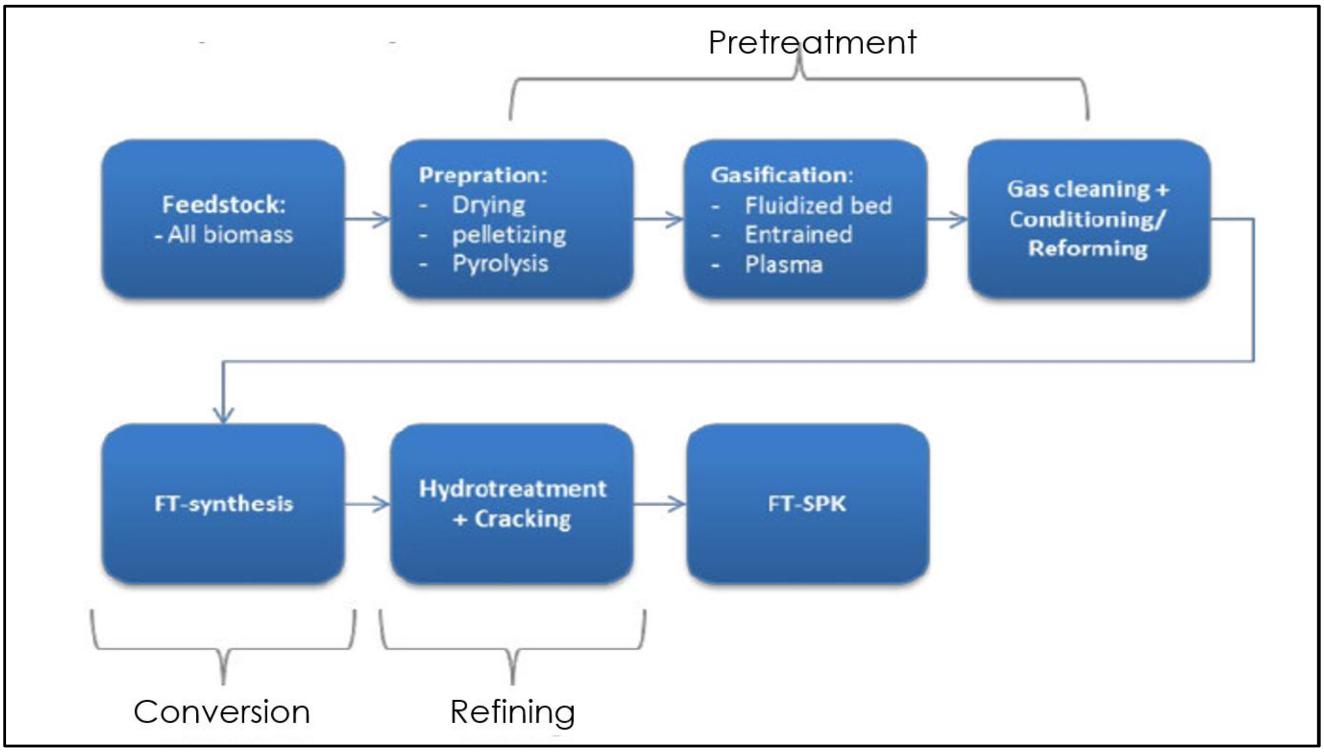
## 2-2: Fischer-Tropsch Biomass Gasification Pathway

The Fischer-Tropsch pathway relies on converting synthetic gas (Synthesis Gas) produced from the gasification of a wide range of biomass materials, mainly consisting of hydrogen and carbon monoxide, into long-chain hydrocarbons, which are then separated into different types of liquid fuels, including sustainable aviation fuel. The process involves the following stages:

- **Synthetic Gas Purification Stage:** This stage ensures that the synthetic gas is free of harmful impurities that may damage the catalyst used in the Fischer-Tropsch process, such as acidic gases.
- **Fischer-Tropsch Reactions Stage:** This takes place in a reactor containing a catalyst, converting synthetic gas into long-chain hydrocarbons.
- **Hydrogenation Processing Stage:** In this stage, Fischer-Tropsch products are stabilized, olefins and oxygenates are hydrogenated, and then cracked in the presence of hydrogen before being isomerized. The resulting liquids are then separated into various products, such as maximum sustainable paraffinic kerosene or middle distillates or diesel with a small amount of naphtha.

Figure (2-3) shows the Fischer-Tropsch pathway for converting biomass into Sustainable Aviation Fuel.

Figure (2-3): Fischer-Tropsch Pathway for Converting Biomass into Sustainable Aviation Fuel

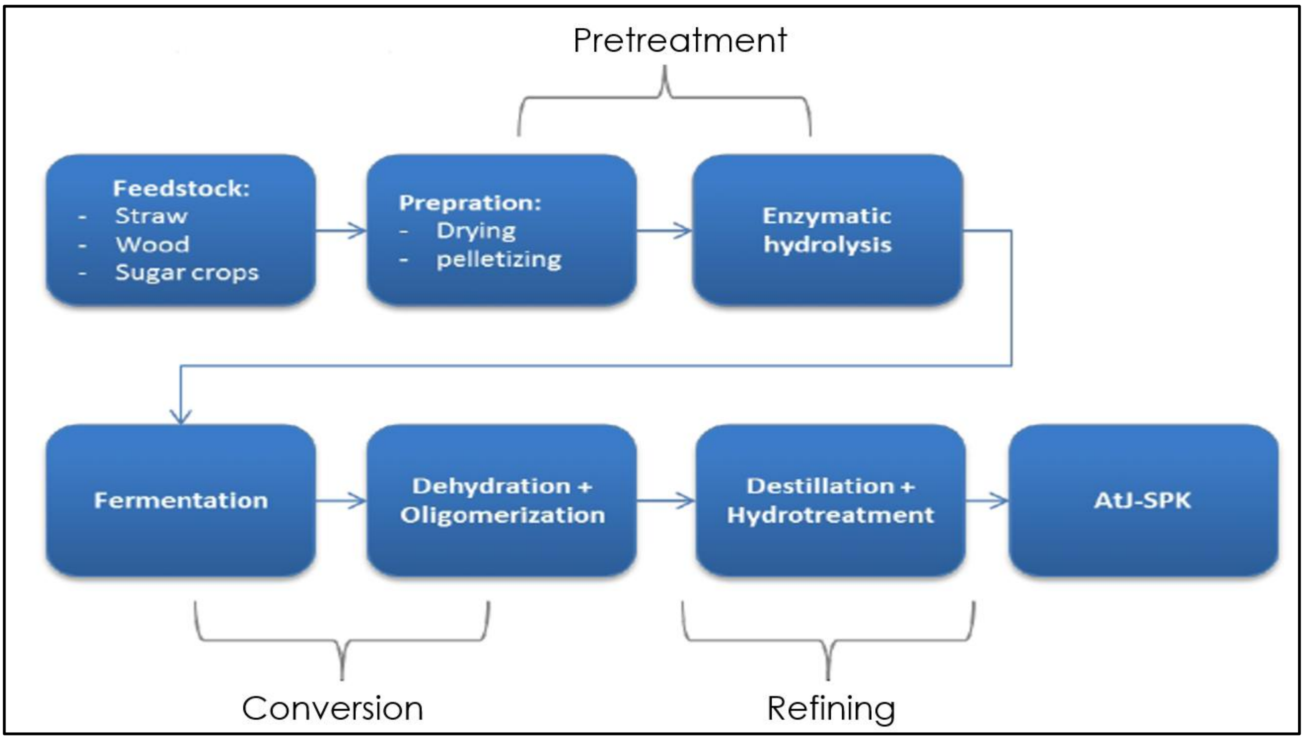



Source: (Wormslev, E., et al., 2016)

## 2-3: Alcohol-to-Jet (ATJ) Pathway

In this pathway, bioalcohols produced from sugars/starch and cellulose crops are converted into hydrocarbons. The most used alcohols in this process are bioethanol and biobutanol (both n-butanol and iso-butanol). The alcohol-to-jet process consists of several stages, with the first stage being the dehydration of alcohol in the presence of a catalyst at temperatures in the range of 300-500°C. The resulting hydrocarbons are then subjected to drying, oligomerization of monomers into fine molecules, and distillation to separate sustainable aviation fuel from other secondary products. Figure (2-4) shows the alcohol-to-jet pathway for converting bio-alcohols into sustainable aviation fuel.

Figure (2-4): Alcohol-to-Jet Pathway for Sustainable Aviation Fuel



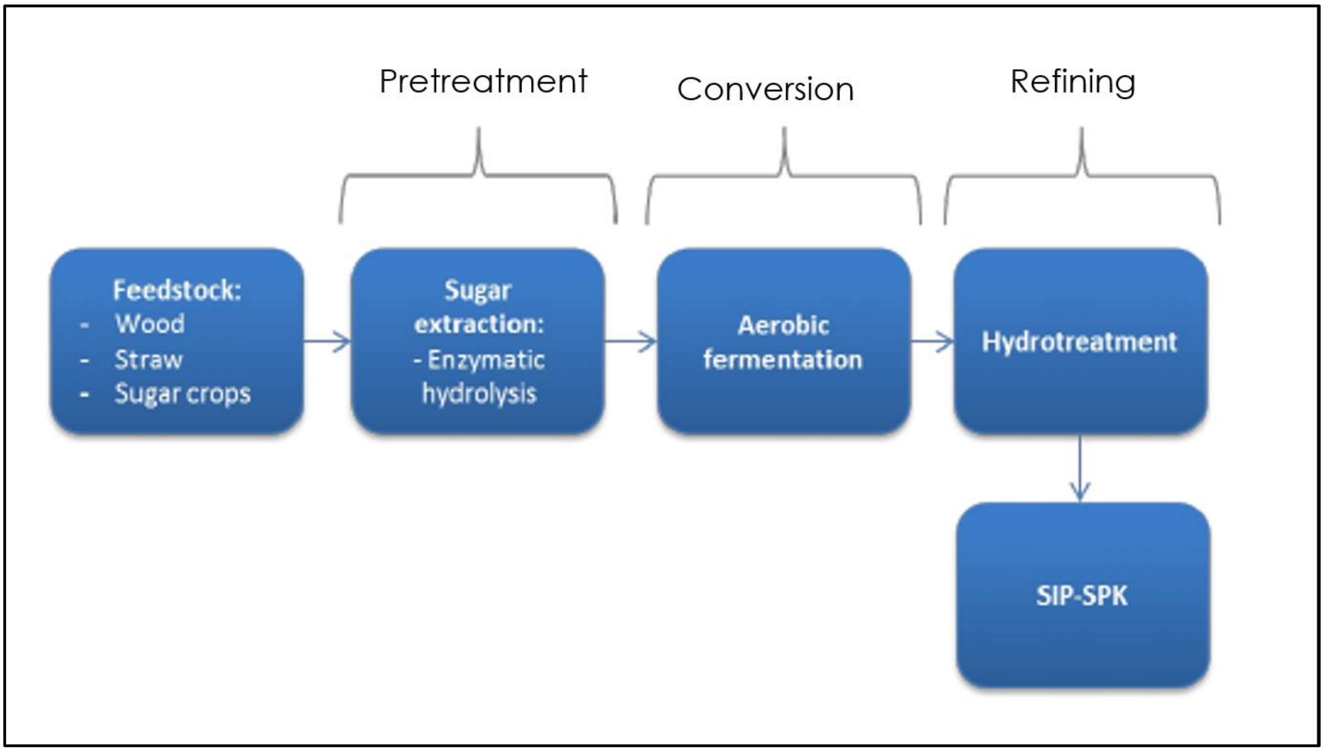

Source: (Wormslev, E., et al., 2016)

## 2-4: Synthetic Iso-Paraffin Aviation Fuel Production Pathway

The synthetic iso-paraffin aviation fuel production pathway is defined as the direct conversion of sugar into hydrocarbons, which was adopted by ASTM in 2014 with a maximum blending percentage of 10% with conventional fuel. This pathway is like the alcohol-to-jet process, as both involve preliminary processing of sugar/starch with an enzymatic hydrolysis step to extract sugar molecules. The difference lies in that the sugars are directly converted into hydrocarbons without going through an intermediary alcohol conversion stage. One of the key advantages of this pathway is the potential for genetically modifying enzymes to produce fuel with specific properties. A disadvantage of this pathway is the need for continuous oxygen supply since the reaction is aerobic, increasing production costs.

Figure (2-5) shows the synthetic iso-paraffin aviation fuel production pathway.

Figure (2-5): Synthetic Iso-Paraffin Aviation Fuel Production Pathway

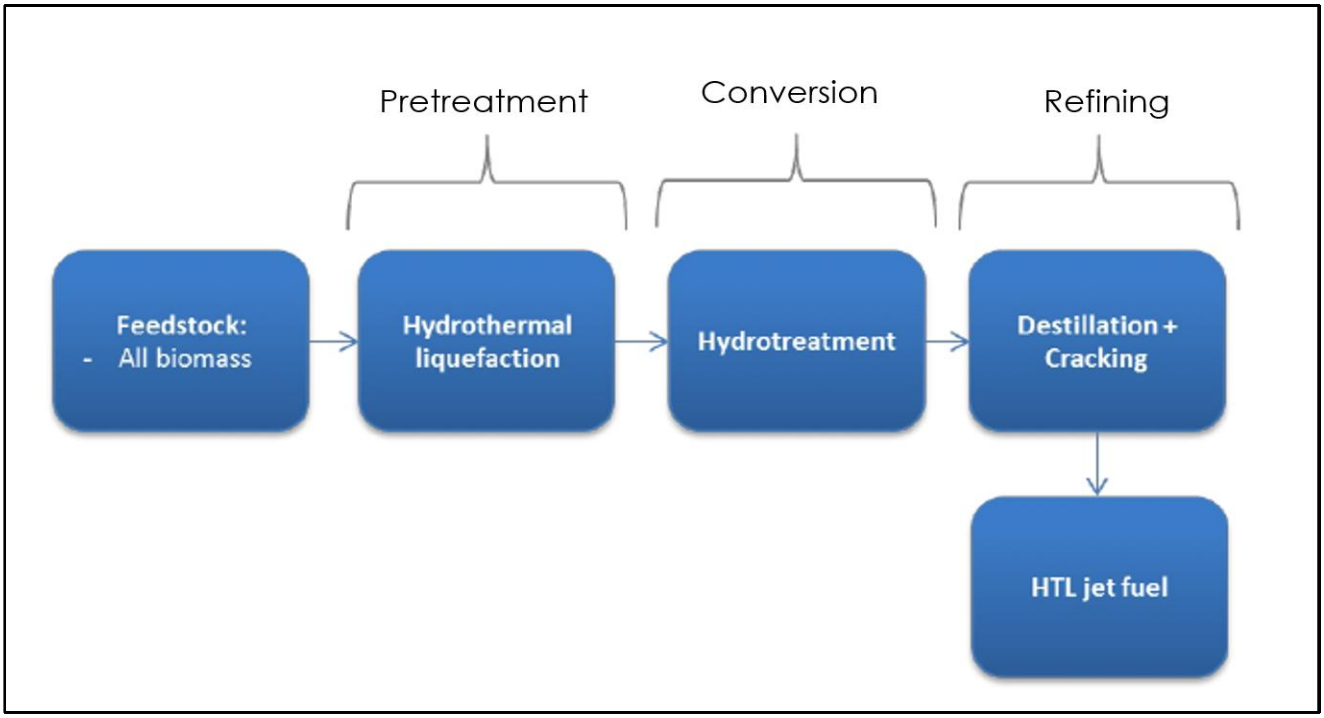



Source: (Wormslev, E., et al., 2016)

## 2-5: Hydrothermal Liquefaction Pathway (HTL)

The hydrothermal liquefaction method involves heating wet biomass to a moderate temperature and conducting a thermochemical reaction under high pressure to produce bio-crude with a lower oxygen content compared to bio-crude produced by the pyrolysis method. However, subsequent processing, such as hydrogenation and distillation, is required to produce aviation fuel. Unlike pyrolysis pathways, hydrothermal liquefaction can utilize a wide range of feedstocks, including lignocellulosic crops, algae, and certain wastes such as animal manure and sewage sludge. Figure (2-6) illustrates the hydrothermal liquefaction pathway for producing sustainable aviation fuel.

Figure (2-6): Hydrothermal Liquefaction Pathway for Producing Sustainable Aviation Fuel

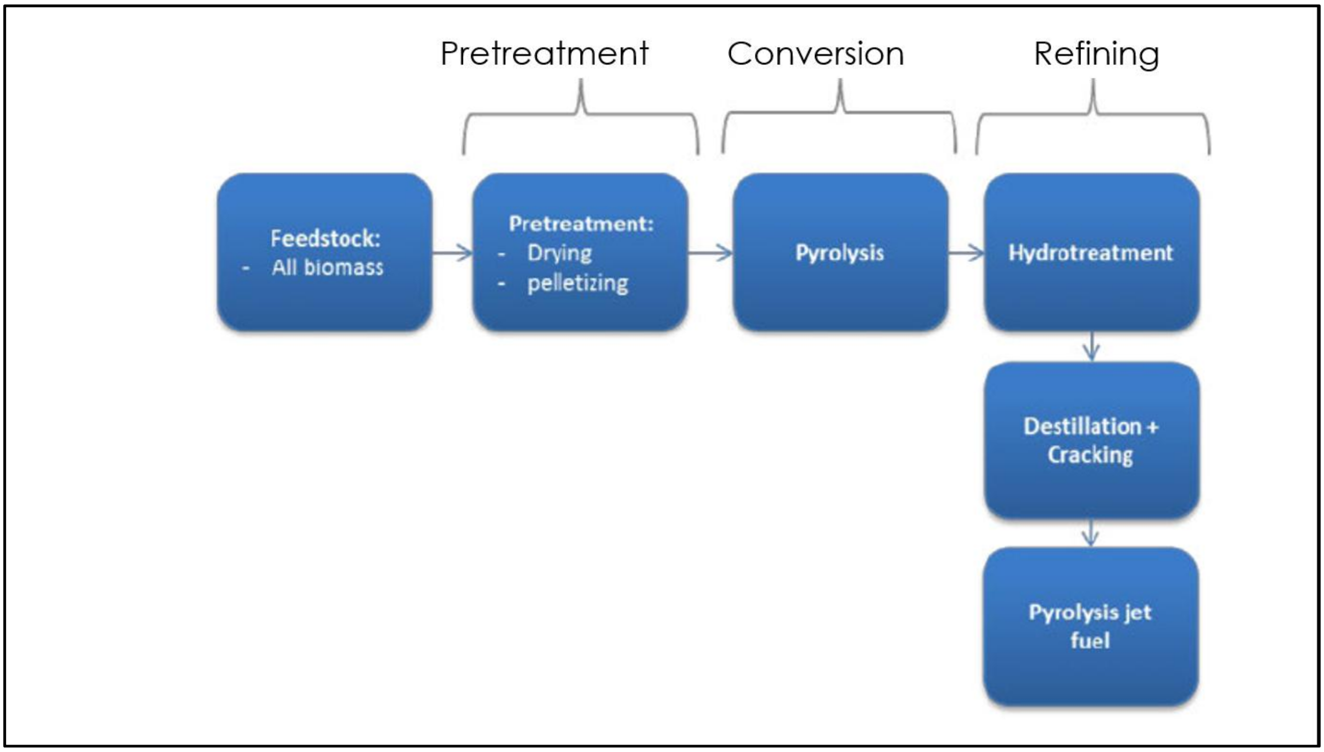



Source: (Wormslev, E., et al., 2016)

## 2-6: Pyrolysis Pathway

The pyrolysis pathway relies on converting lignocellulosic crops into solid biochar and liquid bio-oil through three types of pyrolysis at different temperatures. The first type, known as fast pyrolysis, is carried out at 500 °C to maximize the yield of oil, which is subsequently treated to remove oxygen using a catalyst, making it ready for use and blending with petroleum-based fuels. Figure (2-7) depicts the stages of the pyrolysis pathway for producing sustainable aviation fuel.

Figure (2-7): Stages of the Pyrolysis Pathway for Producing Sustainable Aviation Fuel



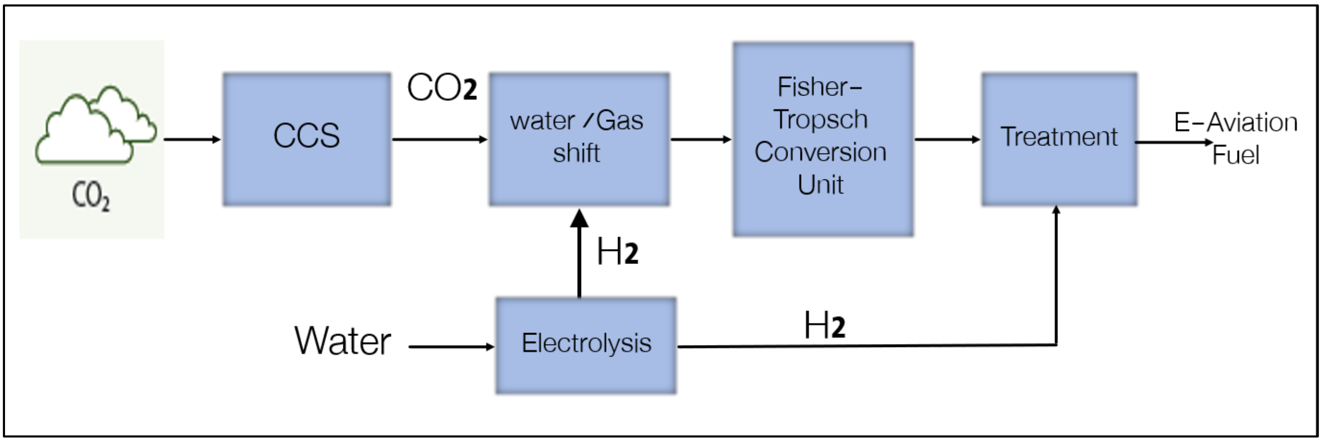

Source: (Wormslev, E., et al., 2016

## 2-7: E-fuel Pathway

E-fuel is produced from the reaction of hydrogen with carbon dioxide, resulting in carbon monoxide and water. When carbon monoxide combines with hydrogen, it forms syngas, which is processed using the Fischer-Tropsch technique to produce e-Fuel, also known as electro-fuel. Figure (2-8) illustrates the production pathway of electro-fuel for aviation.

The drawbacks of producing e-fuel aviation include the large quantities of $CO_2$ required. Capturing CO2 from industrial processes like power plants or oil refineries does not mitigate greenhouse gas emissions, potentially increasing atmospheric $CO_2$ concentrations. Direct air capture (DAC) of $CO_2$ is preferred to offset emissions from other uncontrolled sources like agricultural transport and fertilizer use. Another limitation is the high cost of producing low-carbon hydrogen needed for electro-fuel production.

Figure (2-8): Production Pathway of Electro-fuel for Aviation



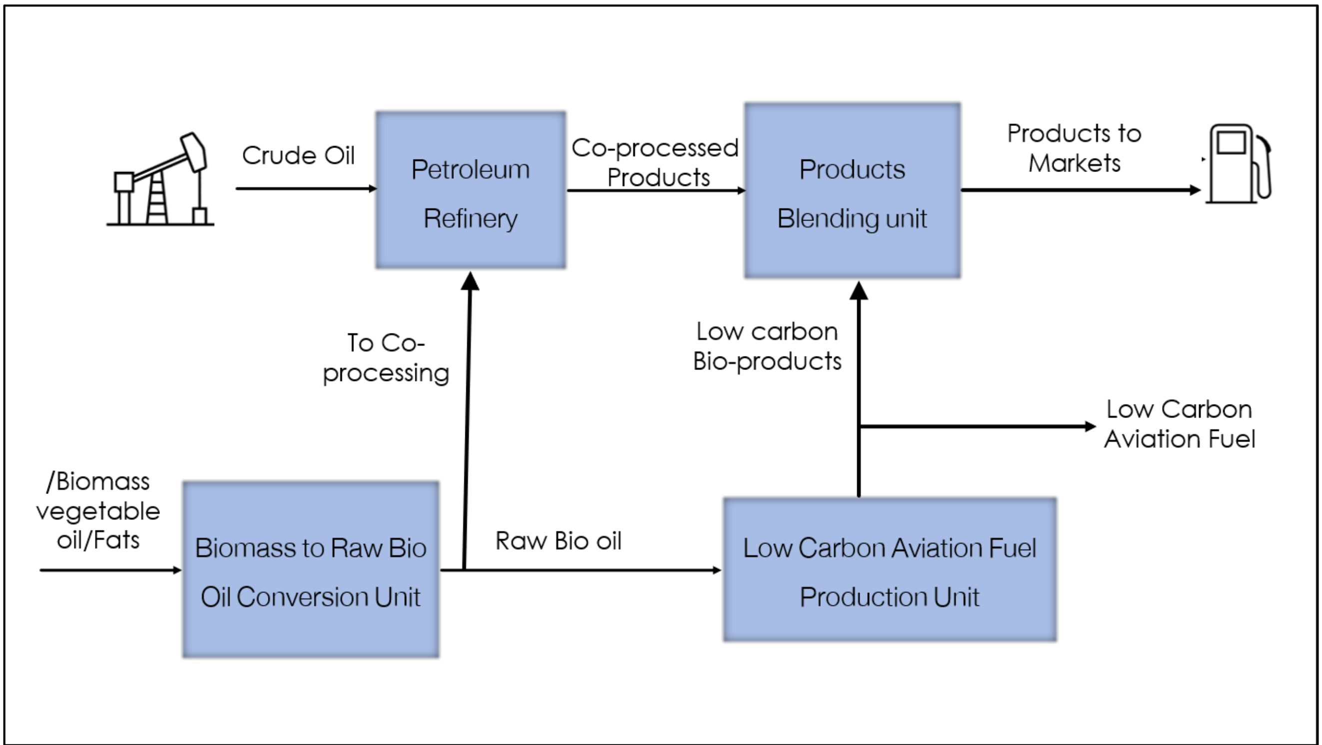

## 2-8: Co-Processing Pathway

Oil refineries play a significant role in producing low-carbon aviation fuel by integrating renewable feedstocks into refining operations, such as in fluid catalytic cracking (FCC) units, hydroprocessing units, or crude oil distillation units. Some refineries with excess capacity in hydroprocessing units might modify their equipment to exclusively process renewable feedstocks or establish standalone biorefineries integrated with existing refineries to utilize available facilities, such as storage tanks, pipelines, blending stations, and utilities like power, water, and hydrogen. This integration reduces investment costs and risks. Refineries have successfully implemented this approach in Europe and the United States. (Herbertson, J., & Wheeler, D., 2022)

The results of several studies have shown that SAF is the most usable type in the short and medium term as part of the trend towards decarbonization, however, there are still many challenges facing the production of this type of fuel, foremost of which is the high production costs compared to kerosene produced from oil in refineries, and the second is the difficulty of obtaining the raw materials needed for the production of sustainable fuels.

Given the need for all possible decarbonization options and the announcement of strategies by many major oil companies to reduce the carbon footprint of their operations and products by 2030 and 2050, options for using fossil fuels need to be considered in the energy mix, especially low-carbon aviation fuel (LCAF). Figure (2-9) illustrates the options for refining bio-oils in oil refineries.

Figure (2-9): Options for Refining Bio-oils in Oil Refineries

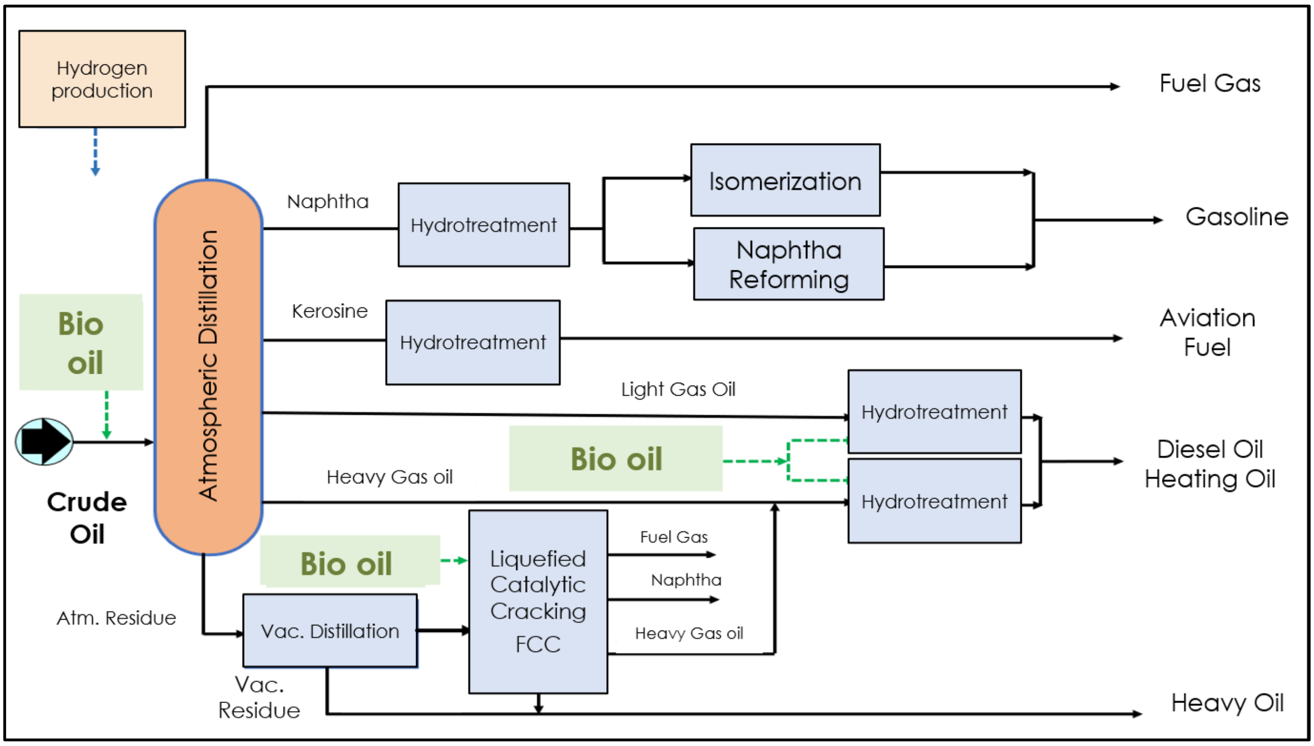



Source: (Sayles, S & Ohmes, R., 2021)

The decision to choose the optimal method for refining biofuels in oil refineries depends on several factors, such as the availability of excess energy in the hydrogen treatment units, and the security of biocrude oils and their properties. For example, the process of establishing a separate hydrogen treatment unit is characterized by taking advantage of the services available in the refinery such as tanks, pipes, hydrogen production units, water and electricity vapor generating units, water treatment units, torch system, and others.

The combined processes of refining biomaterials along with petroleum materials can take place in some refinery units, such as crude oil distillation units, thermal cracking process, FCC fracturing process, hydrogen treatment and hydrocracking processes. (Avery M., and Strohm, J., 2021). Figure (2-10): shows the co-processes of bio-oil refining in an oil refinery.

Figure (2-10): Co-processes of Bio-oil Refining in an Oil Refinery




Source: (OAPEC, 2024)

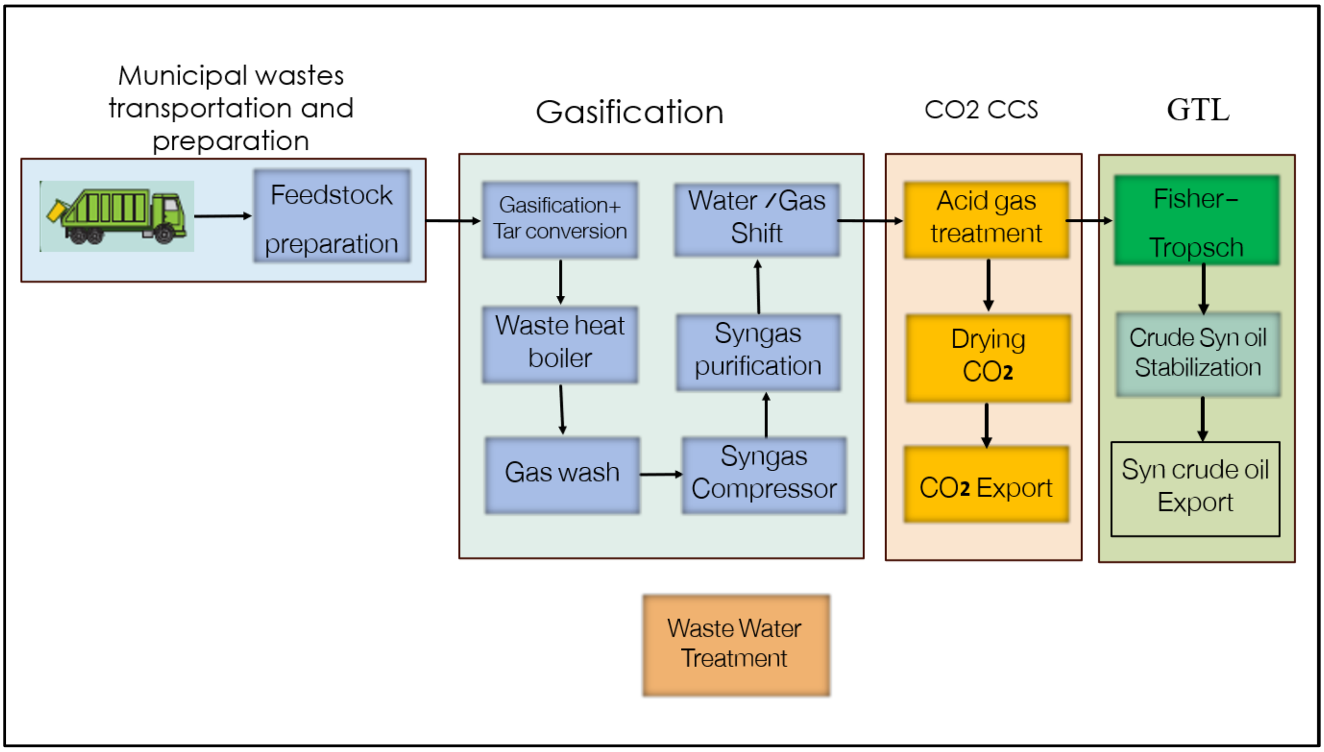
Bio-crude oil can be used in joint operations in an oil refinery, or as feedstock in a standalone unit to produce low-carbon fuels from used vegetable oils, animal fats or municipal waste.

Municipal waste can be transformed into bio-crude oil through four main stages:

- Waste preparation and impurity removal
- Gasification, syngas washing, and compression
- Fischer-Tropsch gas-to-liquid conversion
- Stabilization of crude bio-oil

The facility for converting municipal waste to bio-crude oil includes $CO_2$ capture and purification, as well as an industrial wastewater treatment unit. Figure (2-11) provides a schematic of this process.

Figure (2-11): Converting Municipal Waste into Bio-crude Oil




Source: (Barbara, L., &Galia, C., 2024)

## 2-9: Carbon Intensity Reduction in Producing the LCAF

Producing low-carbon aviation fuel requires applying carbon-intensity reduction technologies throughout its lifecycle, from oil production, transportation, and refining to distribution and consumption. Key technologies for reducing carbon intensity in the lifecycle of LCAF include:

### 2-9-1: Oil Production Phase

Key techniques include:

- **Renewable energy utilization**: Solar energy can be employed to generate heat or steam for enhanced oil recovery (EOR), replacing natural gas or fossil fuels. Wind turbines and photovoltaic cells can generate electricity for compressors and pumps, though these technologies contribute marginally to reducing overall emissions.

Although these technologies do not contribute to a significant reduction in the total emissions of oil production operations, studies have indicated that the use of electricity produced from solar energy in the oil fields to cover the electricity demand of the facility can lead to a reduction in the carbon density of aviation fuel by about 0.36 grams of $CO_2$ equivalent/MJ. The costs associated with the use of renewable energy are estimated in the range of 1.91-4.13 USD/ton oil equivalent. Or US$132-290/ton of carbon dioxide equivalent reduced in the oil production process. (Chiaramonti, D., et al., 2021)

- **Flaring and emissions management**: Monitoring and early detection of leaks can reduce emissions by up to 10.3 grams $CO_2e$/MJ. Factors such as flaring-to-oil production ratios and preventive maintenance programs affect outcomes.

Table (2-2) summarizes the costs of carbon intensity reduction technologies for oil production phase.

Table (2-2): Costs of Carbon Intensity Reduction Technologies for Oil Production Phase

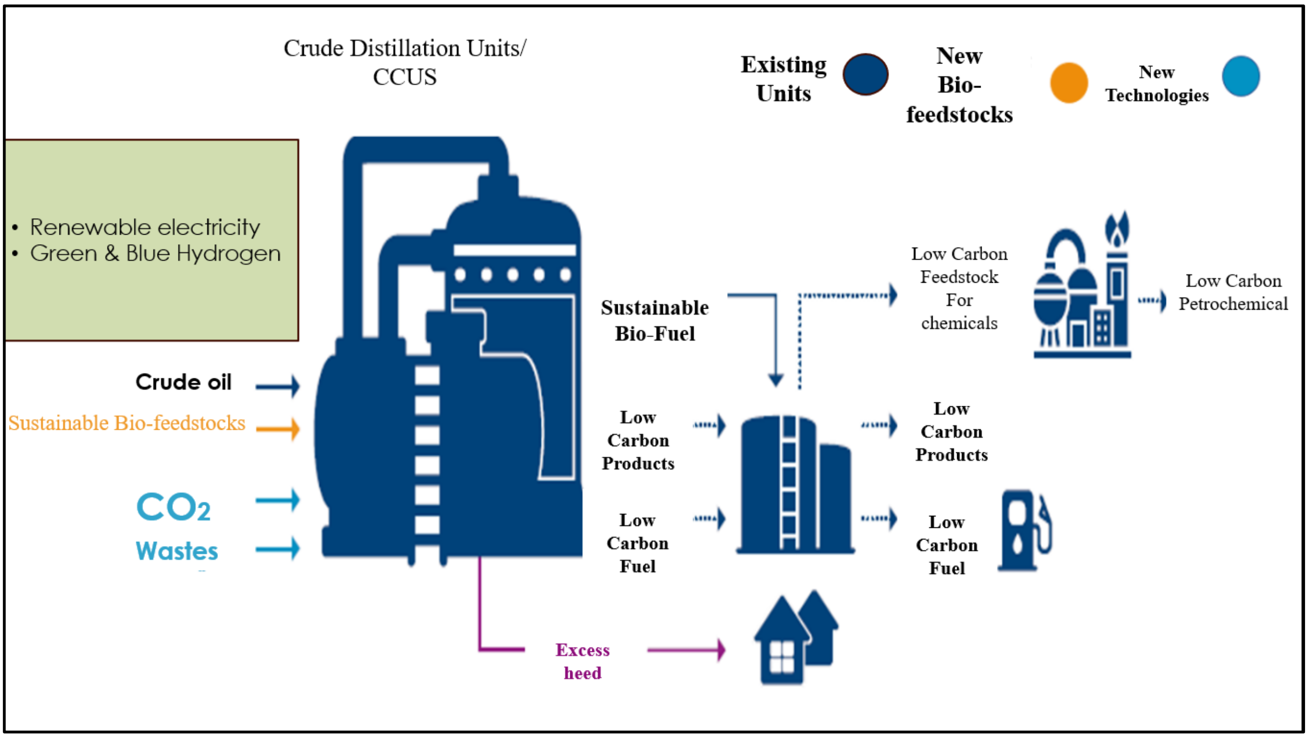
| carbon intensity reduction technologies for oil production phase | Reduction in carbon intensity gCO₂ Equi/MJ | Changes in Cost $/toe | Cost of reduction $/ton Equi CO₂ |
|---|---|---|---|
| Renewable energy utilization | 0.35– 0.36 | 1.91-4.03 | 290-132 |
| Moderate Flaring reduction policy | 1.5 | $2.32*10^{-4}$ | 3.23 |
| Extreme Flaring reduction policy | 1.9 | $2.93*10^{-4}$ | 4.1 |
| Minimum fugitives and venting | 2.3 | 0.57 | 15.91 |

Source: (Chiaramonti, D., et al., 2021)

### 2-9-2 Oil Refining Phase

Carbon intensity reduction of the produced aviation fuel in refining involves several approaches, such as Carbon Capture, Utilization, and Storage (CCUS), producing hydrogen from renewable sources, utilizing renewable heat and power sources and improving energy efficiency minimizes carbon emissions during operations. (Herbertson, J., & Wheeler, D., 2022). Figure (2-12) outlines carbon intensity reduction technologies in oil refineries.

Figure (2-12): Carbon Intensity Reduction Technologies in Oil Refineries




Source: (Chiaramonti, D., et al., 2021)

- **CO2 Capture in Refineries**

Carbon capture and storage is an effective solution to reduce emissions from oil refineries, transporting the captured $CO_2$ to suitable locations for injection into depleted oil and gas well beds or saline aquifers.

Carbon dioxide emissions in oil refineries come from several separate sources, the most important of which are (1) process heaters in refining units, (2) utilities (electricity generation and water vapor), (3) fluid catalytic cracking unit (FCC), and

(4) SMR steam reforming hydrogen production units. (Herbertson, J., & Wheeler, D., 2022)

The effectiveness of the carbon capture technique depends on the concentration of carbon dioxide in the flue gas, the higher the concentration of carbon dioxide, the more effective it is, and since the proportion of carbon dioxide emissions in the main processes of an oil refinery varies from one source to another, we find that the carbon dioxide emissions generated by hydrogen production units represent 5-20% Of the total CO2 emissions in the refinery, the heating furnaces in the refining units account for 30-60% of the total CO2 (depending on the type of fuel used), the utilities (electricity generation and water vapor) 20-50%, and the FCC 20-50%

CO2 capture technologies in refineries include:

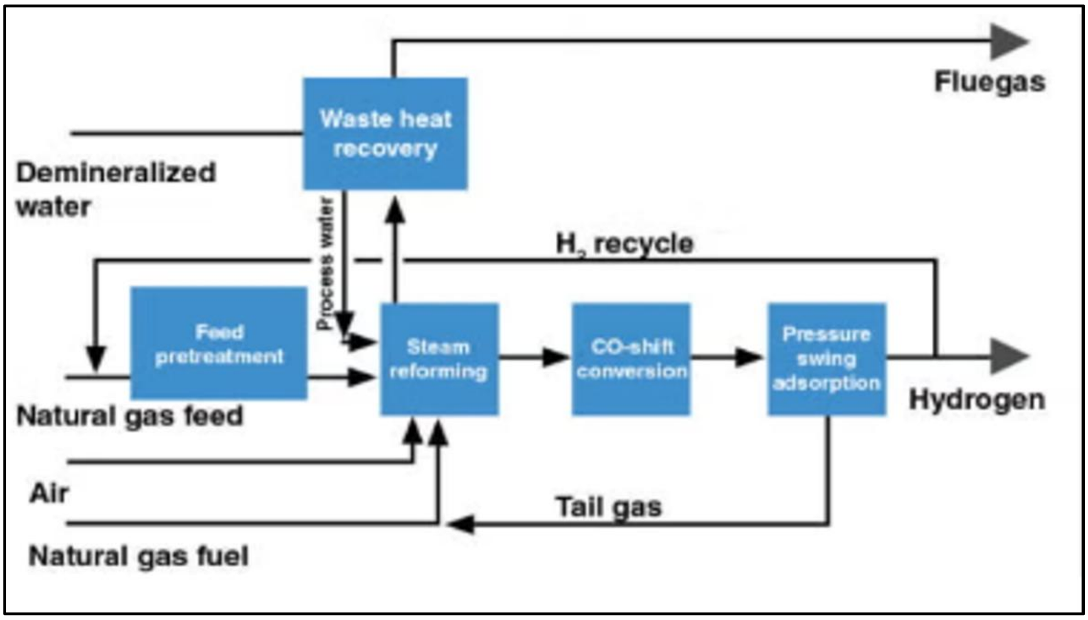
- **Post-combustion capture**: Extracting CO2 from flue gases after combustion.
- **Pre-combustion capture**: Separating CO2 from fuel gases before combustion.
- **Oxy-fuel combustion**: Using pure oxygen instead of air for combustion to produce CO2-rich exhaust.

- **Reducing Emissions in FCC and Hydrogen Units**

- **FCC Units**: Emissions can be reduced through solvent-based $CO_2$ capture or oxy-combustion, with costs ranging from $70 to $120 per ton of $CO_2$.
- **Hydrogen Production**: Steam methane reforming (SMR) for hydrogen production includes pre-treatment, reforming, shift conversion, and purification stages. PSA technology achieves 99.9% hydrogen purity.

Figure (2-13) depicts the SMR hydrogen production process.

Figure (2-13): SMR Hydrogen Production Process.




Source: (OAPEC, 2024)

- **$CO_2$ emissions reduction in a hydrogen production unit using steam methane reforming (SMR)**

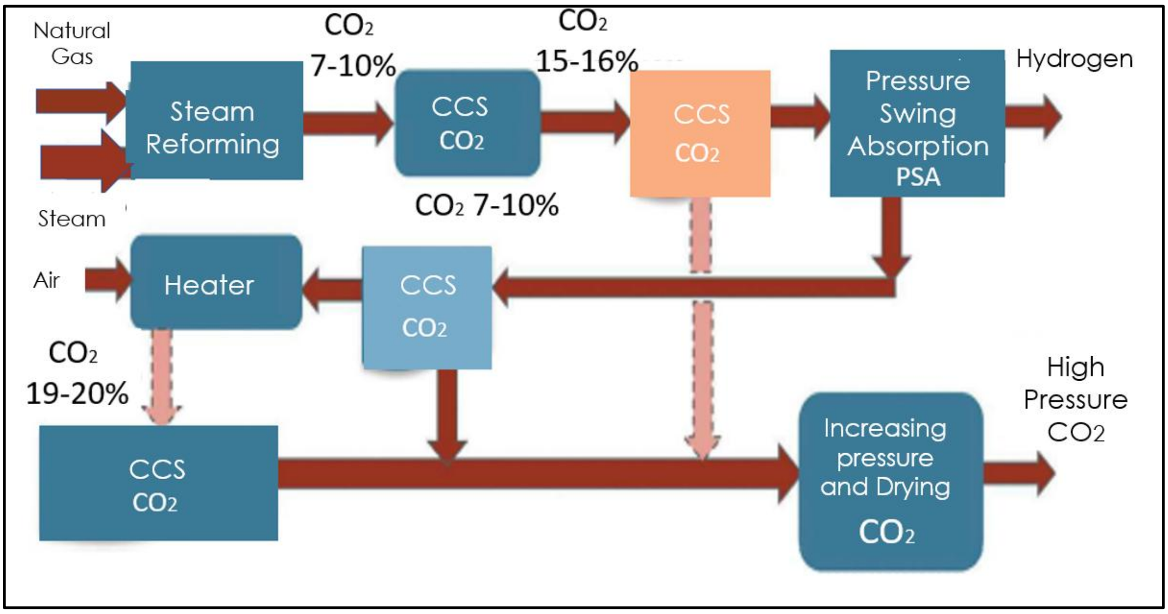
$CO_2$ emissions in a hydrogen production unit using steam methane reforming (SMR) originate from three sources: flue gases from the reformer reactor, off-gas from the pressure swing adsorption (PSA) unit and shifted syngas. Table (2-3) details the characteristics and sources of $CO_2$ capture in a hydrogen production unit with a capacity of 70,000 standard $m^3$/hour. Figure (2-14) illustrates the $CO_2$ capture options in the SMR hydrogen production unit.

Table (2-3): Characteristics and Sources of CO2 Capture in an SMR Hydrogen Production Unit

| Source | Pressure (bar) | Temperature (°C) | $CO_2$ (mol%) | $CO_2$ (tons/day) |
|---|---|---|---|---|
| **PSA feed** | 26 | 35 | 16 | 870 |
| **PSA off-gas** | 1.3 | 30 | 50 | 870 |
| **Flue gas** | 0 | 130 | 20 | 1450 |

Source: (Singh, R. B., 2022)

Figure (2-14): CO2 Capture Options in an SMR Hydrogen Production Unit




*Source: (Singh, R. B., 2022)*

Result of a linear programming (LP) model indicated that capturing and storing $CO_2$ in oil refineries could reduce the total carbon intensity of jet fuel by **3.86 g $CO_2$ equivalent/MJ**. The estimated cost of capturing and storing $CO_2$ is **$0.09 per gallon of refined crude oil**, equivalent to **$171 per ton of $CO_2$ equivalent**.

It is worth noting that the cost of $CO_2$ capture and storage varies from one refinery to another depending on several factors, such as the type of production units, available facilities, the concentration of $CO_2$ in the gases targeted for capture, and the distance to the potential $CO_2$ storage site.

- **Low-Carbon Hydrogen Production and Utilization**

Low-carbon hydrogen is one of the effective solutions for reducing carbon emissions in industrial facilities, especially oil refineries, through the following technologies:

- **CO2 Capture and Storage in Gray Hydrogen Production via SMR:** $CO_2$ capture efficiency ranges between **90–98%**, capturing approximately **1.2–1.5 kg CO2 equivalent per kg of hydrogen produced**.

- **Using Bio-Based Feedstocks for Hydrogen Production:**
  $CO_2$ emissions range between **1–3.3 kg $CO_2$ equivalent per kg of hydrogen produced**.
- **Water Electrolysis with Renewable Electricity (Green Hydrogen Production):**
  $CO_2$ emissions range between **0.3–1 kg $CO_2$ equivalent per kg of hydrogen produced**.

Studies suggest that using green hydrogen instead of hydrogen produced via SMR can reduce $CO_2$ emissions by **0.54 g $CO_2$ equivalent/MJ**, with an additional cost of **$4.45 per ton of refined crude oil**, equivalent to **$190 per ton of $CO_2$ equivalent** (Carter & Hickman, 2021).

Various renewable energy sources, such as solar and wind, can also be utilized in refineries based on geographical location, achieving a total carbon intensity reduction of **4.4 g $CO_2$ equivalent/MJ** for low-carbon jet fuel. Table (2-4) shows carbon intensity reduction techniques and costs in oil Refineries for low-carbon jet fuel production.

Table (2-4): Carbon Intensity Reduction Techniques and Costs in Oil Refineries for LCAF Production

| Technique | Carbon Intensity Reduction (g $CO_2e$/MJ) | Change in Production Cost ($/ton of crude oil) | Reduction Cost ($/ton $CO_2e$) |
|---|---|---|---|
| $CO_2$ Capture in Refinery Operations | 3.86 | 28.60 | 171 |
| Hydrogen Production from Renewable Sources | 0.54 | 4.45 | 190 |

Source: (Chiaramonti, D., et al., 2021)

- **Energy Conservation and Efficiency Improvement**

Energy conservation measures are among the best ways to reduce $CO_2$ emissions from fuel combustion in refinery furnaces. These measures can be classified into low-cost/no-cost measures and medium-to-high-cost measures.

**Low-Cost or No-Cost Measures:**

- Optimizing operational conditions to minimize energy consumption while maintaining process efficiency, such as reducing reflux rates in distillation towers.
- Improving routine maintenance to avoid breakdowns and off-spec products requiring energy-intensive reprocessing.
- Refining high-quality crude oil with low impurities, which requires less energy for deep processing.
- Reducing vented hydrocarbon gases from equipment to the atmosphere and installing recovery systems to capture and reuse them as furnace fuel.
- Cleaning heat exchangers to remove fouling that impedes heat transfer and increases fuel consumption.
- Enhancing thermal integration between units to avoid intermediate cooling between sequential processes.
- Maintaining the functionality of steam traps to prevent energy losses.
- Improving fuel combustion efficiency by adjusting the air-to-fuel ratio in burners, reducing CO2 emissions.

**Medium-to-High-Cost Measures:**

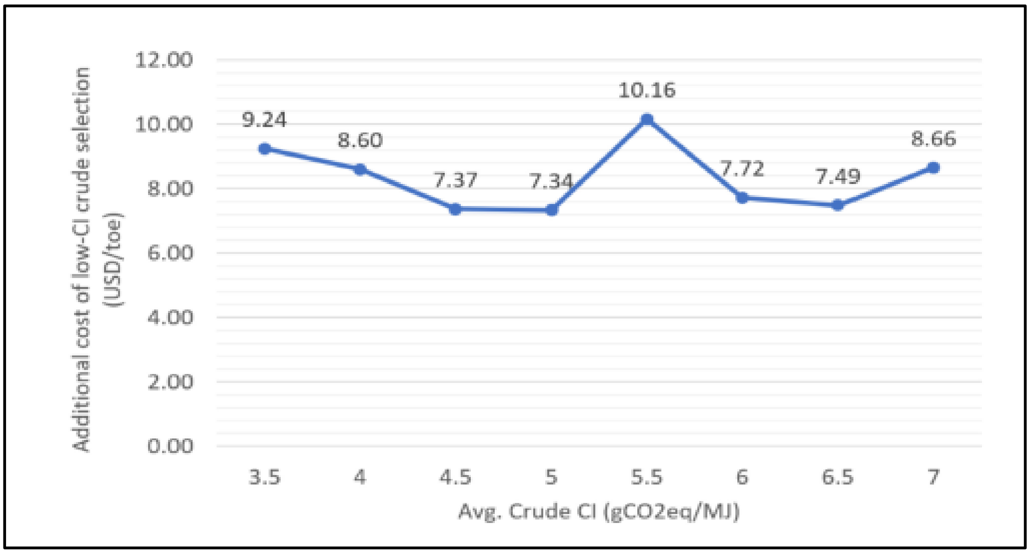
- Replacing internal components of distillation towers with advanced designs that reduce heating and cooling requirements.

- Upgrading heat exchangers to high-efficiency models made from materials that enhance heat transfer.
- Using advanced catalysts that allow reactions at lower temperatures and pressures, reducing energy consumption.
- Recovering waste heat from flue gases for use in combustion air preheating, steam generation, or reheating excess gases in incinerators.
- Recovering hydrogen from refinery off gas streams, compressing it, and using it to generate electricity in gas turbines equipped with CO2 capture systems.

- **Refining Low-Carbon Crude Oil**

There is a direct relationship between the carbon intensity of refined crude oil and the carbon intensity of final products, including low-carbon aviation kerosene. Low-carbon crude oil is typically more expensive than high-carbon crude oil, resulting in additional production costs. Figure (2-15) shows the additional costs for different types of crude oil based on carbon intensity compared to the average EU Crude Oil Price.

Figure (2-15): Additional Costs for Different Types of Crude Oil Based on Carbon Intensity Compared to the Average EU Crude Oil Price



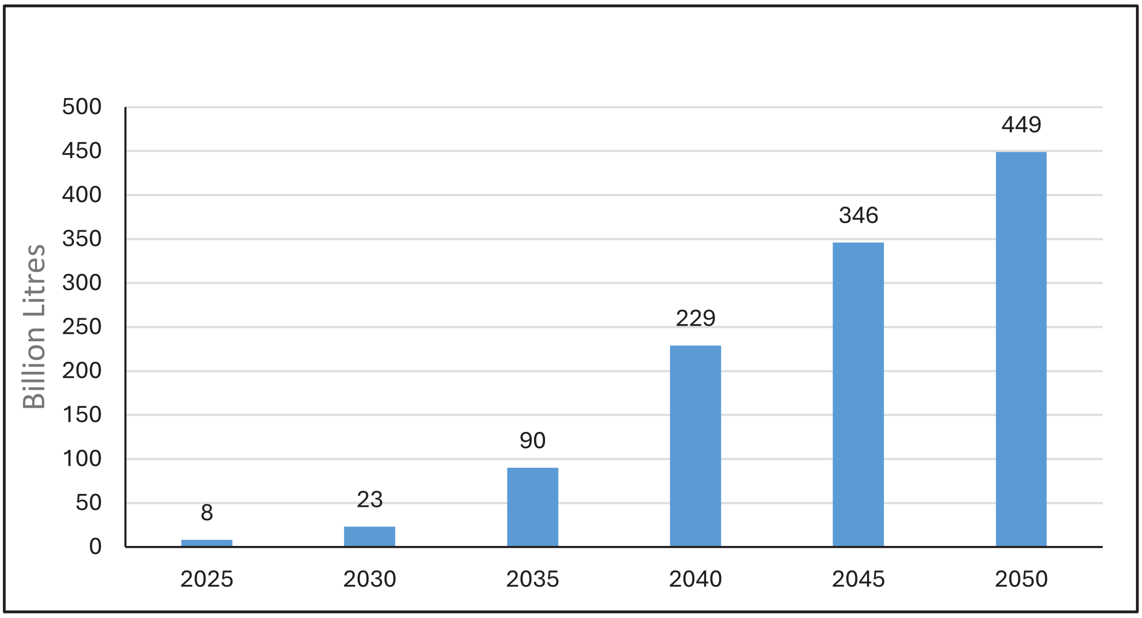

Source: (Chiaramonti, D., et al., 2021)

# Chapter Three

## Challenges in Producing and Consuming Sustainable Aviation Fuel

The production of sustainable aviation fuel (SAF) faces numerous challenges that can only be addressed through government support for investment and the creation of suitable markets. Despite significant governmental backing in many countries worldwide, the production of SAF did not exceed 600 million liters in 2023, equivalent to only 0.2% of the global aviation fuel demand. To achieve the aviation sector's decarbonization roadmap, SAF demand is expected to reach approximately 449 billion liters annually by 2050. Figure (3-1) illustrates the forecasted demand for SAF required to achieve net-zero emissions by 2050. (IATA, 2023)

Figure (3-1): Forecasted SAF Demand to Achieve Net-Zero Emissions by 2050




Source: (IATA, 2023)

One of the key features contributing to the adoption of low-carbon aviation fuel, produced from petroleum or biofuels, is its ability to be blended with conventional petroleum-based jet fuel. This compatibility ensures compliance with standards set by the American Society for Testing and Materials (ASTM 165521) or the equivalent British Ministry of Defense Standard (Defense 91-9122). Moreover, SAF must meet operational performance requirements to ensure the safety of current aircraft engines without necessitating modifications. These specifications include energy content, freezing point, thermal stability, viscosity, combustion characteristics, lubricity, and other aviation fuel properties.

Scaling up the production and consumption of SAF on a commercial level depends on several factors, primarily related to international standards, production approvals, and technological readiness. These factors are elaborated upon below:

## 3-1: High Production Costs

High production costs represent the most significant barrier to the widespread adoption of SAF, with costs ranging between 2.5 to 5 times that of conventional Jet A-1 fuel (Barbara, L., & Galea, C., 2024). However, this cost gap is expected to narrow over time, especially with the implementation of emissions trading systems (ETS) (Soone, J., 2020).

Some technologies, such as the Fischer-Tropsch process, involve high capital costs, accounting for 50-70% of total production expenses, while raw material costs contribute 10-35%. Production costs for Fischer-Tropsch technology can be reduced through economies of scale, although operating the technology at high production levels poses challenges, such as ensuring adequate and reliable raw material supply.

In contrast, the Hydrotreated Esters and Fatty Acids (HEFA) technology relies heavily on feedstocks like vegetable oils, with raw material costs representing the largest share of production expenses. However, using vegetable oils raises environmental concerns, such as the diversion of agricultural land from food production and the inflation of food prices. Some European countries have mitigated production costs by utilizing used cooking oil collected from restaurants, accounting for 90% of biofuel produced through this method (approximately 1 million tons). To address the challenge of transporting raw materials, there is a growing trend toward conducting preliminary processing at biomass production sites before transferring it to SAF production facilities (Pavlenko, N., & Searle, S., 2021).

Additionally, renewable fuel infrastructure development is costly. For example, Brazil has been producing bioethanol since the 1970s. Despite significant government support, it took over three decades to establish a supply chain capable of meeting approximately 40% of local transportation fuel demand, highlighting the complexity of building renewable fuel supply chains.

### 3-2: Low Production Efficiency

Producing SAF requires highly efficient processes to convert raw materials into consumable fuel, involving high energy consumption and challenges in managing production waste.

### 3-3: Lack of Consensus on Sustainability Requirements

The absence of a global consensus on unified sustainability standards creates uncertainty for SAF producers and complicates the selection of appropriate manufacturing technologies. Regional inconsistencies in sustainability criteria can result in an uneven and unfair competitive environment.

### 3-4: Variability in National Policies and Complex Procedures

Differences in sustainability policies and incentives between countries discourage investors. Furthermore, obtaining approval for new fuels can take years, involving not only fuel testing agencies but also aircraft engines and airframe manufacturers. For instance, South Africa's Sasol Fischer-Tropsch fuel took over seven years to gain approval, with a blend cap of 50% with conventional fuel. To date, no synthetic fuel has been approved for 100% blending (BOSCH, J., et al., 2017).

## 3-5: Difficulty in Securing Raw Materials

Competition for the raw materials necessary for SAF production results in price volatility, deterring investment in unstable projects. For instance, the Range Fuel bio-refinery in the United States, designed to produce 380,000 liters of bioethanol annually, failed due to high raw material costs despite substantial funding from the government and private investors.

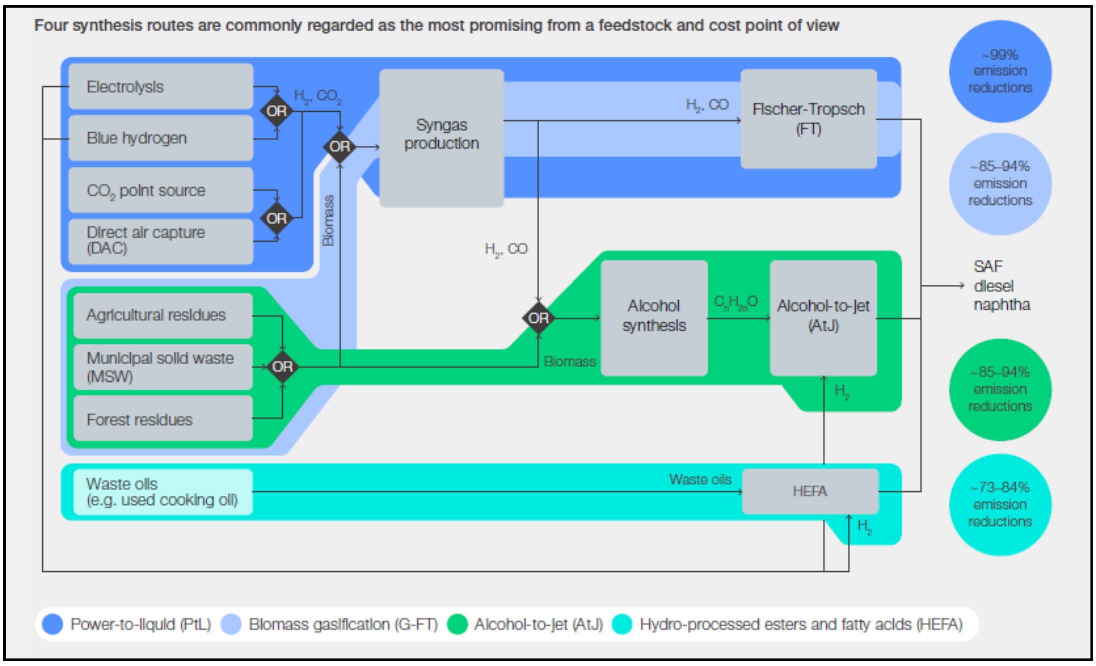
## 3-6: Environmental Impacts of SAF Production and Consumption

The environmental impacts of SAF stem from greenhouse gas emissions throughout its lifecycle, from raw material production to manufacturing and consumption.

- **Production Phase:** Emission reductions vary by technology and fuel type. For example, the Power-to-Liquid (PtL) process can achieve emission reductions of up to 99%, while the HEFA process achieves reductions of 73-84%. Figure (3-2) shows emission reductions for key SAF production technologies.
- **Consumption Phase:** The emissions from burning SAF in high-altitude atmospheric layers have a greater impact compared to ground-level emissions. These include carbon dioxide and nitrogen oxides, which contribute to ozone formation at lower altitudes.

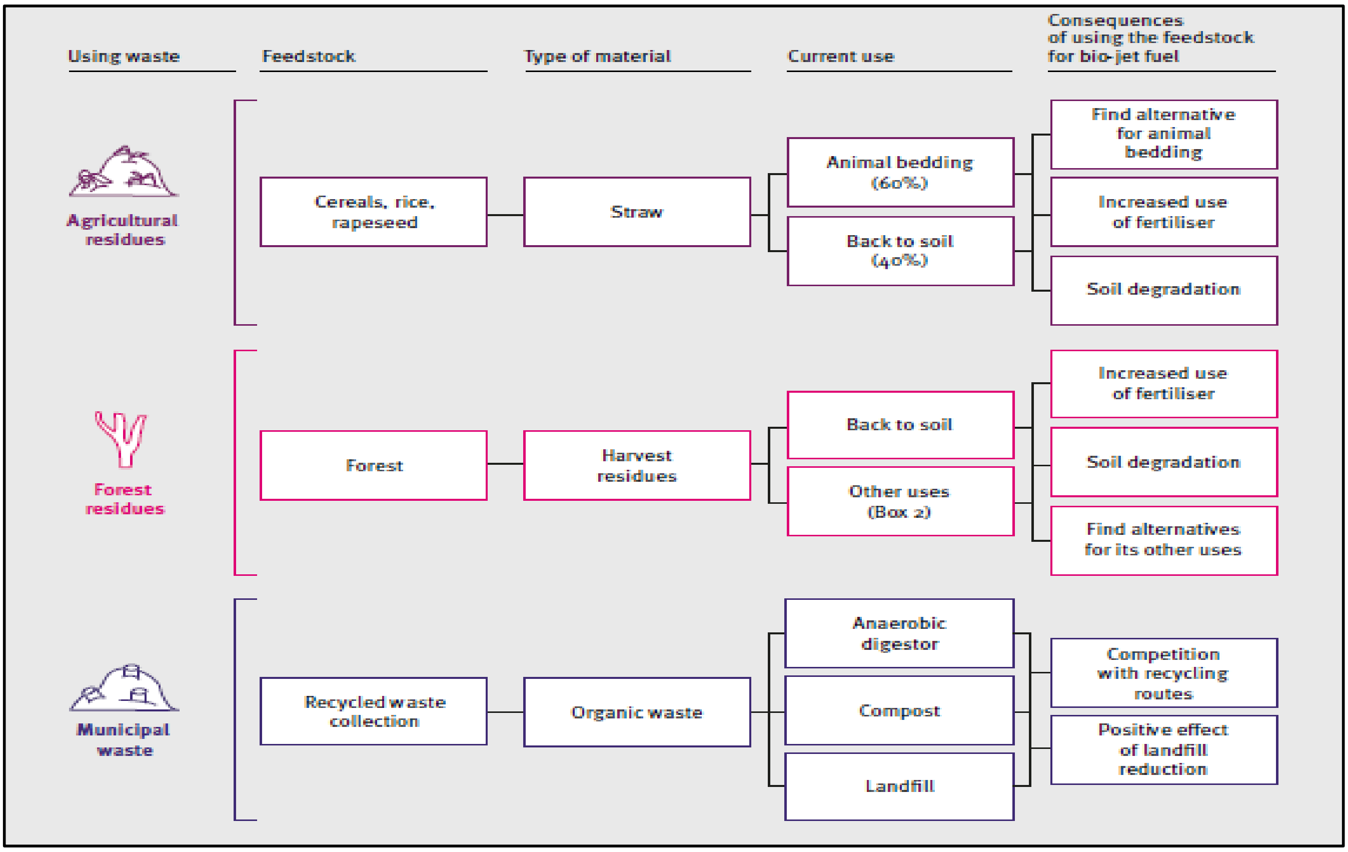
Other environmental concerns include the diversion of agricultural land from food production, pesticide use, and their effects on biodiversity. Figure (3-3) illustrates the environmental implications of using waste as feedstock for SAF production.

Figure (3-2): Emission Reduction Rates for Key SAF Production Technologies




*Source: Barbara, L., & Galea, C., 2024*

Figure (3-3): Environmental Impacts of Using Waste as SAF Feedstock




Source: (Fantuzzi, A., et al., 2023)

The following is an explanation of the most important implications of using renewable agricultural materials to produce sustainable aviation fuel.

### 3-6-1: Greenhouse gas emissions

Biofuel combustion is considered carbon neutral, assuming that the amount emitted is equal to the amount of carbon dioxide removed from the atmosphere by the feedstock (plant biomass) during photosynthesis over its life cycle. This is true for annual plants, where the carbon dioxide released from biofuel combustion is absorbed by a new plant the following year. Biofuel produced from feedstock manufactured by perennial plants will remain in the atmosphere for a longer period, as it takes a longer period for the plant to replace the plant consumed in manufacturing the feedstock. Therefore, the carbon dioxide emitted in this case contributes more to the phenomenon of global warming, as it remains in the atmosphere for a longer period before being absorbed by new plants. Furthermore, harvesting, processing, transportation and other operations in the biofuel supply chain consume energy, the production of which can result in greenhouse gas emissions through the combustion of fossil fuels. The problem can also be exacerbated using genetic engineering of feedstocks.

### 3.6.2: Direct and indirect land use

When a previously uncultivated area of land is brought under cultivation, the carbon stock in the vegetation of the area changes. Changing land use from carbon-rich vegetation, such as forests, to less carbon-rich vegetation, such as fields, reduces the amount of carbon that can be stored in the ground and thus increases $CO2$ emissions. These impacts must therefore be considered when selecting feedstocks and technological pathways for sustainable biofuel production.

Indirect land use change refers to the conversion of food crops into feedstock for biofuel production. For example, if a corn field, previously used to meet food demand, is converted to feedstock, the food demand must be met elsewhere. This may result in food production being shifted to other areas of the Earth, which are subject to the carbon stock change process described above. In practice, emissions from indirect land use change are difficult to identify because they occur at a different location from the actual production of the feedstock, making it difficult to track emissions. Land used to grow food crops should not be used to produce feedstock for biofuels, as this may result in deforestation or wetlands being cleared to create new space for food production or to compensate for reduced food production.

### 3-6-3: Nutrient Leaching

Nutrients are found in high concentrations in many fertilizers, including animal manure. The most important of these are phosphorus (P) and nitrogen (N). When these elements leach from fields into lakes and streams, they can cause eutrophication, which can lead to oxygen depletion in the water, which in turn can kill aquatic animals. However, nutrients (especially phosphorus) are also valuable resources with many uses. Phosphorus is used in the manufacture of fertilizers, mining (e.g. steel production), and soft drinks. Therefore, nutrient recycling should be considered when selecting raw materials and technological pathways to produce sustainable aviation fuel.

### 3-6-4: Harmful effects of pesticides

Pesticides are used to protect crops from pests, such as weeds, fungi, and insects, with the aim of improving crop yields and quality. However, these pesticides have harmful effects on the environment and human health, especially when they leak into water sources. The use of pesticides can be reduced by changing the way land is used. Perennial plants consume less pesticides than seasonal plants.

### 3-6-5: Impact on biodiversity

Biodiversity refers to the variety and reproduction of plants, animals, and other living organisms in an ecosystem. This diversity has many benefits for humanity, as most industrial and agricultural sectors depend on it, such as timber, water, fiber, food, and feed. Changing the use of some lands, such as forests, to grow raw materials for biofuel production may harm the biodiversity of these areas. Therefore, planning must be done when producing biomass so as not to affect biodiversity.

### 3-6-6: Water Use

The cultivation of raw materials consumes a large amount of water, the resources of which have become scarce in many parts of the world, and this problem is expected to increase in the future.

In conclusion, many aspects must be considered when producing the raw materials needed to manufacture sustainable aviation fuel, the most important of which are:

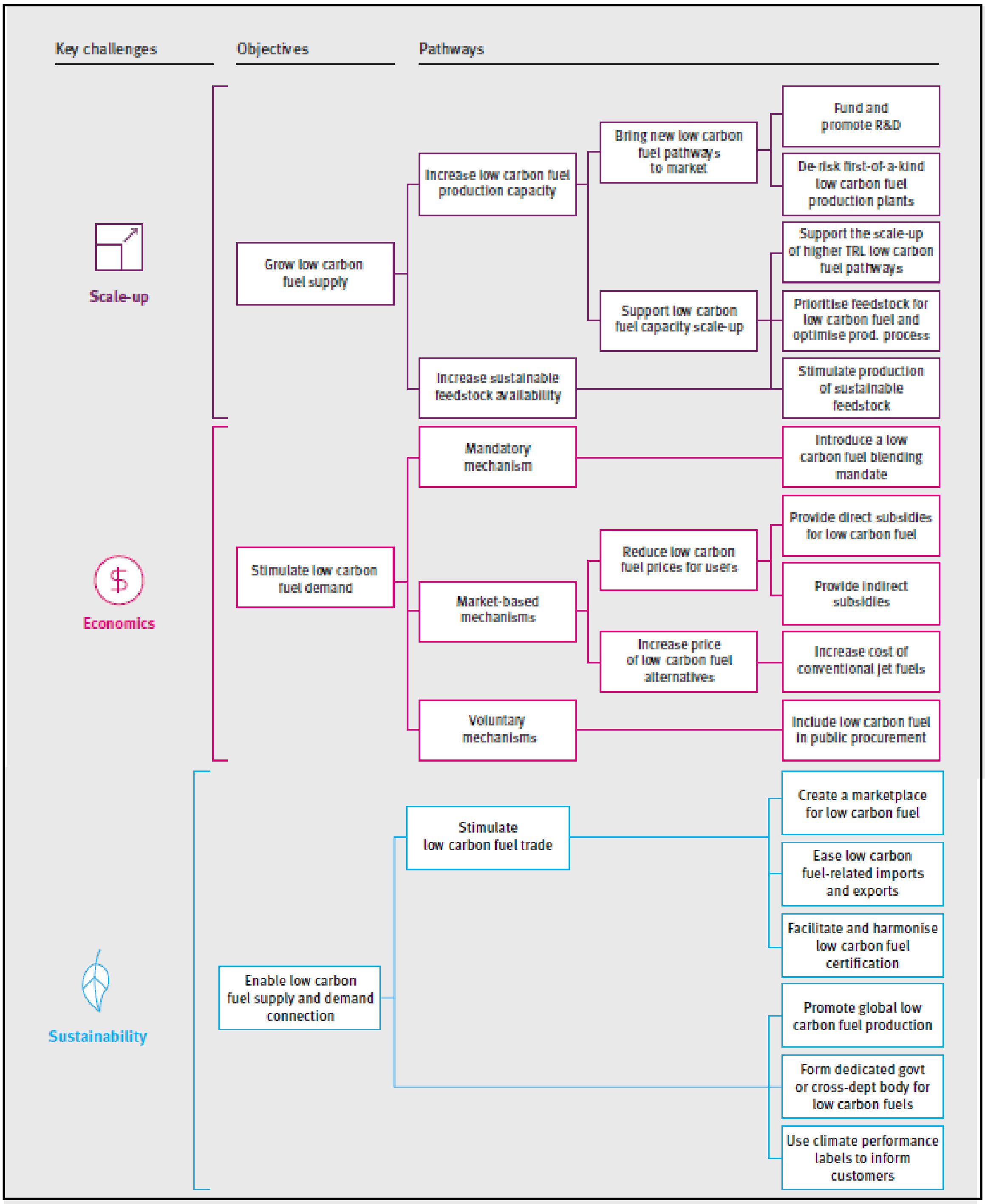
- The raw materials needed to manufacture sustainable aviation fuel need to have suitable areas of land and enough water and nutrients.
- There is a linear relationship between food prices and fuel production from biological sources.
- Considering that planting seed crops produces a larger amount of carbon dioxide than perennial crops, as the plowing process leads to the formation of carbon dioxide gas as a result of the oxidation of carbon stored in the field.
- Implement more rigorous life cycle analyses of low-carbon fuels, by:
    - Including a secondary impact assessment study for renewable fuel choices compared to current fossil fuels.
    - Considering CO2 emissions from fuel production to combustion.

- Including non-$CO_2$ impacts of both production and combustion in low-carbon fuel impact assessments.

## 3-7: Measures to facilitate the spread of sustainable and low-carbon aviation fuels

To facilitate the widespread spread of low-carbon fuels, political and regulatory measures must be implemented that contribute to increasing the supply of low-carbon fuels, stimulating demand, or enabling the link between supply and demand. Figure (3-4) shows the paths to facilitate the spread of low-carbon fuels.

Figure (3-4): Paths to Facilitate the Spread of Low-Carbon Fuels




Source: (Fantuzzi, A., et al., 2023)

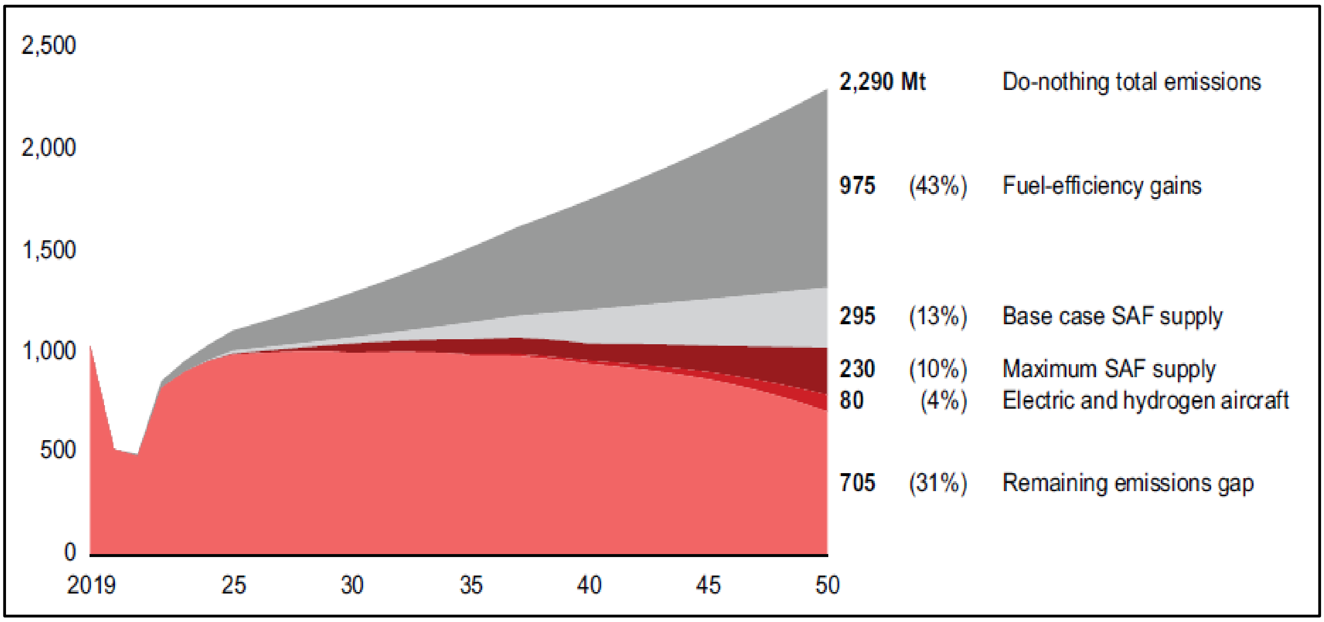
# Chapter Four

## Carbon Emissions Reduction Initiatives in the Aviation Sector

Carbon emissions from the aviation sector account for 11% of total CO2 equivalent, which represent 2.5% of total global emissions, reaching about 670 million tons in 2023, and are expected to triple by 2050, or 2.6 gigatons per year. (Bernard, Y., 2023)

Although many countries around the world have adopted a clear vision to reduce carbon emissions to zero, the most optimistic scenarios do not expect aviation sector emissions to reduce more than 70% of total CO2 emissions by 2050. Figure (4-1) shows the expected reduction in CO2 emissions in the aviation sector by applying reduction technologies.

Figure (4-1): Expected reduction of CO2 emissions in the aviation sector by applying reduction technologies




Source: (Danicourt, J., et. 2022)

The International Civil Aviation Organization (ICAO) has adopted a plan that includes several measures to reduce carbon emissions to zero in the sector by 2050, the most important of which are improving aircraft technologies, developing operating processes, and using sustainable low-carbon fuels, in addition to carbon trading procedures. The European Union has also issued a set of measures and is working on preparing several legislations related to decarbonization in the aviation sector. As for the United States, it has announced the possibility of reducing carbon emissions by 20% by 2030, and to zero by 2050, by removing carbon from the atmosphere in other places in quantities equivalent to the quantities produced by aviation fuel. (Royal Society, 2023)

## 4-1: Fuel Type Change Procedures

Carbon emission reduction measures related to fuel type are focused on four paths, which are hydrogen, ammonia, biofuel, and electric fuel e-fuel. (Sustainable Aviation, 2022)

### 4-1-1: Using Hydrogen as a Fuel

Hydrogen can be used in aircraft either by burning in the engine or through fuel cells to produce electricity needed to rotate the propellers. Hydrogen can be stored either as a liquid at a temperature of (-253 °C) or as a gas compressed to 350-700 bar.

Hydrogen is currently produced on a commercial scale by the steam reforming process of methane using natural gas as a feedstock, with a global production rate of about 70 million tons/year. Hydrogen can also be produced from the electrolysis of water using electricity generated by renewable energy sources, called green hydrogen, or through steam reforming of natural gas with the application of carbon capture and storage technology, called blue hydrogen. (Royal Society, 2023)

Hydrogen can play an important role in the aviation fuel mix, but its use still faces major challenges. Although hydrogen does not release $CO_2$ when burned, and the size of the aircraft engine is smaller and therefore the noise produced by the engine will be reduced, there are difficulties related to the need to modify the design of aircraft engines and structures. The increased weight required to store liquid hydrogen and the short distance that the aircraft can travel are among the biggest obstacles to its use as an aircraft fuel, although the energy density of liquid hydrogen is 2.8 times that of conventional jet fuel. (Newsom, R., et al., 2023)

### 4-1-2: Using ammonia as fuel

Ammonia is a gas produced by the reaction of hydrogen (produced from the steam reforming of natural gas) with nitrogen produced from the air. Ammonia gas can be burned in engines to provide thrust or used in fuel cells to produce electricity needed to rotate propellers. Ammonia can also be stored in liquid form at a temperature of (-30 °C) or under pressure of 1 bar. When green hydrogen is used in the production process, ammonia is called green ammonia, and when blue hydrogen is used, it is called blue ammonia. (Royal Society, 2023)

### 4-1-3: Use of Bio-Jet

Bio-jet fuel is called sustainable aviation fuel (SAF) and is currently produced from biomaterials on a commercial scale, but in very limited quantities that do not exceed 4% of the total fuel consumption of the aviation sector in the world. (According to the International Energy Agency (IEA) report), and it is described as hydrogenated vegetable oil (HVO), or hydrogenated esters and fatty acids (HEFA). The disadvantages of using this type of fuel include its high production costs and the need to mix it with fossil aviation fuel. (BOSCH, J., et al., 2017)

## 4-2: Developments in encouraging the spread of sustainable aviation fuel

The past few years have witnessed many countries moving towards accelerating the development of legislation and standards for sustainable aviation fuels after demands issued by environmental bodies to increase interest in sustainable aviation fuels compared to other renewable fuels used in land transportation. The following is a summary of the most important developments related to sustainable aviation fuels in some regions of the world. (Newsom, R., et al., 2023)

### 4-2-1: The development of sustainable aviation fuel in the United States of America

The journey to issue legislation for sustainable aviation fuel began in 2005 under the US Energy Policy Act, which included the Renewable Fuel Standards (RFS), and the law was then updated in 2007.

In 2021, an ambitious goal was set to produce three million tons of sustainable aviation fuel per year by 2030, and this goal was supported by a set of measures such as tax exemptions, allocating $175 million to fund research projects and the development of sustainable aviation fuel production technologies, and allocating investments and granting loans amounting to $4.3 billion to finance sustainable aviation fuel production projects.

In 2022, the Inflation Reduction Act was issued, which included granting incentives for the consumption of sustainable aviation fuel in the amount of $1.75 per gallon, in addition to financing fuel infrastructure in the amount of $245 million. In 2023, the federal government released a roadmap to reduce the cost of producing sustainable aviation fuel, enhance sustainability, and increase domestic production capacity to 3 billion gallons per year, to achieve a 50% reduction in greenhouse gas emissions from conventional aviation fuel by 2030, and to 35 billion gallons per year by 2050 to cover 100% of domestic demand for aviation fuel in the United States. (Goldner, W., et al., 2022)

At the state level, California lawmakers recently passed a law requiring producers to blend 20% sustainable fuel into petroleum-based aviation fuel by 2030.

### 4-2-2: Sustainable aviation fuel development in the European Union

Despite the challenges facing sustainable aviation fuel production in the European Union, such as limited arable land, high energy costs, and scarce bio-based feedstock, it has succeeded in issuing legislation and initiatives that can help encourage production and consumption. (Barbara, L., & Galea, C., 2024)

The European Union introduced the Emissions Trading Scheme in 2005, a system of tradable allowances for companies covering selected industrial sectors (including power and heat generation, energy-intensive industries, and aviation). The system is based on the principle of "cap and trade", whereby the cap is gradually reduced in line with the overall GHG targets of the participating partners, and has since become the cornerstone of the EU's GHG mitigation instruments, covering today around 45% of total EU emissions.

Around the world, governments are implementing a mix of regulatory mandates and economic incentives to accelerate the production and use of sustainable aviation fuels. Below are key examples of global SAF policy instruments:

• European Union (EU) – Blending Mandates (ReFuelEU Aviation): The EU is leading with a binding SAF blending mandate. Under the ReFuelEU Aviation regulation approved in 2023, fuel suppliers at EU airports must blend a minimum percentage of SAF into jet fuel. The mandate starts at 2% SAF by 2025, rising to 6% by 2030, with steady increases thereafter (including sub-targets specifically for synthetic e-fuels). By 2050, the EU aims for a majority of jet fuel to be sustainable, reflecting an aggressive policy-driven approach. This mandate ensures guaranteed demand for SAF and gives producers confidence to invest in new facilities. Furthermore, the EU's broader policy framework (e.g., the Renewable Energy Directive II) sets sustainability criteria for biofuels – feedstocks must meet strict standards (no high-deforestation risk feedstocks, for instance) to count toward targets. Several European countries have also introduced their own interim mandates or targets (e.g., France requires 1% SAF from 2022 rising to 5% by 2030; Norway already had a 0.5% mandate in 2020, aiming for 30% by 2030). These European policies are creating an integrated market push for SAF.

• United States – Financial Incentives & Targets: The U.S. has not imposed a federal blending mandate, but it has rolled out substantial financial incentives to boost SAF production and uptake. The Inflation Reduction Act (2022) introduced a Blender's Tax Credit for SAF, offering up to $1.75 per gallon of SAF (depending on its lifecycle carbon reduction) as a credit to producers or blenders. This significantly narrows the price gap between SAF and conventional jet fuel, encouraging fuel companies to produce SAF. Additionally, the U.S. Department of Energy and Department of Agriculture have provided grants and loan guarantees for SAF plants (e.g., via the SAF Grand Challenge aiming for 3 billion gallons of domestic SAF production by 2030). California's Low Carbon Fuel Standard (LCFS) also awards credits for SAF, effectively subsidizing each tone of $CO_2$ saved by using SAF. On the demand side, the U.S. government set a goal for the aviation sector to reach 100% of jet fuel demand with SAF or other net-zero fuels by 2050, with an interim aim of 10% of fuel supply (around 3 billion gallons) as SAF in 2030. In summary, the U.S. approach relies on market-based incentives and R&D support rather than mandates, spurring innovation and cost reduction.

• United Kingdom – Mandates in Development & Industry Partnerships: The UK is developing its own SAF mandate and has been actively funding early projects. As part of its Jet Zero Strategy, the UK government announced plans for a 10% SAF blending mandate by 2030 (with a likely start around 2025 in the low single digits, ramping up to 10% over the decade). This is accompanied by the Advanced Fuels Fund, a grant program of £165 million to support the construction of five commercial

SAF production facilities by 2025. The UK also leverages public-private collaboration via the Jet Zero Council, bringing together government, industry (including airlines like British Airways and Virgin Atlantic), and researchers to solve SAF challenges and develop a feasible mandate mechanism. Though the UK was part of the EU ETS, post-Brexit it is setting up its own emission trading scheme and considering how to credit SAF within it. Overall, the UK is combining a forthcoming regulatory requirement with financial backing for domestic industry, closely mirroring EU ambitions but tailoring them to its national context.

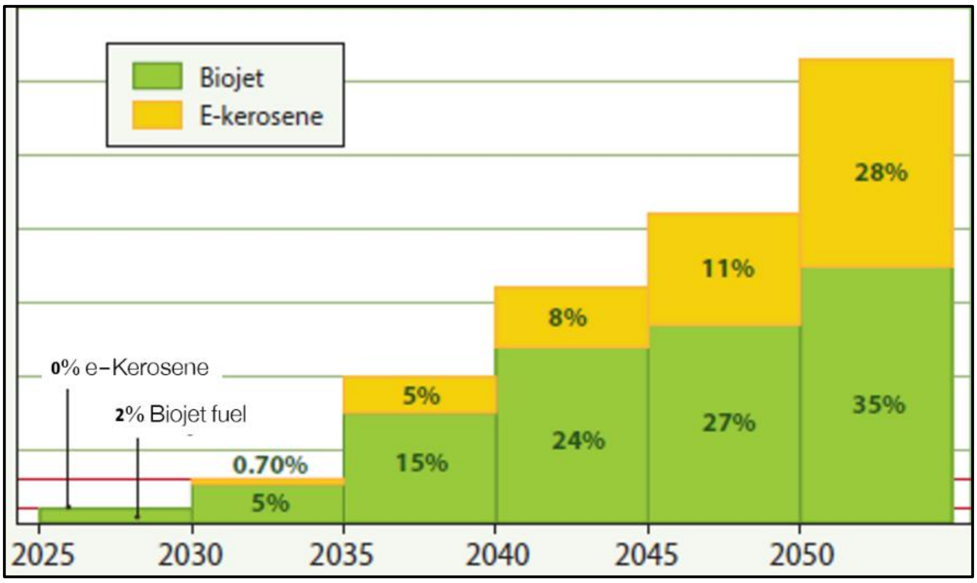
Aviation emissions have been included in the ETS since 2012. This includes emissions to, from and within the EU. International flights are excluded.

The ETS provides for airlines to be granted tradable permits covering a set level of CO2 emissions from their flights each year. The emission cap is to remain the same each year during the period 2013-2020, after which it is reduced by 5% of the average annual level of aviation emissions in the period 2004-2006. About 82% of emissions are allocated as a free pass to the aviation sector and the remaining 18% (plus emissions above the cap) must be offset with carbon credits. In 2020 the European Union adopted a Sustainability and Smart Mobility Strategy that aims to encourage the production and consumption of sustainable fuels in the aviation sector.

The European Union recently launched the ReFuel EU initiative, which aims to support European aviation fuel markets in gradually increasing the use of sustainable aviation fuel, with European airports committing to a blending ratio of 5% by 2030 as a minimum and reaching 63% by 2050, in addition to increasing the blending ratio of synthetic aviation fuel from 0.7% by 2030 to 28% by 2050. The European initiative requires that the carbon intensity of renewable aviation fuel used be 65% lower than that of conventional petroleum fuel. (Bauen, et al., 2022) In 2009, the Renewable Energy Directive was issued, requiring EU countries to ensure that the proportion of transportation fuel from renewable sources is not less than 10% by 2020. In 2016, the EU's energy and climate targets were issued, including setting a target for renewable energy to be at least 27% of total energy consumed by 2030. In the same year, the EU also issued the Sustainable Aviation Fuel Initiative, which includes the establishment of a joint project to produce sustainable aviation fuel with a large production capacity. (Wormslev, E., et al., 2016)

The ReFuel EU decision was also issued, which came into effect on 1 January 2023, because of negotiations that began in early 2022, between three EU institutions, namely the European Commission, the European Parliament, and the Council of the European Union. The decision includes giving a two-year grace period to aviation fuel producing companies to start blending sustainable fuel and electric fuel (e-fuel) with traditional petroleum fuel starting from the beginning of 2025 at a limited percentage not exceeding 2%, gradually increasing to reach 63% by 2050. Figure (4-2) shows the development of the minimum blending of bio- and electric-jet fuel in the European Union ReFuelEU decision.

Figure (4-2): Development of the minimum blending of bio- and electric-jet fuel in the European Union ReFuelEU decision




Source: (Nelson, R., 2022)

At the level of European countries, Germany issued an initiative in 2016 that includes the goal of supporting the production and consumption of sustainable aviation fuel so that its percentage reaches 10% of the total aviation fuel consumed by 2025. In 2021, Norway issued a law requiring airlines to use sustainable fuel at a rate of 0.5% as a first stage, gradually increasing to reach 30% by the year 2030, making Norway the first country in the world to issue a binding law on the use of sustainable aviation fuel. Sweden has also issued a similar law requiring aircraft to mix 1% sustainable fuel to petroleum fuel, with a target of 30% by 2030. Finland and the Netherlands are expected to issue a similar law, followed by the rest of the European Union countries. (Padt, A., 2021)

### 4-2-3: Sustainable aviation fuel developments in Asia

India aims to blend 1% sustainable aviation fuel by 2027, then 2% by 2028, with the plan initially being applied to international flights.

Indian Oil Corporation (IOC) has announced a project to set up a sustainable aviation fuel production unit with a production capacity of 80,000 metric tons per year with LanzaJet at the Haryana refinery, by converting waste gas into ethanol and jet fuel.

Singapore has announced a plan to supply all flights departing the country with sustainable aviation fuel from the beginning of 2026, as part of its commitment to global efforts to transition to the use of fuel.

Malaysia has issued a decision requiring airlines to blend 1% sustainable fuel from the beginning of 2026, as part of the National Energy Transition Roadmap published in 2023, which includes reaching a sustainable fuel blending rate in the aviation sector of 47% by 2050.

In October 2023, Malaysian state oil company Petronas and Japan’s second-largest oil refiner Idemitsu Kosan Co. signed an agreement to cooperate in the development and distribution of sustainable aviation fuel. Petronas also signed an agreement with Malaysia's Palm Oil Board to cooperate in preparing a study on the possibility of using cooking oil and palm oil production waste as feedstock to produce sustainable aviation fuel. (Hydrocarbon Processing, 2024)

In 2017, China decided to implement a national emissions trading scheme to reduce carbon dioxide emissions starting in early 2020, covering coal- and gas-fired power plants as a first phase, and is set to expand to seven other sectors including aviation, and will be the largest in the world to date, covering one-seventh of global carbon dioxide emissions from fossil fuel combustion. (IEA, 2021)

The National Energy Administration of China also announced in November 2023 that it will launch pilot projects to stimulate domestic production and consumption of biofuels, including sustainable aviation fuel (SAF) and biodiesel. It did not provide details on funding and timing.

In December 2023, the State Energy Investment Corporation of China announced a plan to produce 400,000 tons per year of sustainable aviation fuel (SAF) in the northern province of Heilongjiang. The plant will start as a pilot project with a capacity of 10,000 tons per year. The first batch of fuel is scheduled to be produced in late 2025 and will expand to 400,000 tons/year by 2030.

In April 2023, Airbus and China National Aviation Fuel Group (CNAF) signed a memorandum of understanding to increase the production and use of sustainable aviation fuel. A consortium of US-based Honeywell, Guangdong-based Oriental Energy Company Ltd., and the Tianjin Free Trade Zone also signed agreements to jointly produce sustainable aviation fuel with a production capacity of 1 million tons per year.

Japan announced in 2023 a plan to start blending 10% sustainable aviation fuel on international flights by 2030. A group of bodies consisting of Nippon Paper Industries, Sumitomo Corporation, and Green Earth Institute signed a cooperation agreement to explore the possibility of producing bioethanol from wood waste produced by the paper industry to use it as a raw material for producing sustainable aviation fuel by 2027.

It is worth noting that several other global companies are exploring the possibility of producing sustainable aviation fuel in Japan, including Mitsubishi, Boeing, TotalEnergies, and Eneos Holding.

In the Philippines, the airline signed a long-term strategic partnership agreement with Shell Eastern Petroleum to supply its fleet with sustainable aviation fuel by purchasing from the Asia-Pacific and Middle Eastern markets at an initial rate of at least 25,000 metric tons per year. In Australia, Qantas has launched a coalition to develop the production and use of sustainable aviation fuel called the Sustainable Aviation Fuel Alliance, which includes Australian carriers, Macquarie Global Financial Services, Boston Consulting and Woodside Energy. Qantas has also agreed with Airbus to invest $1.34 million in a project to produce sustainable aviation fuel from agricultural waste at a refinery under construction in Queensland, Australia. The refinery is expected to produce 100 million liters of sustainable aviation fuel by 2025. Australia plans to blend 10% sustainable aviation fuel by 2023, and 60% by 2050. In New Zealand, the government, in partnership with Air New Zealand, has allocated $1.34 million to study the potential for sustainable aviation fuel production and consumption.

## 4-3: Initiatives of international aviation bodies

The aviation industry has developed several initiatives to combat climate change, in cooperation and coordination with the International Civil Aviation Organization (ICAO). These initiatives are led by the International Air Transport Association (IATA) and the Air Transport Action Group (ATAG).

### 4-3-1: ICAO Initiative

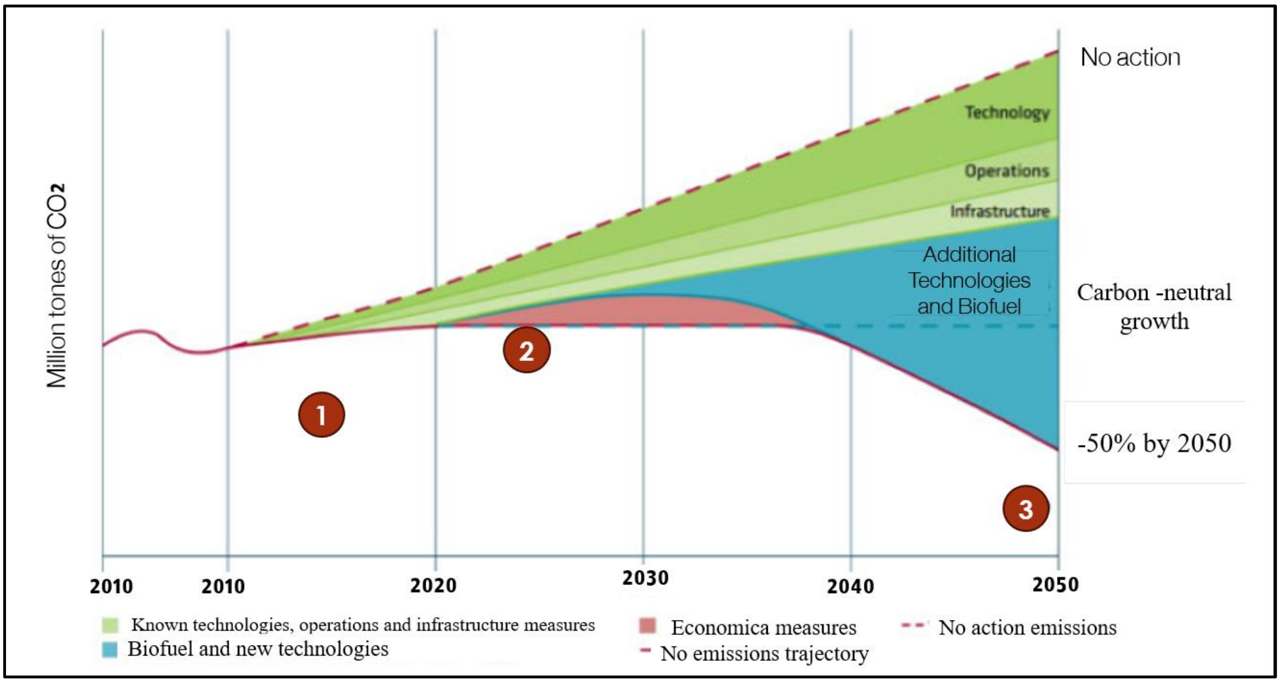
In 2007, ICAO launched a strategy that was adopted by the entire industry in 2008 during the Aviation and Environment Summit. This strategy is based on four main areas to reduce CO2 emissions in air transport: technologies, operations, infrastructure, and economic instruments. However, no clear policy has been presented for biofuels.

In 2016, the International Civil Aviation Organization (ICAO) adopted a global market-based mechanism called the Carbon Offset and Reduction Scheme for International Aviation, which aims to address and reduce carbon dioxide emissions from the international aviation sector by 85% of the 2020 level during the period 2024 to 2035. The mechanism includes the commitment of airlines to the following: (BOSCH, J. et al. 2017)

- An annual improvement of 1.5% in fuel efficiency during the period 2009 to 2020
- Carbon-free growth starting in 2020.
- An absolute reduction of 50% in carbon emissions by 2050.

Implementation of this strategy depends on four main areas: technology, operations, infrastructure, and renewable fuels. Figure (4-3) shows the role of areas for implementing the carbon emission reduction strategy in the aviation sector.

Figure (4-3): The role of areas for implementing the carbon emission reduction strategy in the aviation sector




Source: Wormslev, E., et al., 2016

### 4-3-2: Sustainable Aviation Fuel Users Group Initiative

The Sustainable Aviation Fuel Users Group (SAFUG) was established in 2008, with the aim of accelerating the development and commercialization of sustainable biofuels that can be blended with petroleum fuels and used directly in aircraft. The group consists of air carriers and other aviation industry organizations and consumes about 33% of the global demand for aviation fuel.

The group includes airlines and aviation organizations, using roughly 33% of global aviation fuel demand.

Despite the widespread interest in issuing legislation, it has not adequately addressed the use of sustainable biofuels, except for what has been discussed through carbon emissions trading and trading systems such as emissions trading systems, and therefore airlines are unlikely to support the use of biofuels in the near term. (BOSCH, et al., 2017)

The Sustainable Aviation Fuel Users Group (SAFUG) stipulates that sustainable aviation biofuels must meet the following conditions: (Wormslev, E., et al., 2016)

- Have a minimal impact on biodiversity
- Meet sustainability standards in terms of land, water and energy use
- Does not displace or compete with food crops and feed
- Contributes to improving the economy and raising the standard of living for society
- Does not require any special equipment to handle fuel or distribution systems or change the design of the aircraft engine.

## 4-4: Developments in sustainable aviation fuel production in Arab countries

The Arab region's engagement with Sustainable Aviation Fuel is accelerating, marked by pioneering test flights, collaborative research, and ambitious plans for production plants.

Although most Arab countries have large reserves of oil and gas, they have valuable opportunities to be among the leading countries in the production and export of sustainable and low-carbon aviation fuel, with their infrastructure and financing resources for renewable energy projects, and a diverse list suitable for the production of sustainable fuel such as algae that can be grown in salt water, and some drought-resistant plants such as Jatropha and Salicornia that tolerate high levels of salts in the soil. To maximize the capacity to produce sustainable and low-carbon fuels, Arab countries need to implement some measures, the most important of which are:

- Enhancing cooperation between the energy industry and the aviation sector

Some Arab countries have made remarkable progress in building initiatives and close integrated relationships between the energy and aviation industries, with the aim of enhancing sustainable fuel supplies. These initiatives are concentrated in the Arab Gulf countries due to their extensive infrastructure, in addition to their geographical location close to Asian and European markets, but the role of governments in issuing legislation supporting these initiatives is still absent.

• Issuing supporting legislation and policies

The process of issuing legislation related to the production of sustainable aviation fuel in Arab countries is still in its early stages, except for the United Arab Emirates, which announced a roadmap to support the production of sustainable aviation fuel with the support of the World Economic Forum (Barbara, L., & Galea, C., 2024).

Government legislation and policies play an important role in promoting the spread of sustainable and low-carbon aviation fuels, given the high production costs compared to conventional petroleum fuels, and the need to collaborate with multiple parties such as technology providers, production companies, marketing and distribution companies. For sustainable and low-carbon aviation fuel policies to be effective, they must have the following characteristics:

o Be stable and enforceable so that the private sector is willing to participate in investment.

o Be valid for a sufficient period to cover the timeframe of the project development (e.g. 10 years or more to provide a degree of predictability for investors.

o Be technology-neutral to enable diverse production routes and supply chains to evolve.

o Link incentives to performance (e.g., companies that contribute higher performance in reducing greenhouse gas emissions should be recognized).

o Identify the needs of distressed companies and support them with grants and loans.

o Establish mechanisms to encourage the expansion of sustainable fuel production capacity, promote technological innovation, and drive efficiencies to provide sufficient supply to achieve decarbonization of the aviation sector.

o Be designed with the political support of all relevant government bodies.

o To be flexible and achieve benefits for society and the environment.

• Improving the operational performance of oil refineries

Existing oil refineries in Arab countries can expand the scope of sustainable fuel production by applying co-processing technology that relies on refining renewable raw materials alongside crude oil in order to reduce the carbon footprint of refinery products and produce low-carbon aviation fuel (LCAF), as co-processing is a cost-effective and short-term solution to expand the scope of sustainable fuel production in the region.

• Production of electric sustainable aviation fuel (e-SAF)

Arab countries have a promising opportunity to produce electric fuel and export it to global markets at competitive prices due to their ability to produce electricity from renewable sources at low costs, as they have long periods of sunshine and vast lands, which enables them to produce green hydrogen using electricity generated from solar and wind farms. However, the production of electric fuel currently faces a difficulty related to the economic feasibility of using green hydrogen, as investors resort to using it in green ammonia or methanol production processes, as it is a mature industry and its cost is lower than the cost of producing electric fuel. It is worth noting that the Arab Civil Aviation Organization (ACAO) announced in 2024 its endeavor to adopt an Arab initiative to encourage the development and production of sustainable and low-carbon aviation fuels and other clean energy sources for aviation purposes. This initiative is based on studying the establishment of a joint Arab regional team with the Organization of Arab Petroleum Exporting Countries (OAPEC) and coordinating with financing institutions to finance technical feasibility studies on the potential of Arab countries to develop and produce sustainable aviation fuels. The organization indicates that the current share of sustainable aviation fuel does not exceed 0.2% of total aviation fuel consumption in Arab countries, and that achieving the carbon neutrality goals of the aviation sector requires raising production to 30 billion liters by 2030, and 450 billion liters by 2050. (ACAO, 2024). The following is a presentation of the most important developments in sustainable and low-carbon aviation fuels in Arab countries.

Despite this progress, current SAF output in the Arab region remains negligible – as of 2025, no commercial-scale SAF production facility is operational in any Arab country. All SAF used by Arab airlines thus far has been imported or produced abroad. Key hurdles include:

- Feedstock Limitations: Arid climates limit bio-feedstock agriculture, so innovative solutions (halophytes, waste oils, etc.) are needed. Projects like the UAE’s halophyte farming are promising but not yet scalable.
- High Costs and Policy Gaps: SAF is 2-5 times more expensive than conventional jet fuel. Government subsidies or mandates are not yet established in the region, making it financially challenging for producers and airlines to justify SAF use on a scale.
- Technological Maturity: Synthetic fuel technologies (Power-to-Liquid) are capital-intensive and still maturing. Countries like Saudi Arabia and Oman are

investing in the underlying components (renewables, hydrogen) but converting these to jet fuel is a next step requiring further innovation and investment.

- Logistics and Infrastructure: Airports in the region need infrastructure upgrades to store and distribute SAF. Coordination will be required to ensure new SAF production can seamlessly integrate into airport fueling systems.

Encouragingly, Arab countries are increasingly viewing SAF not just as an environmental necessity but as an economic opportunity – a way to diversify and future-proof their pivotal aviation and energy industries. The coming years will likely see more collaborative ventures (perhaps a regional SAF center of excellence, joint investments, or cross-border supply agreements). For example, one could envision UAE and Saudi Arabia co-developing a large SAF plant, combining UAE's waste feedstock with Saudi's hydrogen and CO2 resources, supplying fuel to both Emirates and Saudia.

By capitalizing on their strengths – abundant renewable energy (solar), existing fuel infrastructure, wealth of engineering talent, and significant capital – Arab countries can transform from SAF laggards to leaders. The milestones achieved so far serve as proof-of-concept. The true test will be scaling those successes. If planned projects materialize, by the late 2020s the Arab region could host several SAF production sites, fueling not only local airline fleets but potentially exporting sustainable fuel to Asia and Europe. Such developments would solidify the region's role in the global clean aviation energy landscape and help ensure that the growth of Middle Eastern aviation (with its major hubs and airlines) is compatible with global climate goals.

### 4-4-1: Sustainable aviation fuel developments in the United Arab Emirates

In 2014, the Biojet Abu Dhabi initiative was launched, aiming to explore the possibility of establishing a supply chain for biojet fuel in the United Arab Emirates, in cooperation between Etihad Airways, Boeing, Abu Dhabi Oil Refining Company (Takreer), Total of France, and the Masdar Institute of Science and Technology. In 2015, the group issued a roadmap that includes some recommendations related to the possibility of producing bio-based vaccines, the types of technologies that can be used, and the procedures that can be implemented to establish a supply chain for sustainable aviation fuel.

UAE authorities (e.g., Abu Dhabi National Oil Company (ADNOC) and Abu Dhabi Waste Management Center) are evaluating a commercial-scale municipal solid waste-to-jet fuel facility. By using household and industrial waste as feedstock (via gasification or pyrolysis and fuel synthesis), such a plant could address two issues: waste management and sustainable fuel supply. This project, still in planning as of 2025, aims to produce tens of millions of liters of SAF per year in the late 2020s, supporting UAE airlines.

The UAE's burgeoning investments in green hydrogen (e.g., large solar-powered electrolysis projects) are laying a foundation for Power-to-Liquid (PtL) synthetic fuels. There are exploratory partnerships (involving companies like Masdar, ADNOC, and international firms) to produce e-kerosene (synthetic jet fuel) by combining green hydrogen with captured CO2. For instance, at the 2023 UAE Climate Tech conference, plans were discussed for pilot e-fuel plants in Abu Dhabi to produce carbon-neutral jet fuel, leveraging the country's abundant solar energy. Status: Planned/Under Study – No such plant is operational yet (as of 2025), but feasibility studies and international MOUs are in place, indicating strong ambition.

The UAE's government and aviation sector are aligning on SAF promotion. As Dubai prepares to host COP28 (Nov 2023), policy announcements are expected, potentially including incentives (like blending mandates or price support) to kickstart a domestic SAF market. Emirates and Etihad are urging policies to make

SAF more available and affordable locally. Notably, the UAE is a member of ICAO's Committee on Aviation Environmental Protection and has pledged support for 2050 net-zero emissions in aviation, implying a significant role for SAF. Both major airlines (Emirates and Etihad) have set targets (e.g., Etihad aims for 10% SAF usage by 2030) and are participating in global SAF initiatives, ensuring that the UAE will continue pioneering SAF in the region.

It is worth noting that the United Arab Emirates has announced a national roadmap for sustainable aviation fuel, through which it has set a goal of achieving an annual production of up to 700 million liters of sustainable aviation fuel by 2030, which will contribute to reducing up to 4.8 million tons of carbon dioxide.

The UAE has also announced its commitment to achieving zero carbon emissions by 2050. On January 30, 2023, the UAE conducted the first test flight of its kind in the Middle East using 100% sustainable aviation fuel in one of the engines of a Boeing 777 aircraft. The test flight took off from Dubai International Airport and flew for an hour in the coastal area adjacent to Dubai. The sustainable fuel used in the experiment consists of two types, the first produced by Beste, which is made of hydrogenated esters, fatty acids and synthetic paraffinic kerosene HEFA-SPK, and the second produced by Virent, which consists of hydrogenated deoxygenated synthetic aromatic kerosene HDO-SAK. The importance of this experiment lies in proving the possibility of using 100% sustainable fuel, while the percentage of blending sustainable fuel with traditional petroleum fuel in regions of the world has not reached more than 50%.

On October 24, 2023, the UAE carried out the first test flight from Dubai International Airport to Sydney using sustainable aviation fuel produced by Shell and sent it to the aviation fuel network at Dubai International Airport. The fuel mix consists of 40% sustainable aviation fuel and 60% conventional jet fuel, Jet A-1, amounting to 350,000 gallons. (Hydrocarbon Processing, 2023)

In 2023, Abu Dhabi National Oil Company obtained a certificate from the International Carbon Sustainability Certification System (ISCC) to produce sustainable aviation fuel at the Ruwais refinery, which has a refining capacity of 920,000 barrels per day. The UAE is the first country to obtain such a certificate in the Middle East, which will enable it to supply international airports with low-carbon and sustainable aviation fuel from used vegetable oils.

In 2024, the UAE's Abu Dhabi Future Energy Company (Masdar) signed an agreement with the French company Total Energies to explore the possibility of producing sustainable aviation fuel and methanol. The project aims to capture CO2 from industrial sources as feedstock in addition to green hydrogen produced from renewable energy, which will be used to produce green methanol and sustainable aviation fuel (SAF). This project comes within the framework of the UAE's National Hydrogen Strategy and Low-Carbon Hydrogen Production Policy, which includes supplying national airlines at the country's airports with sustainable aviation fuel at a rate of 1% of the total fuel consumed by 2031. The project is expected to contribute to raising the UAE's hydrogen production to 1.4 million tons per year by 2031 (1 million tons/year of green hydrogen and 0.4 million tons/year of blue hydrogen) then to 7.5 million tons/year by 2040, then to 15 million tons/year by 2050. (Kapoor, P., 2024)

On the other hand, the United Arab Emirates has completed a roadmap in cooperation with the World Economic Forum to produce sustainable aviation fuel and renewable hydrogen by applying the Power to Liquid technology, so that it can produce about 15-73% of its aviation fuel consumption from sustainable fuel produced using the Power to Liquid technology.

Abu Dhabi National Oil Company (ADNOC), Masdar, and British Petroleum have also signed a memorandum of understanding to complete a feasibility study for a project to produce sustainable aviation fuel from municipal waste and hydrogen.

### 4-4-2: Sustainable Aviation Fuel Developments in the Kingdom of Bahrain

Bahrain's focus has been on improving energy efficiency and participating in global carbon reduction frameworks. While no specific SAF projects have been publicized, the national carrier Gulf Air has partnered with sustainable tourism initiatives, which implicitly encourage lower-carbon flights. Bahrain's Oil and Gas Holding Company (Noga holding) in 2021 indicated interest in biofuel research as part of diversifying the downstream sector. Given Bahrain's smaller scale, a likely approach for SAF is partnering in a regional venture (for example, co-investing in a SAF plant in Saudi Arabia or UAE) and then securing a share of the fuel for Bahrain's use.

Bahrain has begun using sustainable aviation fuel through Gulf Air, the national carrier of the Kingdom of Bahrain, in cooperation with Formula 1, Boeing, Rolls-Royce, the aircraft engine manufacturer, and Neste, the sustainable aviation fuel manufacturer, in a low-emission air show at the opening of the 2021 Formula 1 season at the Bahrain International Circuit in Sakhir. This initiative comes to confirm the Kingdom's commitment to international requirements to reduce carbon emissions for the aviation sector.

### 4-4-3: Sustainable Aviation Fuel Developments in the Kingdom of Saudi Arabia

Saudi Arabia, as one of the world's largest oil producers, is approaching SAF from the perspective of leveraging its emerging clean energy programs and strategic vision for diversification:

The NEOM mega-project in northwest Saudi Arabia – designed as a futuristic carbon-neutral city – includes green hydrogen production at an unprecedented scale.

A flagship venture is the NEOM Green Hydrogen Project, a joint venture with Air Products and ACWA Power, slated to produce 650 tons of green hydrogen per day by 2026 (which will be mainly converted to 1.2 million tons of ammonia annually for export). While the initial focus is on ammonia for power generation and transport, NEOM has indicated interest in producing synthetic fuels for aviation as part of its energy portfolio. Plans are being drawn to use a portion of the green hydrogen and captured carbon, from either industrial sources or direct air capture in the future, to produce e-kerosene for aircraft. This would make Saudi Arabia a potential supplier of carbon-neutral jet fuel by the late 2020s or 2030s. No dedicated SAF plant is online yet, but groundwork (utilities, export facilities at NEOM's port) is in progress.

Saudi Aramco is investing in research on alternative low-carbon fuels, in collaboration with global aviation companies. For example, Aramco has been involved in developing and testing fuel formulations for motorsports (e.g., synthetic fuels for Formula 1) which have technological overlaps with jet fuels. They are examining Fischer-Tropsch processes using captured $CO_2$ and hydrogen, and co-processing opportunities in refineries to produce SAF. Additionally, in 2020, Aramco and Boeing signed MoU to explore sustainable aviation technologies, presumably including fuels. Saudi Aramco has not yet moved to commercial SAF production, but it is building know-how that could translate to a domestic SAF supply chain later. This aligns with Saudi Arabia's broader circular carbon economy approach (reducing, reusing, recycling carbon), wherein SAF would allow continued use of liquid fuels in aviation with drastically reduced net emissions.

Saudi Arabian Airlines (Saudia) and the newly launched Riyadh Air (set to begin operations in 2025) are the country's flag carriers driving sustainable aviation commitments. Saudia has pledged to support IATA's 2050 net-zero goal. It announced exploratory partnerships to secure SAF for international flights – for instance, discussing supply agreements for routes to Europe where airports (like Paris or London) offer SAF. Saudia operated a demonstration flight in 2021 using a SAF blend on a Jeddah–Madrid route to coincide with the Saudi Green Initiative forum, signaling intent. However, regular SAF use is not yet in place for Saudia's operations as local supply is lacking.

Regarding the policy, Saudi Arabia's government has not mandated SAF usage yet, but it has incorporated sustainable fuel development in national strategies. The Saudi "Vision 2030" and the Saudi Green Initiative include aims to localize fuel industries and reduce carbon footprints. In late 2022, the Ministry of Energy set up a circular carbon economy national program, under which advanced fuels like SAF are a key pillar.

Internationally, Saudi Arabia joined the Clean Skies for Tomorrow coalition (under the World Economic Forum) to collaborate on scaling SAF. The expectation is that by the time NEOM's hydrogen is online, Saudi policy will support domestic SAF plants (through public-private partnerships or incentives) to utilize that hydrogen for aviation, aligning economic diversification with climate goals.

Saudi Aramco and Italian oil company Eni signed an agreement with the American company United Airlines, the largest airline in the world, to join the efforts of the British company (OXCCU) to explore opportunities to reduce the high cost of sustainable and low-carbon aviation fuel in cooperation with the American company Energy Venture and the British University of Oxford. (Sky News, 2023)

This project comes within the framework of the Kingdom's efforts to achieve environmental sustainability and sustainable development based on the goals of the Kingdom's Vision 2030, which gave the protection of the environment and natural resources the utmost importance, through the announcement of the "Saudi Green

Initiative" and the "Middle East Green Initiative", which will outline the direction of the Kingdom and the region in protecting the land and nature and placing it on a roadmap with clear and ambitious features, and will contribute to achieving global goals related to climate change.

### 4-4-3: Sustainable aviation fuel developments in the State of Qatar

Qatar Airways, the national carrier, is part of the Oneworld alliance, which in 2021 committed to 10% SAF use across the alliance by 2030. This means Qatar Airways has pledged to gradually incorporate SAF on its routes, particularly from airports where SAF is available. For instance, Qatar Airways has started uplifting SAF for certain long-haul flights departing from Europe. In 2022, some Qatar Airways flights out of London Heathrow used a blend containing a few percent SAF, as Heathrow is one of the airports supplying SAF to airlines (fueled by Neste's production). Qatar Airways has also joined industry forums advocating for SAF and invests in "Book-and-Claim" programs – paying for SAF's environmental benefit on flights where direct use isn't possible, to stimulate the market. Status: Operational (limited use) – Qatar Airways uses SAF on specific flights from overseas hubs; no known use from Doha yet due to lack of local supply.

- Gas-to-Liquids (GTL) Fuel and Future Convergence: Qatar is home to the Pearl GTL plant, the world's largest facility converting natural gas into liquid fuels (operated by Shell and Qatar Energy). Pearl GTL already produces jet fuel fraction as part of its output – used as blending component in conventional Jet-A1. While GTL fuel is fossil-based (thus not a sustainable fuel), it burns cleaner (low sulfur) and demonstrated Qatar's capability in fuel innovation (Qatar Airways flew a commercial flight on a GTL-kerosene blend in 2009). Looking forward, Qatar is examining how its GTL expertise can pivot to sustainable production:

- One route is bio-GTL: supplementing the GTL process with biomethane or captured CO2 with green hydrogen to create a partially renewable jet fuel.
- Another is building a biorefinery or HEFA plant alongside GTL facilities to process bio-feedstocks (like used cooking oil or algal oils) using existing refining infrastructure. Qatar Energy has signaled interest in advanced biofuels R&D in collaboration with universities (e.g., Texas A&M at Qatar), focusing on algae cultivation which could thrive in the Qatari climate and be fed into SAF production.
- A third approach is Power-to-Liquids: Qatar's huge solar energy expansion and plans for carbon capture at LNG facilities might allow the country to generate synthetic hydrocarbons. For instance, capturing CO2 from its LNG export terminals and using new solar farms to produce hydrogen could feed a reactor to produce SAF, effectively making use of Qatar's carbon and energy resources in a circular way.

While concrete projects have not been publicized, Qatar Energy and Qatar Airways formed a task force in 2023 to evaluate domestic SAF production options, acknowledging that reliance solely on imported SAF is not a long-term solution. Status: Planned (feasibility stage) – as of 2025, no SAF plant exists in Qatar. The nation is currently studying pathways, with a likely decision in the next few years aligning with global trends and the alliance's 2030 target.

In addition to the 2009 GTL flight, Qatar Airways' cargo division achieved a milestone in December 2021 by operating a Boeing 777 freighter from Frankfurt to Doha using a blend with 30% SAF. This was part of a freight partnership with Deutsche Bahn Schenker and demonstrated Qatar Airways Cargo's commitment to sustainable logistics. It illustrated that Qatar is willing to pilot SAF usage when partners provide access to supply. Another milestone is Qatar's hosting of the ICAO Conference on Aviation and Alternative Fuels in 2024 (planned in Doha), emphasizing the country's intent to be a player in the policy and dialogue space around SAF.

The Qatari government, through the Ministry of Transport and Qatar Civil Aviation Authority, supports the ICAO Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) and is developing a national roadmap for aviation emissions. SAF is a cornerstone of that roadmap. While oil and gas remain Qatar's economic bedrock, officials recognize that creating a SAF industry domestically could be a strategic move to future-proof Qatar's role in aviation fuel markets as global airlines demand more low-carbon fuel. We may see Qatar announce a pilot SAF facility or a major investment in a foreign SAF project to secure supply soon.

Qatar Airways signed an agreement with Shell to supply 3,000 metric tons of pure sustainable aviation fuel at Schiphol Airport in Amsterdam. The project aims to enable Qatar Airways to blend at least 5% sustainable jet fuel during the 2023-24 financial year, as a first step towards the target of 10% of total fuel consumed by 2030. Qatar Airways is the first airline in the Middle East and Africa to purchase a significant amount of jet fuel in Europe more than government requirements.

Qatar Airways has also signed an agreement with Gevo. Inc., a producer of sustainable aviation fuel to purchase 25 million US gallons of pure sustainable jet fuel over five years, with deliveries expected to begin in 2028 at various airports in California. Qatar Airways will supply 5 million US gallons of pure sustainable jet fuel each year and blend it with its existing supply of conventional jet fuel.

### 4-4-4: Sustainable aviation fuel developments in the State of Kuwait

Kuwait has significant oil refining operations and a large national airline (Kuwait Airways), but public steps toward SAF have been minimal so far. The country has been slower in renewable energy adoption compared to its neighbors. However, Kuwait's Environment Public Authority has begun mentioning sustainable fuels in its long-term climate plans. One of Kuwait's visions is to transform its massive Al-Zour refinery complex into a diversified hub that could, in the 2030s, incorporate biofuel processing units. Also, as a member of OPEC and OAPEC, Kuwait is involved in regional studies on oil demand changes; such studies increasingly mention alternative aviation fuels. We might expect Kuwaiti research institutions (like KISR – Kuwait Institute for Scientific Research) to initiate small SAF pilots (for example, experimental production from date palm residues or used cooking oil) to build know-how. Status: Not active yet – likely to follow once regional SAF success stories emerge.

Kuwait Petroleum International, a subsidiary of Kuwait Petroleum Corporation (KPC), which operates under the name Q8 in Europe, has significantly increased its presence in the aviation fuel market. Through Q8Aviation, the company has positioned itself as a major supplier of jet fuel in Europe, taking advantage of the decline in the oil refining industry in this region, and has been able to establish a giant supply chain through the import facilities it established in Rotterdam and Slovenia, attracting more than seventy international and regional airports, and its annual sales of jet fuel have reached more than 8 billion liters, supplying more than 2,000 aircraft belonging to about 200 global airlines. As part of its efforts towards sustainability, Q8Aviation has signed cooperation agreements and strategic partnerships to provide sustainable aviation fuel, including, for example, an agreement with EasyJet to meet the requirements of sustainable aviation fuel for the next five years, to help EasyJet achieve its goal of reaching net zero carbon emissions by 2050. (Q8Aviation, 2024)

### 4-4-5: Sustainable Aviation Fuel Developments in the Arab Republic of Egypt

Egypt has recently stepped into the SAF arena, mainly propelled by its role in international climate action and a desire to be a clean energy leader in Africa:

- **EgyptAir's COP27 SAF Flight:** In November 2022, during the COP27 UN Climate Conference hosted in Sharm El Sheikh, **EgyptAir operated its first SAF-powered flight**. The flight, from Paris Charles de Gaulle to Sharm El Sheikh, was operated with a Boeing 787 Dreamliner and used a blend of SAF (supplied in France, reportedly around 30% of the fuel). This symbolic journey – carrying delegates to the climate summit – showcased Egypt's commitment to sustainable aviation. It was a partnership with Air France-KLM and fueled by SAF produced by TotalEnergies in Europe, emphasizing international cooperation. The event marked the **first use of SAF by an African airline** and set the stage for more regional airlines to follow suit.
- **National Strategy and Planned Projects:** Following COP27, Egypt's government has turned attention to developing **domestic SAF capabilities**:
    - The Ministry of Civil Aviation and the Ministry of Petroleum formed a working group in 2023 to draft a **"Sustainable Aviation Fuel Roadmap for Egypt."** This roadmap assesses feedstock availability (such as jatropha, an oil crop already researched in Egypt's deserts, and abundant municipal solid waste and agricultural residues from the Nile Delta), technology pathways, and investment needs for SAF production.
    - There are discussions to retrofit or upgrade an existing refinery (likely in Alexandria or Suez) for co-processing vegetable oils into jet fuel.

This would allow near-term production of SAF by using available refining capacity. Egypt's large refining infrastructure and experience with refining biofuels (the country already blends bioethanol in transport fuel) make this a feasible step.

- Another proposal in early stages is the construction of a dedicated **bioresidue-to-jet plant**. In mid-2023, Egypt signed an MoU with a consortium of European technology companies to explore building a facility that gasifies agricultural waste (like rice straw, which is plentiful and often burned) and then synthesizes liquid fuel. This plant, if it proceeds, would be one of the first of its kind in Africa, targeting a production of perhaps 50–100 million liters of SAF annually by 2030.
- Egypt is also tapping international climate finance and partnerships: the EU and Egypt's cooperation on energy (reinforced during COP27) includes a component on **sustainable fuels**, potentially unlocking funding or technical support for SAF projects. Additionally, Egypt's membership in OAPEC (Organization of Arab Petroleum Exporting Countries) has led to knowledge exchange with Gulf countries on alternative fuels.

- Key players in Egypt's SAF initiative include EgyptAir (which as the flag carrier would offtake SAF for blending at Cairo and other airports), EGPC (Egyptian General Petroleum Corporation) and its refining subsidiaries (which would produce the fuel), and the Ministry of Environment (ensuring projects align with climate goals). International stakeholders like UN ICAO (through its ACT-SAF program) and companies like TotalEnergies, Eni, or Technip are engaged through partnerships and technology sharing agreements to support Egypt's plans. *Status:* Planned / Early Development – as of 2025, Egypt has no operational SAF production, but concrete steps (policy frameworks, feasibility studies) are underway. With its strong political will exhibited at COP27, Egypt is poised to have one of the first SAF production sites in Africa in the coming years.

If even one of the proposed projects comes to fruition, Egypt could supply not only its own airlines but potentially neighbors (e.g., flights refueling in North Africa on routes between Europe and Asia). Its strategic location and Suez Canal zone infrastructure could make it a regional SAF hub. Challenges remain, such as securing consistent feedstock and investment, but Egypt's momentum is a positive sign for SAF adoption beyond the Gulf states. Egyptian Solid Waste Recycling Company (ECARU), Qalaa Holdings, and the French company Axens signed an agreement to prepare economic and technical studies for the project to produce bioethanol and sustainable aviation fuel (SAF). (Hydrocarbon processing, 2023)

### 4-4-6: Sustainable Aviation Fuel Developments in the Sultanate of Oman

The Omani government's Vision 2040 includes developing alternative energy exports. In 2022, Oman announced large-scale solar and wind projects aimed at generating green hydrogen in Duqm and Salalah. One identified use-case for this green hydrogen is producing e-fuels for aviation. For example, the planned Hyport Duqm project (a green ammonia plant by 2026) could later be expanded with a methanol or Fischer-Tropsch unit to produce liquid fuels like SAF. Oman's unique position – having both oil refining expertise and new renewable projects – makes it plausible to see a Power-to-Jet Fuel demonstration plant by the late 2020s. Additionally, Oman Air has begun sustainability initiatives: in 2023, an Oman Air new aircraft delivery flight from Seattle to Muscat used a small SAF blend, signaling openness. Oman is also in discussions with the ICAO's ACT-SAF program to build

Abu Dhabi National Oil Company (ADNOC), Masdar, and British Petroleum have also signed a memorandum of understanding to complete a feasibility study for a project to produce sustainable aviation fuel from municipal waste and hydrogen.

### 4-4-2: Sustainable Aviation Fuel Developments in the Kingdom of Bahrain

Bahrain’s focus has been on improving energy efficiency and participating in global carbon reduction frameworks. While no specific SAF projects have been publicized, the national carrier Gulf Air has partnered with sustainable tourism initiatives, which implicitly encourage lower-carbon flights. Bahrain’s Oil and Gas Holding Company (Noga holding) in 2021 indicated interest in biofuel research as part of diversifying the downstream sector. Given Bahrain’s smaller scale, a likely approach for SAF is partnering in a regional venture (for example, co-investing in a SAF plant in Saudi Arabia or UAE) and then securing a share of the fuel for Bahrain’s use.

Bahrain has begun using sustainable aviation fuel through Gulf Air, the national carrier of the Kingdom of Bahrain, in cooperation with Formula 1, Boeing, Rolls-Royce, the aircraft engine manufacturer, and Neste, the sustainable aviation fuel manufacturer, in a low-emission air show at the opening of the 2021 Formula 1 season at the Bahrain International Circuit in Sakhir. This initiative comes to confirm the Kingdom's commitment to international requirements to reduce carbon emissions for the aviation sector.

### 4-4-3: Sustainable Aviation Fuel Developments in the Kingdom of Saudi Arabia

Saudi Arabia, as one of the world’s largest oil producers, is approaching SAF from the perspective of leveraging its emerging clean energy programs and strategic vision for diversification:

The NEOM mega-project in northwest Saudi Arabia – designed as a futuristic carbon-neutral city – includes green hydrogen production at an unprecedented scale.

(research phase) – no production yet, but strong potential leveraging Morocco's renewables; early experiments with e-fuel tech are likely by 2025-2026.

## 4-5: Comparative Analysis: Global vs. Arab SAF Policies

Taking the above into account, we can identify key differences and gaps between global SAF policy approaches and the current situation in the Arab region:

### 4-5-1: Blending Mandates

Virtually all progressive SAF mandates are outside the Arab world. The EU's enforceable blending schedule and similar mandates in some countries (plus airlines' alliance commitments to specific SAF percentages) ensure a clear demand signal for producers globally. In the Arab region, no such mandates exist, meaning there is no guaranteed domestic market for SAF. Arab airlines will soon face mandates when flying abroad (e.g., fueling in Europe), but at home they are under no obligation to use SAF.

### 4-5-2: Economic Incentives

Leading countries use tax credits, subsidies, and emissions trading benefits to make SAF financially viable. The Arab region currently lacks dedicated SAF financial incentives – notable given that several Arab governments do use incentives in other energy areas (for example, generous subsidies for electric power or EVs in some cases, or massive investment in green hydrogen). The gap in price support means any SAF in the region is significantly more expensive than elsewhere, discouraging adoption. Meanwhile, global competitors are driving costs down via economies of scale spurred by these incentives. For instance, U.S. producers benefit from the blender's credit and California's LCFS, allowing them to undercut any potential producer in the Middle East who would have to rely on full market price. This could leave Arab initiatives uncompetitive unless similar support is provided or costs fall dramatically.

### 4-5-3: Regulatory Framework and Governance

Global jurisdictions are adapting their regulatory frameworks to accommodate and promote SAF (e.g., certifying new SAF pathways quickly, integrating SAF into carbon trading schemes, requiring transparency in lifecycle emissions). In Arab countries, while technical certification is aligned with global standards (ASTM, etc.), regulatory frameworks specific to SAF are underdeveloped. For example, there are no established sustainability criteria for SAF feedstocks tailored to regional conditions, nor any requirement for fuel suppliers to even report SAF volumes. By comparison, in the EU fuel suppliers must meet the mandate and in places like the UK, proposals include requiring airlines or fuel providers to report their SAF usage annually as part of compliance. Arab regulators have an opportunity to develop such frameworks, but currently the governance around SAF is minimal – essentially defaulting to international guidelines without local augmentation. One example of this gap: If a company wanted to produce SAF in an Arab country, there is likely no clear policy on how it could count towards any climate commitments or how it would be treated tax-wise, whereas in the West those policies are defined.

### 4-5-4: Infrastructure and Supply Chain Support

Countries with active SAF policies often pair them with support for infrastructure – funding new biorefineries, ensuring airports can store and distribute SAF, etc. In the Arab region, meaningful projects (UAE’s planned waste-to-jet plant, Saudi’s NEOM fuel project, Egypt’s potential refinery co-processing) are largely driven by state oil companies or special economic zones, not through broad-based policy initiatives. There are few if any government grant programs or incentives to encourage multiple private players to build SAF facilities. Additionally, airport authorities in the region have not yet announced initiatives to integrate SAF logistics (for instance, no known plans to build shared SAF fueling infrastructure or dedicated SAF storage at major hubs like Dubai or Doha – whereas leading airports in Europe (e.g., Heathrow, Schiphol) already have such infrastructure in place or underway to meet mandates). This lack of supply chain readiness in policy terms could become a bottleneck when more SAF is available – essentially, the region could quickly find that even if it buys or produces SAF, the infrastructure to handle and deliver it to aircraft is insufficient, unless policies start to encourage upgrades now.

### 4-5-5: Feedstock Strategy

A crucial aspect of SAF policy is ensuring sustainable, abundant feedstock for production. Globally, policies often delineate what feedstocks are eligible and encourage certain types (like wastes, residues, advanced feedstocks) through incentives or mandates. The EU, for example, gives double counting credit for certain waste-based fuels, and the US targets cellulosic and waste feedstock in its incentives. In the Arab region, no explicit feedstock policies for SAF exist yet. However, because arable land and traditional bio-resources are limited, any SAF policy must emphasize non-traditional feedstock (like municipal waste, industrial off-gases, $CO_2$ and green hydrogen for synthetics, salt-tolerant plants, used cooking oil, etc.). We see project choices reflecting this (halophytes in UAE, solid waste in UAE, green hydrogen in KSA), but these are not yet codified into a coordinated strategy or policy. For instance, there is no regional equivalent of the EU’s ban on crop-based biofuels for aviation – but that’s because crop-based SAF isn’t on the table in the region anyway. A feedstock policy gap also appears in the lack of incentives for feedstock collection: e.g., governments could encourage collection of waste oils or farming of energy crops by guaranteeing purchases or providing subsidies, but such measures are not in place yet. In contrast, global practices like Brazil’s support for bioethanol feedstock farming, or Europe’s waste directive that improves feedstock availability, have no parallel in Arab countries for SAF.

### 4-5-6: Airline and Industry Obligations

Many global airlines have voluntary commitments or are being subjected to alliances' collective targets (oneworld, SkyTeam, Star Alliance each have SAF aspirations for 2030). Some governments also pressure or partner with their flag carriers on SAF usage (e.g., Japan's and Australia's governments working with their airlines to secure SAF supplies ahead of big events). In Arab countries, the big airlines (Emirates, Etihad, Qatar, Saudia) have each made public statements of support for SAF and executed demonstration flights, but these are not backed by any government requirement. There's a subtle difference: for instance, when Emirates did its 100% SAF test in 2023, it was a self-motivated initiative to show leadership; there was no UAE policy compelling it. In Europe, by contrast, airlines know that by 2025 they must be using at least 2% SAF or pay for it indirectly, so their motivation blends compliance with initiative. The gap here is that Arab airlines' commitments remain largely aspirational and subject to change if not reinforced by policy. The table (4-1) summarizes key policy dimensions, comparing leading global approaches to the status in various Arab countries.

Table (4-1): key policy dimensions, comparing leading global approaches to the status in various Arab countries

| Policy | Global Leading Examples | Arab Region Status |
|---|---|---|
| **Blending Mandates** | **Mandatory SAF blending targets** enforced by law. *Example:* **EU ReFuelEU Aviation** requires 2% SAF by 2025, ~6% by 2030, scaling to a high percentage by 2050. Some countries (France, Norway) already enforce modest blends. | **No binding SAF mandates** in any Arab country. No laws requiring airlines or fuel suppliers to use SAF. All SAF use to date is voluntary or for demonstrations. |
| **Financial Incentives** | **Tax credits, subsidies, and funding** to reduce SAF cost and encourage production. *Examples:* **USA's SAF Blender's Tax Credit** (up to $1.75/gal credit) and grants for new SAF plants; **UK's grants** (e.g., £165m for SAF projects). These lower investment risk and fuel price. | **Absent or indirect incentives.** No dedicated SAF tax credits or subsidies in Arab countries. Funding mainly via state-owned companies' investments (e.g. Aramco, ADNOC R&D spending). Some general renewable energy funding exists, but nothing SAF-specific to bridge the price gap. |
| **Regulatory Frameworks** | **Robust policy frameworks** integrating SAF into climate goals. *Examples:* EU allows SAF to count as zero-emission under EU-ETS (avoiding carbon costs), ICAO's CORSIA gives credit for SAF use. Governments set sustainability standards for SAF (feedstock sourcing rules) and require reporting of SAF use. | **Minimal SAF-specific regulation.** Arab states follow international standards (ASTM blending limit 50%) but have **no local SAF sustainability criteria or reporting mandates**. Participation in CORSIA is the main regulatory driver (indirect, as airlines can use SAF to meet targets). No emission trading scheme or carbon pricing that credits SAF (except UAE is exploring crediting SAF in its future carbon market). |
| **Infrastructure Support** | **Public investment and facilitation for SAF supply chain.** *Examples:* EU's Innovation Fund and national funds finance biorefineries; governments often | **Project-based infrastructure development.** A few high-profile projects (UAE waste-to-jet plant, Saudi synthetic fuel project at NEOM) driven by sovereign investment. No |

| Policy | Global Leading Examples | Arab Region Status |
|---|---|---|
| | co-fund airport infrastructure upgrades for SAF (storage tanks, blending facilities). Some countries encourage feedstock supply chains (farmers, waste collectors) through policy. | widespread infrastructure policy (e.g., no mandates for airports to be SAF-ready). Feedstock supply efforts are ad hoc (e.g., pilot farms, waste oil collection trials) rather than incentivized by policy. |
| **Feedstock Strategy** | **Defined strategies for sustainable feedstocks.** *Examples:* EU restricts crop-based fuels and promotes waste/residue feedstock via double-counting; US supports diverse feedstocks (municipal solid waste, agricultural residues) through R&D programs. National biofuel policies (e.g., Indonesia's jet biofuel plan) integrate with agricultural policy. | **Underdeveloped strategy.** Recognition of feedstock challenges (limited farmland, water) so focus is on *non-food feedstocks*, but no formal policy to develop them. Some R&D into local resources (halophytes in UAE, waste gas in KSA) and plans to import feedstock if needed. No clear governmental guidelines on what feedstocks should be prioritized for SAF production. |
| **Airline & Industry Commitments** | **Airline obligations and voluntary coalitions.** *Examples:* Oneworld alliance members (incl. Qatar Airways) pledge 10% SAF by 2030; governments sometimes require airlines to use SAF on specific routes/events (e.g., Japan's requirement for airlines to use SAF for the 2020 Olympics, which got delayed). Airlines in EU/US face pressure from investors and customers to report SAF usage. | **Voluntary initiatives only.** Arab airlines have piloted SAF (Emirates, Etihad, Qatar Airways) and set tentative targets (Etihad aims 10% SAF by 2030, Qatar Airways via alliance commitment). However, **no government-imposed obligations** or penalties for not using SAF. Industry's push for SAF depends on individual leadership (e.g., airline CEOs championing it) rather than regulatory compliance. |

# Chapter Five

## Conclusions and Recommendations

Arab countries have the chance to learn from global best practices and tailoring them to local contexts. Here are actionable recommendations and opportunities for policy harmonization:

- Introducing Gradual Blending Mandates or Targets:

  Arab governments could start with modest SAF blending targets (e.g., 1–2% by 2030) for fuel uplifted at their major airports, sending a market signal. This could be initially voluntary or as part of an MoU with airlines and fuel suppliers, eventually becoming mandatory. Aligning these with global timelines (for instance, an Arab Gulf state aiming for 5% by 2030 like the EU) would ensure airlines and suppliers in the region move in step with international partners. Countries with large state-owned airlines (UAE, Qatar, Saudi) can implement this readily by issuing directives to their national carriers to use a certain blend on flagship routes, effectively a pseudo-mandate that can later be formalized.

- Implement Financial Incentives to Spur Local Production:

Adapt the success of the US incentive model by offering tax credits or production subsidies for SAF. For example, Arab oil-exporting countries could redirect a portion of fossil fuel subsidies towards SAF producers – essentially a "reverse subsidy" making, say, each liter of SAF produced eligible for a government premium payment. Alternatively, governments can use offtake agreements or price floors: committing that national airlines or the military will buy SAF at a fixed (higher) price, thus de-risking investments in plants. Given the wealth funds in the Gulf, establishing a Green Aviation Fuel Fund to co-invest in SAF facilities (domestically or even abroad in exchange for supply) could quickly increase regional SAF capacity.

- Strengthening Regulatory Frameworks & Regional Collaboration:

Governments should create specific SAF regulatory task forces within their civil aviation authorities and energy ministries. These bodies would develop guidelines for SAF certification, handling, and integration into the fuel supply. They should also engage with international bodies (ICAO's Global SAF Clearinghouse, ISO committees on fuel standards) to stay updated. Regionally, Arab states could form a "MENA SAF Alliance" under groups like the Arab Air Carriers Organization or OAPEC to share knowledge and possibly coordinate on setting common targets or developing joint infrastructure (for example, a network of SAF storage facilities spanning key airports, or a shared SAF research center). Harmonizing technical standards and sustainability criteria regionally would also ease cross-border SAF trade in the future.

- Focus on Feedstock Strategy & Sustainability Policies:

It's crucial to identify what feedstocks the region can provide without harming food or water security. Policies can then support those feedstocks:

  - For waste-based SAF, cities can implement policies for waste segregation and collection aimed at converting waste to fuel (e.g., used cooking oil collection programs in large municipalities, turning a waste management problem into a SAF resource, as done in some European cities). Incentives for companies to supply waste materials to SAF producers (instead of landfilling or low-grade uses) would help.
  - For power-to-liquid SAF, policies should integrate with renewable energy and hydrogen strategies. For instance, if a country auctions off acres for

solar plants, it could require a portion of the generated hydrogen to be allocated for jet fuel synthesis, or at least not exclude e-fuel projects from industrial planning. Ensuring that any carbon capture projects consider aviation fuel as an output will align with global moves (Germany, for example, ties e-fuel projects to its PtL quota for aviation).

  - Explicit sustainability safeguards in policy will also be important. Arab countries can adopt the sustainability criteria of CORSIA or EU RED II for any SAF produced or used, to guarantee international acceptance. This includes lifecycle emissions thresholds, avoiding high-indirect impact feedstocks, and monitoring land use. Incorporating these criteria into national regulations now (even before production starts) will streamline future SAF exports and be used in international routes.

- Leverage Airline Commitments and Create Accountability:

Governments can formalize the already existing voluntary commitments by airlines. For example, if Etihad says 10% by 2030, the UAE government could incorporate that into a national policy or agreement, effectively holding the airline accountable and possibly tying progress to incentives (such as reduced landing fees for flights achieving SAF use targets – a policy tool some European airports have tried). Airlines in the region are largely state-owned or have significant government influence, so aligning their corporate strategies with public policy goals is feasible. Additionally, Arab civil aviation regulators could require airlines to report annually on SAF usage and CO2 emissions. This transparency, even without a mandate, can create a competitive and reputational push for airlines to do more (naming and faming the best performers, for instance).

- Public-Private Partnerships (PPP) for SAF plants: Partner local companies (like oil refineries) with international tech providers in joint ventures, supported by government loan guarantees or equity stakes. This mirrors how some biofuel refineries in the West were built with government-backed loans.

• Dedicated R&D and Training Programs: Establish centers of excellence for SAF within existing petroleum research institutes or universities to innovate on region-suitable technologies (e.g., direct solar fuel production, desalination-coupled biomass). Also train a workforce for this new industry.

• Policy Pilots and Scaling: Start with pilot regulations at a free zone or a specific airline route. For example, designate one international airport (like Dubai World Central or NEOM's future airport) to operate as a "Green Aviation Hub" with only SAF-fueled flights beyond 2030 as a pilot, then expand successes to national level.

- There are strong incentives for Arab countries to align with global SAF policies, not least because their airlines serve international routes heavily. Harmonization could involve:
  - Reciprocal Recognition: If Arab countries produce SAF, ensuring it meets EU/US standards means it can be sold into those markets. Therefore, adopting similar sustainability and certification standards domestically is wise policy.
  - Joint Initiatives: Arab governments could join global coalitions like the International Aviation Climate Ambition Coalition (# Comparative Analysis of Global vs. Arab Region SAF Policies and Mandates

• The main barrier to sustainable aviation fuel production is cost, with prices ranging from two to eight times higher than conventional aviation fuel, according to an analysis by international institutions.

• Investing in low-carbon aviation fuel supports the industry's transition to sustainability and drives progress in other green technologies.

• Stimulating sustainable aviation fuel production requires significant policy incentives to close the price gap between conventional aviation fuel and biofuels.

• To reach the net-zero emissions target, all available pathways to sustainable, low-carbon aviation fuel production must be exploited.

• Funding and support for research and development institutions is critical to finding new technologies to improve sustainable, low-carbon aviation fuel production.

• One of the most important characteristics that contribute to the widespread use of low-carbon aviation fuel produced from oil or biofuel is the possibility of blending it with conventional petroleum fuel, and that its characteristics comply with the requirements of the specifications set by the American Society for Testing and Materials (ASTM 165521), or its equivalent in the British Ministry of Defense standard (Defence 91-9122), in addition to the operational performance requirements and conditions that ensure the safety of current aircraft engines without the need to make any modifications to them.

Oil refineries can play an important role in the production of low-carbon aviation fuel, by applying the technology of co-processing renewable raw materials in oil refining operations such as fluid catalytic cracking units (FCC), hydrotreating units or crude oil distillation units. Some refineries that have surplus capacity in hydrogen processing units may resort to modifying some equipment in these units so that they become capable of processing only renewable raw materials or establishing integrated biorefineries with the oil refinery so that they benefit from the services available in the refinery from warehouses, pipelines, mixing and preparation stations for final products, in addition to other services such as electricity, water, steam, hydrogen, industrial wastewater treatment units, and others.

• The process of refining oils derived from biomass to produce low-carbon aviation fuel in oil refineries is gaining increasing interest within the efforts to meet the requirements of reducing carbon emissions resulting from petroleum products at all stages of their life cycle, starting from production operations to consumption.

• Co-processing has proven to be an effective path to enhance the production of low-carbon aviation fuel.

• The production of low-carbon aviation fuel requires the application of carbon intensity reduction technologies at all stages of the fuel production life cycle, starting from the oil production stage in the fields, through its transportation to refineries, then refining and production operations in refineries, and transporting the product to distribution stations and up to the consumption stage.

• To facilitate the widespread deployment of low-carbon fuels, policy and regulatory measures must be implemented that contribute to increasing the supply of low-carbon fuels, stimulating demand, or enabling the link between supply and demand.

• The process of decarbonizing the aviation sector requires the combined efforts of all relevant bodies and institutions, and coordination and integration between technology providers, government institutions, environmental protection agencies, energy markets, investors, and consumers.

• Given the need for all possible options for decarbonization and the announcement by many major oil companies of their strategies to reduce the carbon footprint of their operations and products by 2030 and 2050, fossil fuel options must be considered in the energy mix equation, especially low-carbon aviation fuel (LCAF).

• The aviation sector must look for opportunities and seek to solve the difficulties facing the production and consumption of sustainable fuels, to be able to reduce carbon emissions and ensure a sustainable future.

• Producers of sustainable fuels and energy should focus on deploying current sustainable fuel production capacities and demonstrating the certainty of continued demand in the long term, to encourage investors to finance future projects.

• Governments should work to issue legislation that supports the production and consumption of sustainable aviation fuel and seek to establish production projects that enhance the availability of fuel in the markets.

• Although most Arab countries have large reserves of oil and gas, many of these countries are leading the way in diversifying the energy mix and reducing carbon emissions and have valuable opportunities to be among the leading countries in the production and export of sustainable and low-carbon aviation fuel, with their infrastructure and financing resources for renewable energy projects, and diverse lists suitable for the production of sustainable fuel, such as algae that can be grown in salt water, and some drought-resistant plants such as Jatropha, and other plants that tolerate high levels of salts in the soil.

• Some Arab countries have witnessed remarkable developments in the field of encouraging the production and use of sustainable aviation fuel and have concluded partnerships and agreements with some specialized international companies. These developments are concentrated in the United Arab Emirates, Bahrain, the Kingdom of Saudi Arabia, the State of Qatar, the State of Kuwait, the Arab Republic of Egypt, and the Sultanate of Oman.

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