Detailed scheme and report of the infrastructure tailored solution for delivering SAF in fellow and other Airports

D 9.1

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List of acronyms

Abbreviation	Extended name
ADR	Aeroporti di Roma
AFS	Aircraft Fuel Supply
AMS	Amsterdam Schiphol Airport
ASTM	American Society for Testing and Materials
ATJ-SPK	Alcohol to jet synthetic paraffinic kerosene
BRU	Brussels Zaventem Airport
CAFHI	Changi Airport Fuel Hydrant Installation Company Pte Ltd
CEPS	Central Europe Pipeline System
CHJ	Catalytic hydrothermolysis jet fuel
CoQ	Certificate of Quality
CPH	Copenhagen Airport
CPK	Warsaw Airport
ETS	Emissions Trading System
FCO	Rome Fiumicino "Leonardo da Vinci" Airport
FT	Fischer-Tropsch hydroprocessed synthesized paraffinic kerosene
FT-SKA	Synthesized kerosene with aromatics derived by alkylation of light aromatics from non-petroleum sources
GHG	Greenhouse Gas
HC-HEFA-SPK	Synthesized paraffinic kerosene from hydrocarbon - hydroprocessed esters and fatty acids
HEFA	Hydrotreated Esters and Fatty Acids
HRS	Hydrant Refueling System
HVO	Hydrotreated Vegetable Oil
KM SFPP	Kinder Morgan Santa Fe Pacific Pipeline
LCAF	Lower Carbon Aviation Fuels
LHR	London Heathrow Airport
LTOU	Lithuanian Airports
NZE	Net Zero Emissions
SAF	Sustainable Aviation Fuel
SEA	Seattle-Tacoma International Airport
SFO	San Francisco International Airport
SIN	Singapore Changi Airport
SIP	Synthesized iso-paraffins from hydroprocessed fermented sugars
VNO	Vilnius International Airport

List of symbols

Symbol	Meaning
	SAF/JET A-1 Producer
	SAF/JET A-1 Storage
	Pipeline transport
	Ship transport
	Railway transport
	Truck transport
	Pipeline distribution
	Truck distribution
	End user

Executive summary

The imperative to promote Sustainable Aviation Fuel (SAF) in line with European regulations requires the establishment of robust, efficient and scalable supply chains at airports, representing a critical strategic consideration.

This deliverable outlines the strategies implemented or intended to be implemented by the partner airports of this Deliverable 9.1 of the ALIGHT project to promote the adoption of Sustainable Aviation Fuel (SAF) within their own airport facilities. In this regard, the role of the airport is to evolve into a pivotal intermediary within the SAF supply chain, facilitating transactions between producers of such sustainable fuel and end-users, particularly airlines. In this context, airports play a crucial role in enhancing the efficiency of SAF distribution by providing the necessary infrastructure.

To highlight the themes indicated above, this deliverable has been divided in 4 Chapters detailed below.

Chapter 1 provides a complete framework regarding the supply chain to be adopted for the SAF supply. Indeed, starting from production and blending, continuing through transportation and storage, and culminating in distribution and utilization, this Chapter offers a thorough roadmap for the lifecycle of SAF in the aviation ecosystem and it highlights the pivotal role of airports in this supply chain, highlighting their growing importance in the integration and adoption of SAF within airport operations.

Chapter 2 conducts a detailed examination of the SAF supply chain layers of Copenhagen (the Lighthouse Airport), Rome Fiumicino, Vilnius and Warsaw airports, offering unique insights into the implementation and optimization of SAF supply chains within specific contexts of reference. Copenhagen Airport is taken as a reference for airports with high daily fuel demand and consequently high demand for Sustainable Aviation Fuel (SAF), similarly to Rome Fiumicino Airport. Furthermore, both the airports use a Hydrant Refueling System (HRS) for fuel distribution into the airport. Vilnius Airport, on the other hand, serves as an example of infrastructure for airports that handle lower fuel volumes and lack an HRS distribution system for aircraft refueling. Lastly, Warsaw airport, still under construction, was analyzed to understand how to best implement the supply chain to guarantee the availability of SAF in the short, medium and long term.

Chapter 3 shares the experience of some of the leading airports in the world that have embraced SAF integration through an efficient supply chain. These examples illustrate how the use of incentive and innovative strategies as well as specific collaboration frameworks have made it possible to develop and implement the adoption of SAF within airport operations, driving substantial progress towards the sustainability goals of the airports themselves.

Chapter 4 evaluates the scalability of the proposed solutions for small and large airports highlighting their strengths and areas of concern. Optimal solutions have been outlined for both airport types (small and large airports), identifying the main drivers in order to promote the adoption of SAF within the airport premises, considering the storage type and methods of

transportation and final distribution. In addition, the Chapter provides insights into the geographical distribution of SAF producers at the Global and European level, emphasizing the importance of not only increasing the quantity of SAF produced but also the number of suppliers which can supply a specific airport.

As regard the conclusions of the study covered by this Deliverable 9.1 and structured as indicated above, they are indicated in the specific Chapter 5.

Introduction

Aviation accounts for about 2% of global carbon dioxide emissions[1], having grown faster in recent decades than rail, road, or shipping. Low-emission fuels, improvements in airframes and engines, operational optimization and demand restraint solutions are needed to reduce emission and reach the Net Zero Emissions by 2050 (NZE) Scenario. In this scenario, as indicated in the Figure 1, the use of Sustainable Aviation Fuels (SAF) is the main contributor to the reduction of CO_2 emissions, in fact they contribute to the 65% reduction of CO_2 emissions, followed by offsets and carbon capture (19%) and new technology applications (13%). Also, infrastructure and operational efficiencies give a 3% contribution to reach the net zero goal.

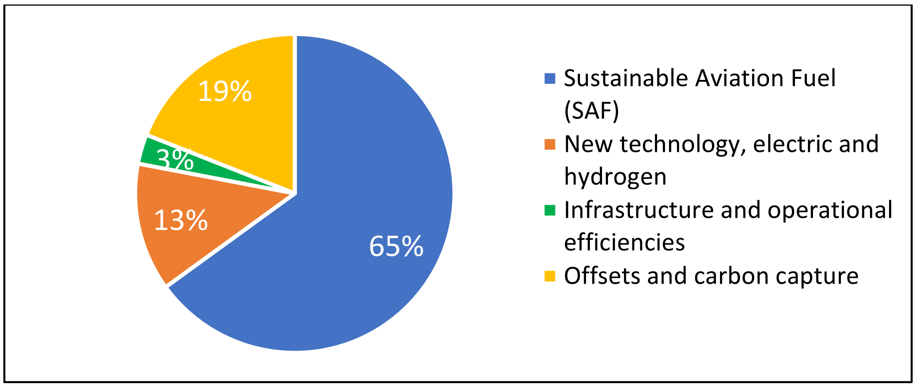

Figure 1 - Contribution to achieving Net Zero Carbon in 2050[2].

In that context, SAF will play a key role in achieving the 2050 decarbonization targets, also because they can be produced from a wide range of sources and can largely be used by existing planes.

The CO_2 emissions amount associated with SAF life cycle depend on the feedstock type and the production process. In Figure 2 it is possible to appreciate the quantity of CO_2eq associated with the life cycle of SAF produced according to different methodologies compared with the emissions of traditional jet fuel (89 gCO_2eq/MJ). It should be noted that in the values reported for biofuels produced from biomass the contribution associated with combustion is equal to zero. Compared to the value of traditional jet fuel emissions (89 gCO_2eq/MJ), for example, the CO_2eq emissions associated with the production and combustion of 1 MJ of SAF produced through a HEFA[I] process with used cooking oil feedstock are 13.9 gCO_2eq, with 84% lower CO_2eq emissions.

[I] Hydroprocessed Esters and Fatty Acids. Certified by ASTM since 2011, this process uses lipids as feedstock, such as vegetable oils, fatty acids, and waste fats which, after an initial deoxygenation phase, are subjected to hydrotreatment. The conversion process that leads to the production of HEFA type fuel is therefore connected to the production of hydrotreated vegetable oil (HVO), of which the jet fuel component is a part.

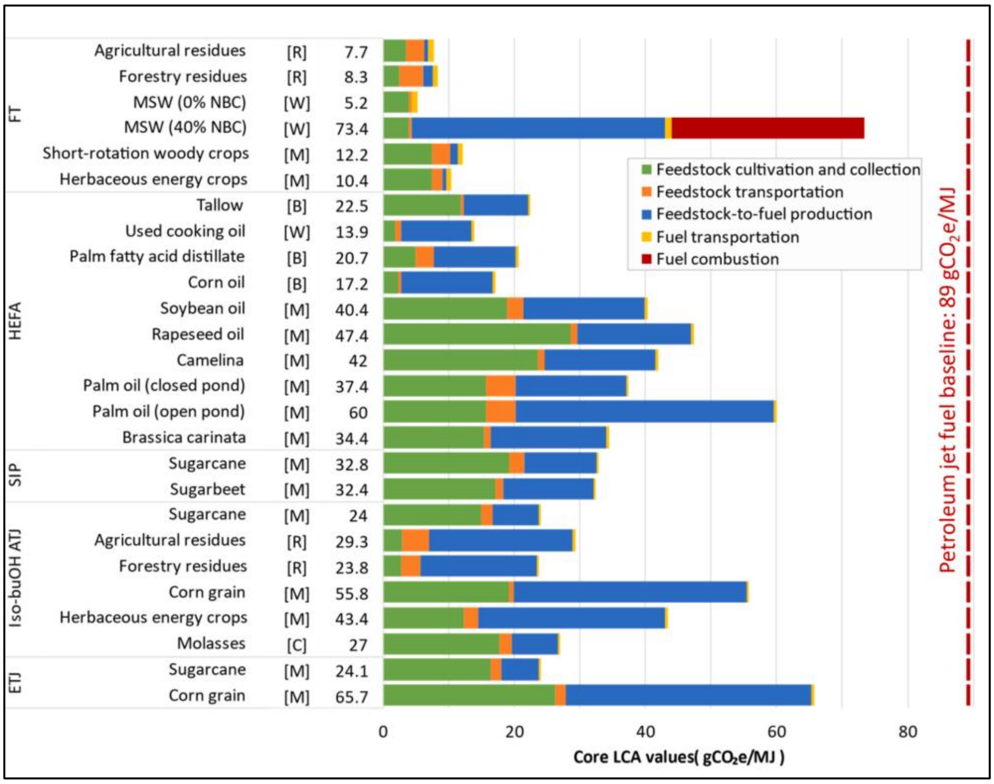

Figure 2 – CO_2eq emissions comparison between SAF and petroleum jet fuel[3,II].

On average, SAF reduces CO_2eq emissions by approximately 80% over its lifecycle compared with fossil fuel and is a major tool for aviation to reach its Net Zero Emissions target by 2050[4].A major SAF advantage is that it is drop-in fuel, capable of being used with conventional jet fuel and via existing fuel infrastructure, with no additional investment needed.

Furthermore, from a regulatory point of view, the 'ReFuel EU' Regulation (EU COM (2021) 561 final) requires aviation fuel suppliers to blend an increasing minimum percentage of SAF into the fuel mixture sold to aircraft operators. The regulation sets a minimum quota of 2% to 2025 of sustainable aviation fuels rising to 5% in 2030, 20% in 2035 up to 63% in 2050 for airlines departing from EU airports.

To achieve these goals, it is essential to guarantee a supply chain that can allow airlines to use SAF. In fact, the role of airport managers consists in making available the appropriate infrastructure for the refueling of SAF, also taking into consideration the greater future volumes.

[II] Feedstocks are categorized as main products [M], co-products [C], residues [R], wastes [W], and by-products [B]

1 Use of SAF in the airports

The SAF supply chain for airlines that specially request it from the relevant airport can be complex depending on several factors, such as the volumes involved, the distance between the production site and the airport, the size of the airport itself, the type of the infrastructure and the distribution for the final use.

The phases of the SAF supply chain will be detailed in the next paragraph, but as will be possible to notice, the deployment of SAF sees airports as catalysts between the upstream producer in the supply chain and the airlines that require the sustainable fuel. Therefore, the role of airports goes from ensuring the efficiency of the infrastructure in the distribution phase to promoting the diffusion of SAF through incentive systems for airlines requesting it.

1.1 Supply Chain of SAF

Despite this complexity inherent in the supply process itself, it is possible to trace the main phases that characterize supply chain (as indicated in the Figure 3 below).

In particular, the first phase of the supply chain is the production phase, which can take place through different production processes. The HEFA (Hydrotreated Esters and Fatty Acids) is currently the most widespread and uses animal fats, vegetable oils and waste oils as feedstock.

Once produced, the SAF is transported to the blend terminal for blending with JET A-1 in varying percentages depending on the production process and demand. This phase is sometimes not present, because the blending process is carried out in the same place of SAF production. The blended SAF is then transported via different possible transportation methods (e.g. pipeline, truck, train, ship) to the airport fuel storage site.

The storage options at the airport can be either in a dedicated tank for blended SAF or combined with conventional JET A-1 fuel (so called mixed SAF) in a mixed storage configuration.

The final phase of SAF distribution can be accomplished in many ways, from the storage tanks, through a combination of fuel pipelines, fuel hydrant systems, and fuel delivery trucks.

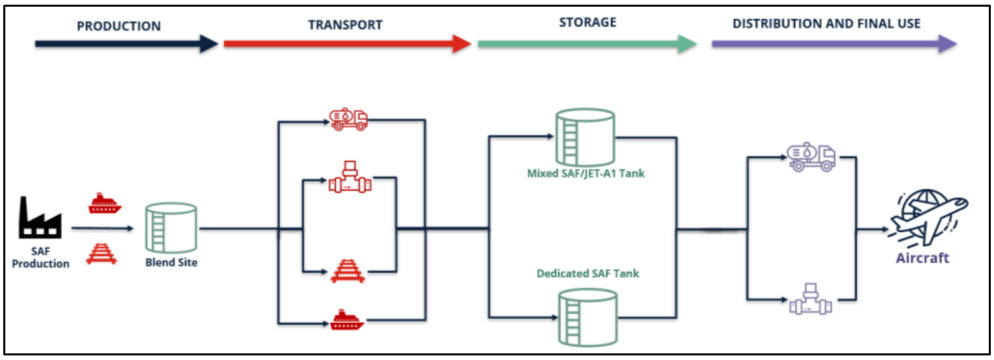

Figure 3 – SAF supply chain.

Each single phase has been explored in detail below.

1.1.1 Production

SAF is generally produced from biological sources, typically sustainable feedstocks such as plant matter, solid waste such as packaging, paper, textiles, food or used cooking oil, with potential sources including forestry waste and energy crops. It can also be produced from drawing CO_2 out of the atmosphere using low-carbon electricity.

Each batch of jet fuel needs to be certified prior to usage but, while conventional jet fuels are certified as ASTM D1655 fuels (or derivates thereof), neat SAF is certified to the stringent specification requirements listed in the ASTM D7566 Annex corresponding to the SAF production pathway.

Multiple technology pathways exist for producing fuels approved by ASTM (American Society for Testing and Materials), with blending limitations dictated by ASTM D7566 Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons. The most prevalent pathway is Hydroprocessed Esters and Fatty Acids (HEFA), but also the alcohol-to-jet pathway with ethanol feedstock is starting to spread.

Once the SAF blend is formulated, it undergoes certification in accordance with the ASTM D7566 blend requirements. Consequently, it attains an ASTM D1655 certification, rendering it fully compliant with JET A-1 standards (as indicated in the Figure 4). This certification classifies it as a 'drop-in fuel,' indicating its compatibility with existing jet fuel infrastructure and equipment, thereby facilitating its seamless integration into aviation operations.

Both ASTM standards are continually updated to accommodate technological advancements in SAF production.

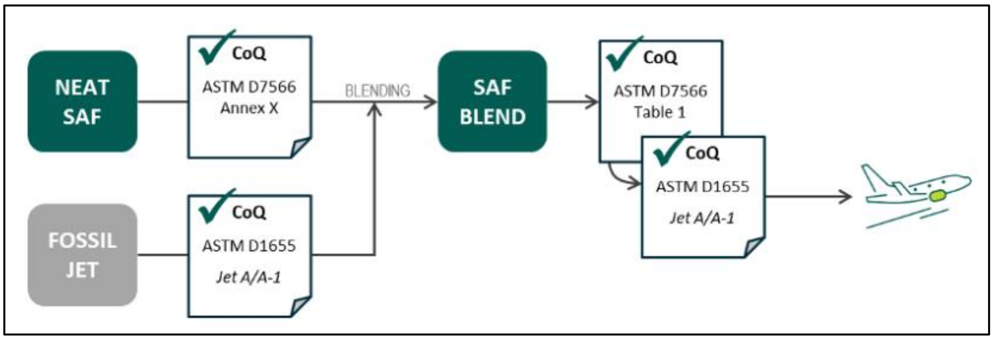

Figure 4 - Certification Path – Credit: Skynrg[5].

SAF must be blended with traditional JET A-1 fuel to use it in an aircraft, with different percentage depending on the production process. In Table 1 it is possible to appreciate the maximum blending percentages for the different production processes currently at up to 50%. The limitations are due to the passive use of conventional JET A-1 fuel for engine systems like the sulphur content that allows fuel seals to swell in engines, preventing fuel leaks[6].

Maximum blending percentage	Production processes[III]
50%	FT, HEFA, FT-SKA, ATJ-SPK, CHJ
10%	SIP, HC-HEFA-SPK, co-processing of HEFA
5%	Co-hydroprocessing of Fisher-Tropsch hydrocarbons in a conventional petroleum refinery, Co-hydroprocessing of esters and fatty acid in a conventional petroleum refinery

Table 1 – Maximum blending percentage related to specific SAF production processes.

At the time of writing Gevo, Alder Renewables, Fulcrum BioEnergy, Shell Aviation, and Neste are the main companies that emerge as leaders within the Sustainable Aviation Fuel (SAF)[7], through an examination of its offtake volume, representing the quantity of SAF that the company has committed to supply.
These companies spearhead the industry's transition towards a more sustainable aviation ecosystem and bolster the credibility of SAF through substantial supply commitments.
This metric encapsulates both a company's production capabilities and its market penetration, offering insights into its role in advancing the industry.

1.1.2 Blending process

Regarding the **blending** process, there are several options for its implementation[8], the most important ones are listed below.

A. **Delivering neat SAF and JET A-1 separately to a storage site outside the airport who serves the airport and blending them at the desired ratio into a third tank**: this option can ensure the best quality and allow total control of the percent volume of blended SAF but requires a Certificate of Quality (CoQ) for fuel in the third tank containing JET A-1 and SAF.

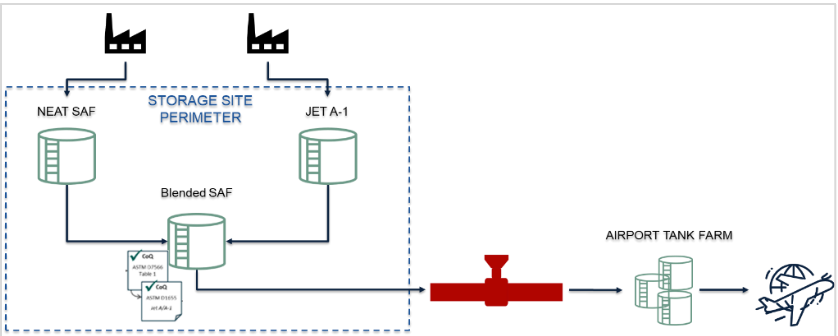

Figure 5 – Blending SAF process – Option A.

[III] See "List of acronyms" for extended process names.

B. **Offload neat SAF into a JET A-1 storage tank at a storage site outside the airport**: this option is less challenging and may be the best one for the initial small volumes of SAF in the short term, also because SAF can be delivered to the storage site by rail or truck. Since a CoQ is required for the fuel mixed with the SAF, it is necessary to equip the tank with equipment suitable for mixing and measuring devices to measure the blending percentage.

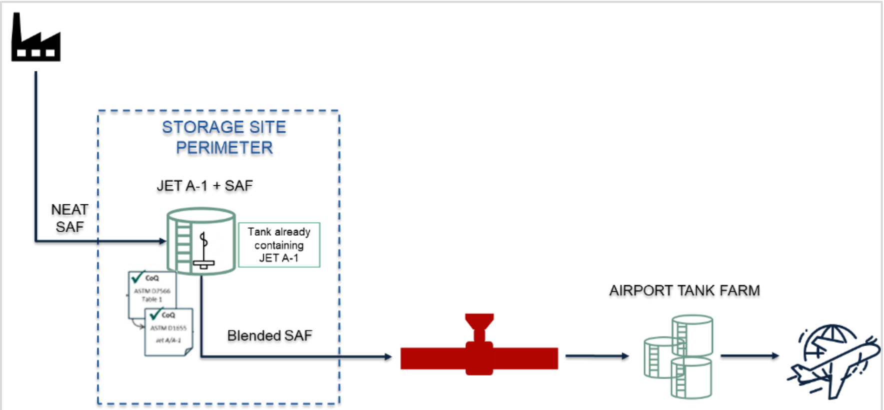

Figure 6 – Blending SAF process – Option B.

C. **Blending process into pipeline**: this option consists of storing JET A-1 and neat SAF in separate tanks and inject them both into the airport pipeline. Main limitations of this option are the quality control at the airport and the need to establishing mixed SAF as ASTM D1655 at the airport.

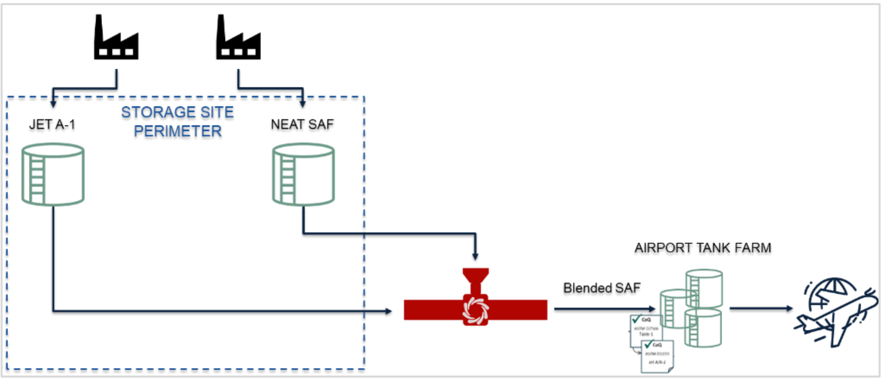

Figure 7 – Blending SAF process – Option C.

D. **Blending at refinery**: In this scenario, neat SAF is blended at a secondary refinery which is different from the first one that produces Jet A-1 and owned by a different company. However, a potential obstacle arises from the fact that, in case the refinery doesn't produce SAF, it should import it by a third party and this could be a problem because most refineries lack offloading equipment capable of accepting fuel produced by a third party into their tanks. Moreover, introducing SAF into the JET A-1 storage tank would necessitate recertification of the fuel to ensure compliance with safety standards.

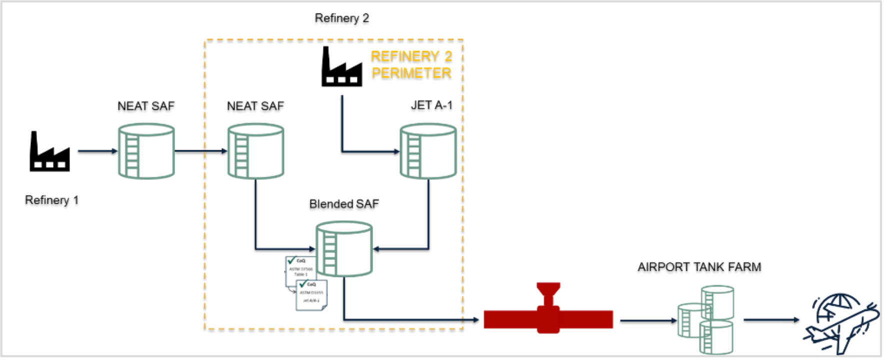

Figure 8 – Blending SAF process – Option D.

E. Greenfield/brownfield site outside the airport: creating a new facility to store and blend JET A-1 fuel with neat SAF is an option, but it comes with considerable costs compared to utilizing existing terminal equipment or constructing new tank(s) at an already established site. Additionally, obtaining permits for the new facility and setting up a pipeline to connect it either directly to the airport or to the airport's existing pipeline would require a substantial investment of time.

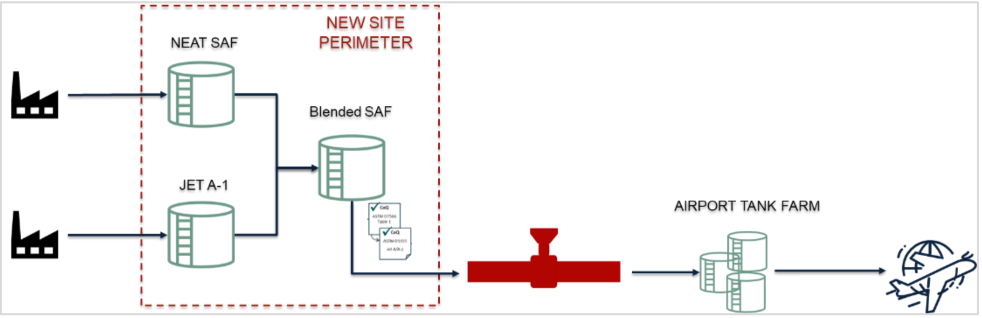

Figure 9 – Blending SAF process – Option E.

A further possible option, currently not feasible given the current legislation, is the blending process within the airport grounds. This case study would deserve further in-depth analysis.

The options A, B, D and E can also be used to blend fuel for delivery by truck to airports not connected to pipelines.

1.1.3 Transport

Regarding the **transport** of blended SAF, the modalities may differ depending on the distances and volumes involved and can be via:

- Ship;
- Pipeline;
- Railway;
- Truck.

When dealing with low volumes of fuel, such as when only a few airlines require a small amount of SAF, or in smaller airports with limited demand, the use of fuel trucks turns out to be the optimal solution.

On the other hand, high volumes of fuel necessitate a shift away from truck-based supply management, both logistically and economically. In such cases, pipelines or rail transport become the preferred modes of transportation.

Regardless of volume, when SAF is co-processed with conventional JET A-1 fuel, transporting the blended SAF through pipelines to the farm tank at the airport offers several advantages. This method allows for seamless integration with existing infrastructure, minimizing the need for significant alterations. Once at the airport, the mixed SAF can then be distributed efficiently using systems like the Hydrant Refuelling System (HRS) or via trucks, ensuring smooth operations without disrupting the established infrastructure.

1.1.4 Storage

About the **storage** in the fuel farm at the airport, it can be differentiated into two main modes:

- **Segregation of the blended SAF in a dedicated tank**: in this case the blended SAF is stored in a dedicated tank, ensuring the blending percentage specified by the supplier.
- **Mixing of blended SAF with traditional JET A-1 fuel in the same tank**: in this case, the blended SAF is mixed into the tanks with traditional JET A-1 fuel, obtaining a final percentage of SAF (so called mixed SAF) which may vary in the end use respect to the percentage initially specified by the supplier.

1.1.5 Distribution

Distribution within the airport can take place according to two main methods:

- **Hydrant Refuelling Systems (HRS);**
- **Refueler Trucks.**

The Hydrant Refuelling Systems (HRS) is the one that most facilitates the using of SAF even for high volumes. It can enable a more efficient fuelling process connecting the storage tanks directly to the aircraft parking position. This type of distribution is prevalent in large and modern airports, the same ones that in a first step may receive SAF physically to meet the targets imposed by the regulations. Such airports opt for fuel HRS due to their cost-effectiveness, simplified logistics and safer operational procedures. While fuel trucking systems may offer cost savings, the overall benefits of hydrant dispenser systems typically outweigh these considerations.

HRS distribute fuel to aircrafts and operate under high pressure with large diameter piping that end in hydrants, which are also known as fill stands.

Airports not equipped with the HRS will be able to support the development of SAF and its supply at the airport site by refueler trucks. A refueler truck is a tanker that carries fuel in its tank, having a tank capacity of 23,000 liters or more, and is equipped with necessary pumping systems to be hooked to an aircraft and top up its fuel.

1.1.6 Final use

Considering the **final use** of SAF in aircrafts, there are currently different methods:

- **Refueling in segregated mode** (Figure 10), ensuring its separation from the pure JET A-1: entails high costs for airports with a fixed distribution system which would have to review their infrastructure system in order to implement it. One of the main advantages of this solution is the physical delivery to the customer, but on the other hand it involves higher costs for separate infrastructure and transport and operationally inflexibility and non-scalability.

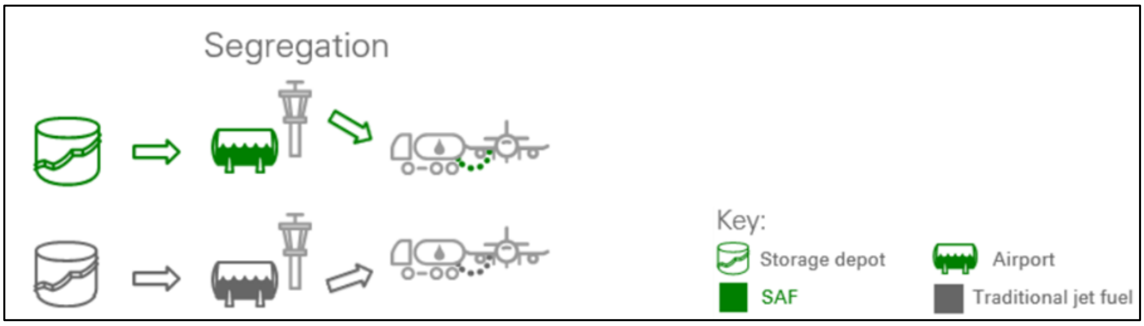

Figure 10 - Example of Segregation SAF distribution mode ICAO Environment[9].

- **Mass balance mode** (Figure 11): this solution is used when blended SAF is mixed with conventional fuel and utilizes existing pipelines for final distribution, this mass balance is about tracking physical fuel volumes and percentages and is currently the most feasible in the short to medium term. This solution allows to use the existing infrastructure, enabling a lower carbon footprint than a segregated supply chain, but higher than book and claim and allows fuel suppliers to achieve their SAF targets by delivering the required SAF quota to specific airports or larger centralized locations, instead of transporting small volumes to each individual airport[10].

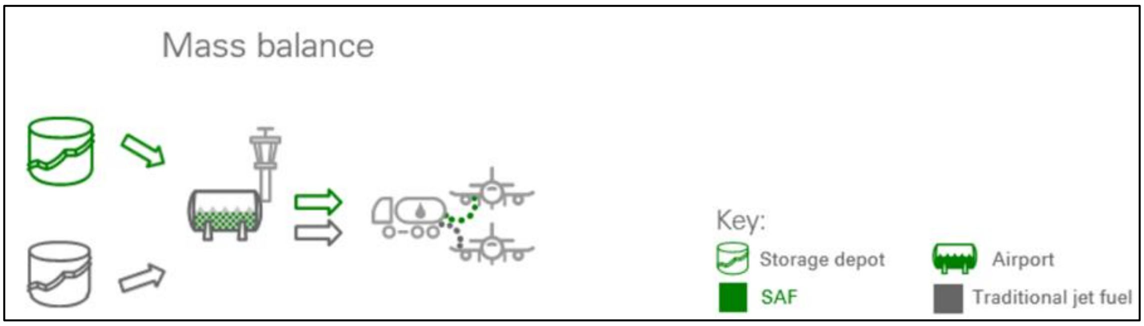

Figure 11 - Example of Mass balance SAF distribution mode ICAO Environment.

- **Book and Claim** (Figure 12): provides the possibility of purchasing SAF without the aircraft being physically supplied with SAF molecules. This solution allows to use existing infrastructure, enables reduction in logistics cost and carbon emissions. However, the legislation currently does not encompass the Book & Claim system, but there remains the possibility for its future adoption. ReFuelEU mandates that by July 1, 2024, the Commission shall assess potential enhancements or additional measures to the existing SAF flexibility mechanism. The objective is to further optimize the procurement and utilization of SAF in aviation during the flexibility period, integrating elements of a Book & Claim system.

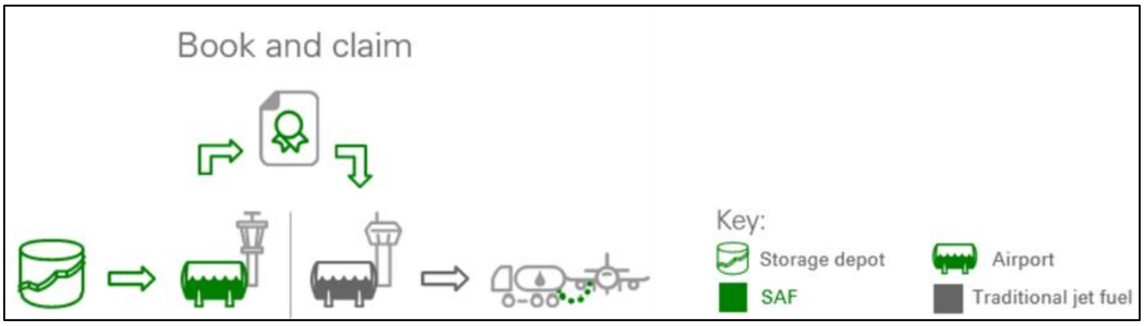

Figure 12 - Example of Book and Claim SAF distribution mode ICAO Environment.

1.2 Airport role in SAF value chain

To ensure one of the different supply chain modes described in the previous paragraph to develop the final use of SAF, airports play a vital role as they are the actor tasked with facilitating sustainable fuel supply for airlines that explicitly request it through their adequate fuel infrastructures.

The role of airports within the SAF value chain remains ambiguous, with uncertainties regarding key responsibilities among airports, infrastructure owners, fuel providers, and users. There are significant gaps in knowledge of SAF among airport staff, despite the growing importance of SAF in aviation sector. Currently, airports play a minor role in SAF deployment, but there is a consensus on the need to expand their involvement in the future. Innovative approaches can be explored to enhance airport support for SAF deployment, including raising regulators' awareness of economic development pathways and incentives to accelerate SAF development. Additionally, airports can assist in aggregating SAF demand from airlines, organizing awareness campaigns for passengers, and incorporating SAF into their greenhouse gas reporting. In fact, scope 3 Greenhouse Gas (GHG) emissions are becoming increasingly important in the reporting of an airport's total emissions, the implementation of SAF would contribute to a decrease in scope 3 emissions, the greater the quantity of SAF used. Consequently, SAF can be considered strategic from a sustainability perspective.

However, challenges persist, such as restrictions on airports' ability to use funds to bridge the SAF price premium. Efforts should be made to address these barriers and foster greater collaboration across the aviation industry to facilitate the widespread adoption of SAF. The different systems of distribution can play an important role in the supply chain, depending on the volumes of the fuel considered.

Considering the role of airports as catalysts in the use of SAF, several airports like Schiphol and Heathrow have already acted by establishing SAF Incentive Funds[11].

2 SAF Supply Chain in Lighthouse and Fellows Airports

The SAF supply chain used within the Lighthouse Airport (Copenhagen) and the fellows Airports is described in detail below, characterizing each phase present in Figure 3 indicated in the previous Chapter.
All airport supply chains described below refer to the as is situation.

2.1 Copenhagen Airport (CPH)

Copenhagen Airport (CPH Airport) is located 8 km from Copenhagen city center, in 2023 accommodated over 26 million passengers and consumed approximately 890,000 cubic meters of traditional JET A-1 fuel. The JET A-1 fuel is typically sourced from various regions including Europe, the Middle East, and the Far East and it is transported to an import terminal via oil tankers before being distributed to Copenhagen Airport.

CPH Airport has ambitious climate goals and wishes to be carbon neutral in 2050, so its goal is focused on becoming a green-powered airport through extensive use of renewable energy sources, transitioning to fossil-free ground transport infrastructure, and accelerating efforts towards achieving Net Zero Emissions in the aviation sector. This entails a comprehensive shift towards renewable energy, the adoption of greener ground transport options, and the implementation of innovative technologies to reduce greenhouse gas emissions associated with aviation activities. Through these initiatives, CPH airport aims to significantly reduce its carbon footprint and contribute to a more sustainable future for air travel.

CPH Airport currently manages SAF in a manner similar to traditional JET A-1 fuel in terms of supply chain logistics. This entails importing both traditional JET A-1 fuel and SAF from external manufacturers, without specific targets set for increasing SAF usage within the airport's operations. The following Table 2 provides a summary of the main information characterizing the CPH Airport.

Airport overview		SAF information		Transport and distribution at a glace	
Passengers [Mln/y]	26	SAF supplier	Neste Oil	Near port	7 km
Flights [x1000/y]	219	SAF pathway	HEFA	Near railway station	8.6 km
Fuel needs [MlnL/y]	890	SAF blend	<50%	HRS	Yes

Table 2 – CPH Airport data and profile.

Given the airport's significant fuel consumption and passenger traffic (as indicated in Table 2), there exists a notable opportunity to transition towards greater utilization of SAF which would significantly contribute to decreasing aviation carbon footprint[12].

Some aviation companies flying from CPH are already in a post-test phase regarding the use of SAF during their flight and have included it in their business model, as Air Greenland that use approximately 5% of SAF along the route to and from Copenhagen.

The following paragraphs contain a detailed description of the SAF supply chain for each phase, considering production and blending, transport and storage, and final distribution within the Copenhagen airport grounds.

Production & Blending

The following Figure 13 shows the SAF suppliers' routes to the CPH Airport.

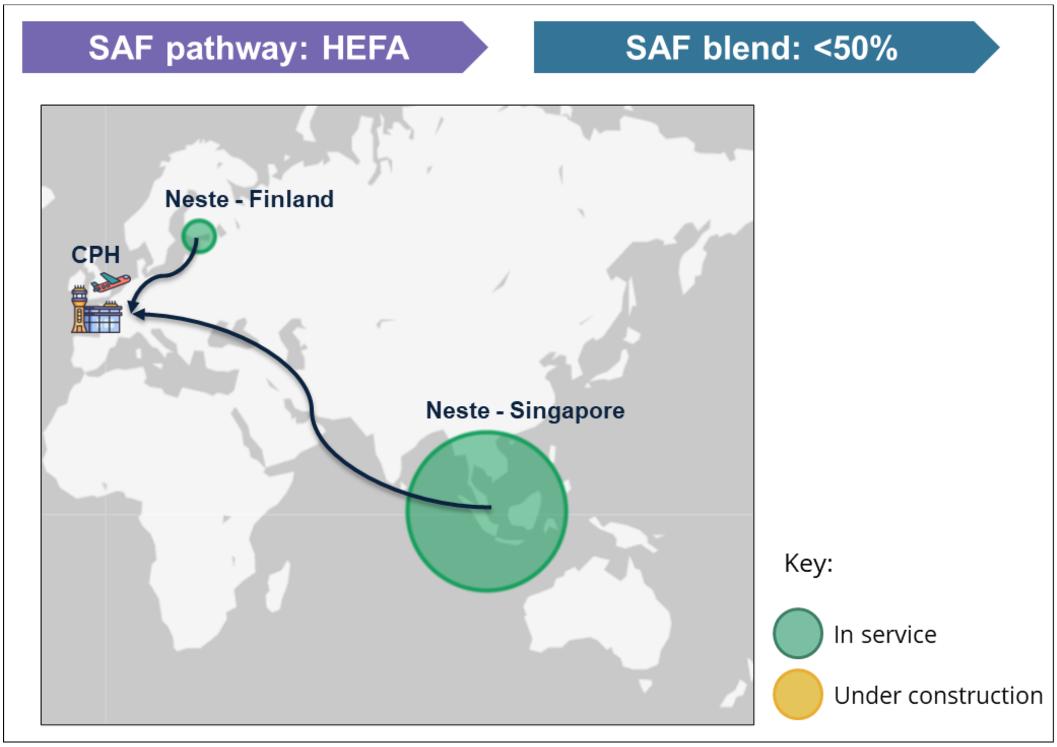

Figure 13 - CPH Airport SAF suppliers' routes.

SAF is imported from Asia (Singapore) and Finland by Neste Oil, the two facilities have a production capacity of 3.3 billion liters/year and 0.1 billion liters/year respectively.

The blending process is implemented by the manufacturer maximum 50% SAF. It is a natural SAF produced from used cooking oil and animal fast waste by HEFA process. At the time of writing, there is no collaboration with the local manufacturer but there is some project that will be implemented in the future. SAF is certified by the manufacturing company and is imported already mixed and certified.

Transport & Storage

The transportation system utilized for blended SAF is the same of the traditional fuel. Blended product is imported and comes by sea in small cargos, and it is stored in a storage terminal.

From the storage terminal it is delivered to the airport by a 7 km pipeline. Then, within the airport it is distributed by a hydrant system.

Before the storage, an external authorized society carry out some tests to assess that blended SAF quality complies with the ASTM regulations.

Blended SAF is stored in tanks typically owned and operated by fuel providing company like Oiltanking. In storage terminal blended SAF is stored in one dedicated tank, the others are dedicated for the storage of traditional fuel. The storage facility is in Prøvestenen, at 6.8 km from CPH Airport.

Distribution inside airport perimeter

Blended SAF is directed to the airport via pipeline. Here it is subjected to a filter process and a quality check. After this process, the blended SAF is commingled with other batches from pipeline and storage tank in the airport.

Within the airport it is distributed by a hydrant system and at the aircraft stands a fueling vehicle is bringing the pressurized fuel from this system up to the aircraft.

Currently Air Greenland is one of the main airlines using SAF at CPH, operating daily an A330-800 aircraft from CPH to SFJ with a theoretical 5% SAF blend.

Supply Chain Layout

Below a representative diagram of SAF's supply chain from production to final use in the airport.

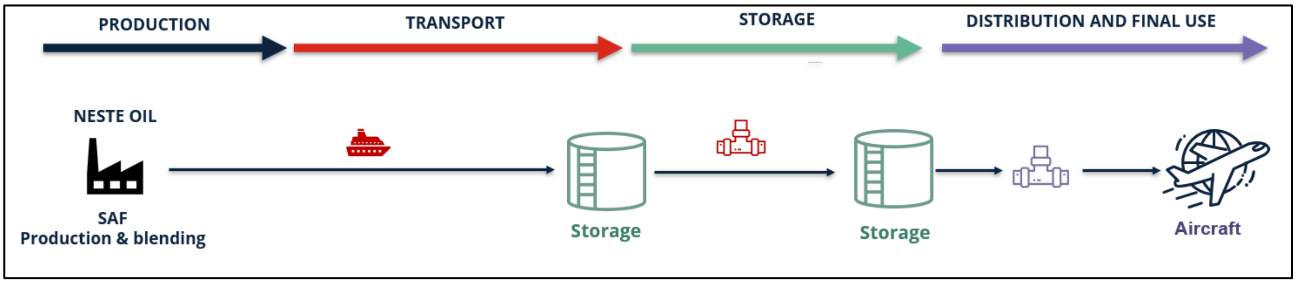

Figure 14 - CPH Airport Supply Chain Layout.

2.2 Rome Fiumicino Airport (FCO)

Rome Fiumicino "Leonardo da Vinci" Airport (FCO) is managed by Aeroporti di Roma (ADR), and it is located 30 km from Rome city center. It registered more than 40.5 million of passengers in 2023 with an average need of 4 million liters per day in off-season and 7 million liters per day in peak season of traditional JET A-1fuel, counting more than 105 companies operating.

In this scenario, assuming an average blending of 20% to comply with the 2% minimum limit in 2025, it will be necessary to guarantee a flow rate of blended SAF of around 400,000 liters per day for the low season period and 700,000 liters per day for the high season period.

The adoption of Sustainable Aviation Fuel (SAF) is a primary strategy to reduce carbon emissions and contribute to the airport's broader goal of achieving Net Zero Emissions by 2050, demonstrating its strong commitment to environmental sustainability. Additionally, the airport prioritizes the utilization of renewable energy sources and implements energy-saving measures to further enhance its environmental performance.

As evidence of the above, the airport attained Airport Carbon Accreditation level 4+ in 2021, highlighting its significant progress in carbon management and environmental stewardship.

Fiumicino airport currently obtains traditional JET A-1 fuel from different suppliers via storage sites in Civitavecchia and the port of Fiumicino, both connected with the storage site operated by SERAM near the airport site. Considering the fuel distribution infrastructure, FCO airport is one of the main airports using a Hydrant Refueling System (HRS) for the fuel distribution, which would allow the introduction of SAF without disrupting the infrastructure.

The following Table 3 provides a summary of the main information characterizing the FCO Airport while the following paragraphs provide a detailed description of the SAF supply chain for each phase, considering production and blending, transport and storage, and final distribution within the Rome Fiumicino airport grounds.

Airport overview		SAF information		Transport and distribution at a glace	
Passengers [Mln/y]	40.5	SAF supplier	Eni	Near port	4.8 km
Flights [x1000/y]	268	SAF pathway	HEFA	Near railway station	1 km
Fuel needs [MlnL/y]	1,820	SAF blend	20%	HRS	Yes

Table 3 – FCO Airport data and profile.

Production & Blending

To date, ENI SAF is available in the Italian supply chain, but tomorrow other producers could produce or process SAF.

The following Figure 15 shows the SAF suppliers' routes to the FCO Airport.

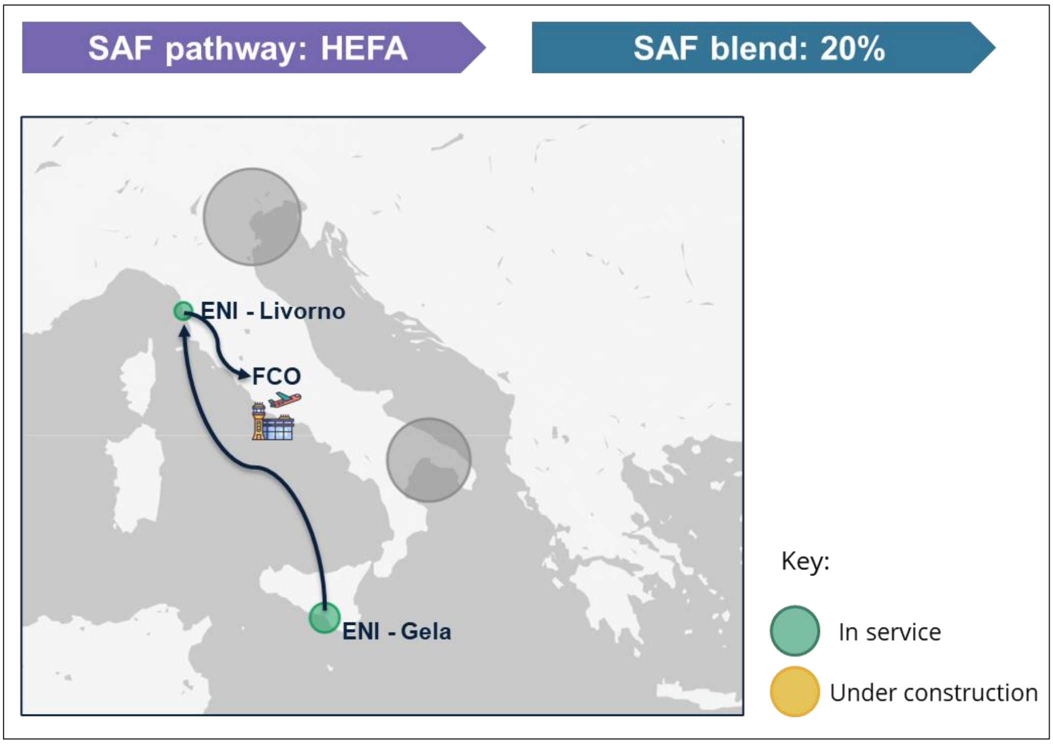

Figure 15 - FCO Airport SAF suppliers' routes.

SAF is produced at ENI's Gela plant, via the Hydro-processed Esters and Fatty Acids (HEFA) process. This factory is currently capable of producing 0.1 billion liters/year of SAF from 100% renewable raw materials[13]. After being produced, the so-called Eni Biojet SAF, entirely biogenic in nature, is blended and tested at the designated logistic site within the Eni Jet Fuel, resulting in blended SAF fuel with a hypothetical average blending percentage of 20%. Blending is carried out in dedicated tanks at the Eni refinery in Livorno through controlled mixing.

In addition to the two ENI sites in Gela and Livorno, ENI has two other plants in Italy located in Venice and Taranto which however do not supply the FCO Airport. The announced SAF production capacity of the four plants will be about of 1.5 billion liters/year, capable of satisfying the Italian market's potential obligation by 2025.

Transport & Storage

SAF is transported by sea in cargo ships to ENI's Livorno refinery, where is blended with traditional JET A-1 fuel in specific tanks, to verify the safety and quality standards.

Then, the blended SAF is transported by sea from Livorno to SODECO storage site in Civitavecchia, which will then supply via pipeline the storage near the airport operated by SERAM, where is mixed in the same tanks with traditional jet fuel.

Blended SAF is stored in SODECO's storage site of Civitavecchia, in the same tank of conventional jet fuel. The jet fuel containing blended SAF is directed to SERAM's storage site by a pipeline with a flow of 350 m^3/h.

Distribution inside airport perimeter

At the end, blended SAF from the storage site mixed with traditional fuel will be distributed through the HRS, currently used for the supply of Jet Fuel to airlines at Fiumicino airport.

The use of this distribution system allows for not modifying the existing infrastructure, making it ready for the reception and management of SAF.

Supply Chain Layout

Below a representative diagram of SAF's supply chain from production to final use in the airport.

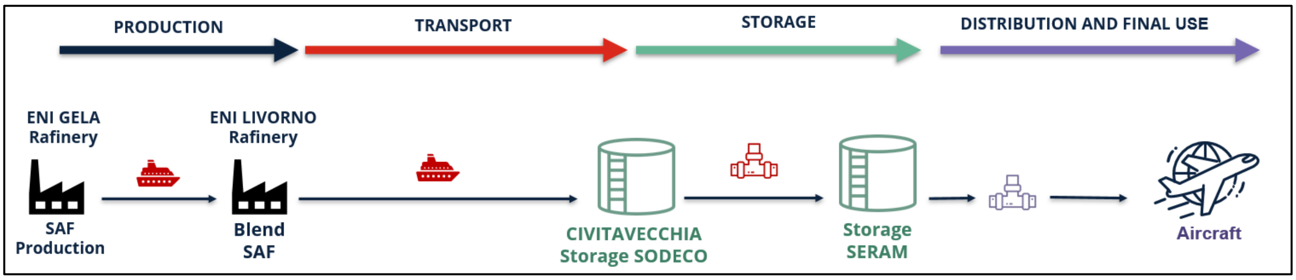

Figure 16 - FCO Airport Supply Chain Layout.

2.3 Vilnius International Airport (VNO)

Vilnius International Airport (VNO) is part of Lithuanian Airports (LTOU), and it is located 5.9 km from Vilnius being the largest of the three commercial airport in Lithuania with around 4.4 million of passengers in 2023 with an amount of traditional fuel used of 76,899 t in 2023.

The following Table 4 provides a summary of the main information characterizing the VNO Airport.

Airport overview		SAF information		Transport and distribution at a glace	
Passengers [Mln/y]	4.4	SAF supplier	Orlèn S.A.	Near port	310 km
Flights [x1000/y]	N/A	SAF pathway	HEFA	Near railway station	1.8 km
Fuel needs [MlnL/y]	94	SAF blend	N/A	HRS	No

Table 4 - VNO Airport data and profile.

Currently, traditional JET A-1 fuel is transported by rail, covering approximately 320 km from the oil refinery to the airport.

Among the airlines interested in using Sustainable Aviation Fuels (SAF) are Finnair, Ryanair (which plans to use only the mandatory quantity starting in 2025, if it is available), and

Lufthansa, but currently no airlines use blended SAF simply because it is not yet available at Vilnius Airport (VNO).

Considering compliance with ReFuelEU requirements, various scenarios can be developed to address this challenge. One scenario could involve the development of SAF storage and distribution infrastructure at Vilnius Airport, allowing airlines to meet regulatory requirements and adopt a more sustainable solution for their flights.

During the end of 2023, LTOU with ministry of transport and organization of civil aviation carried out some research about possible utilization of SAF. They have some contact with potential interested stakeholders as ground handlers or airlines companies. Although, them were interested just in gathering some information, especially regarding economic drivers, to develop their own business: Finnair, SAS and Lufthansa investigate to figure out which airport was good to use SAF.

LTOU has the target to increase the provision of SAF to reaching and try to go above the 2% year by the 2026.

The following paragraphs contain a detailed description of the SAF supply chain for each phase, considering production and blending, transport and storage, and final distribution within the Vilnius International airport grounds.

Production & Blending

The following Figure 17 shows the SAF suppliers' routes to the VNO Airport.

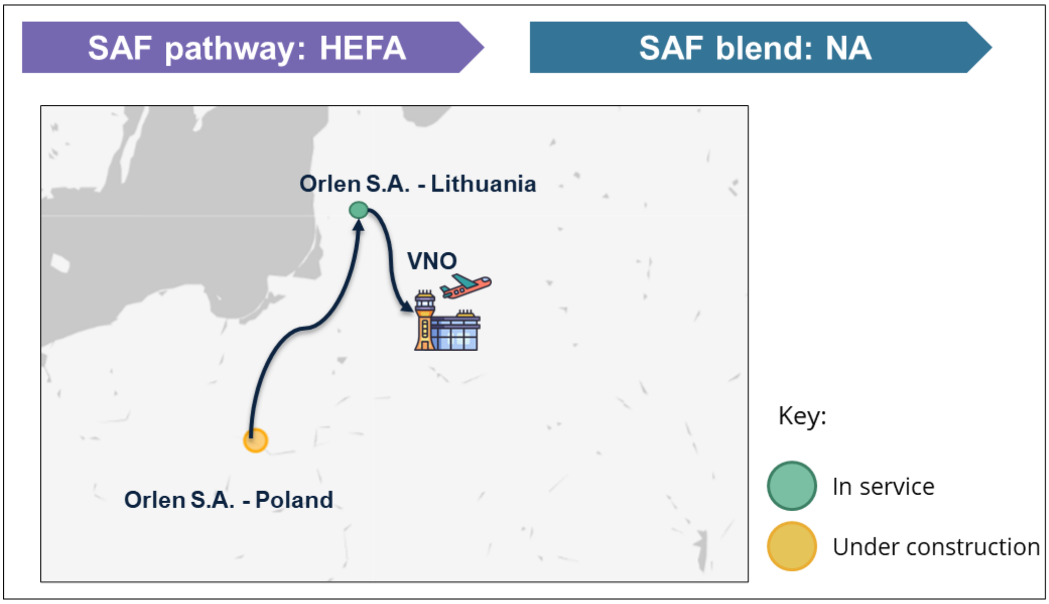

Figure 17 - VNO Airport SAF suppliers' route.

VNO is a small airport and can operates efficiently with a single fuel provider.

Orlen S.A. is the main SAF supplier for VNO and is planning on blending on site of the oil refinery in Lithuania. In 2025 they are planning on joint buying 100% SAF from some producers to all the group companies, transport it to Lithuanian refinery, and blend a SAF mix at any proportion. They can dedicate two tanks for SAF mix with different percentages, however, preferably only one type of blend should be produced, due to the need to clean the transportation containers and any other tanks, where SAF mix is contained.

Orlen S.A. is planning on providing the mixed JET A-1 fuel already in 2025 buying SAF from independent providers. Starting from 2026, however, the Orlen S.A. group is planning on running the SAF production in Plock by the Vistula River in central Poland, using HEFA technology. Once the line is started, SAF for Lithuanian refinery and Baltic market will be provided by Polish production. They might even provide a 4% to ensure the needed 2%/yearly, therefore they are planning to provide SAF mix of at least 2.5 %.

Orlen S.A. facilities in Poland announced a SAF capacity of 0.4 billion liters per year, and they have signed an agreement with LTOU on cooperation in implementing pro-environmental solutions helping to meet the requirements of the EU's Fit for 55 package.

Transport & Storage

Currently, traditional fuel is transported by rail from the refinery to the storage site. The same transportation system can be used for the supply of SAF.

The storage is owned by LTOU, but it is rented for long term (10 years) to company Baltjet, they will be able to dedicate one of the two 4,000 meters cubes currently present reservoirs for SAF. They are committed by the contract to make any changes to the infrastructure if it will be needed for SAF deployment.

Distribution inside airport perimeter

VNO airport has not a pipeline or hydrant system and necessitates the use of trucks for transporting SAF within the airport. This logistical arrangement ensures that the sustainable aviation fuel reaches its destination efficiently and safely, allowing for seamless operations despite the absence of more advanced infrastructure.

Supply Chain Layout

Below a representative diagram of SAF's supply chain from production to final use in the airport.

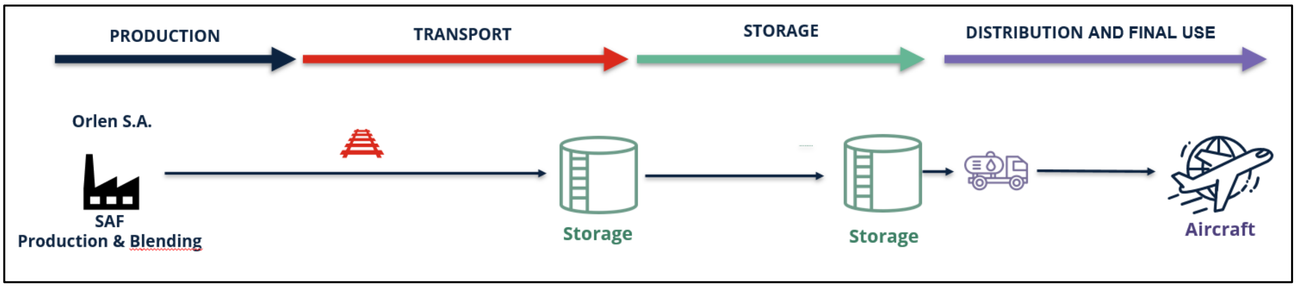

Figure 18 - VNO Airport Supply Chain Layout.

2.4 Warsaw Airport (CPK)

CPK airport will be operational from 2028 and will be situated approximately 40 kilometers southwest of Warsaw. By the year 2028, it is projected to consume around 2 million cubic meters of total fuel. During its initial operational phase, CPK airport is expected to serve nearly 30 million passengers annually under the baseline scenario. This trajectory is forecasted to increase, with passenger numbers reaching approximately 40 million by 2035 and 50 million by 2044. As the forecast extends towards 2060, CPK airport anticipates handling nearly 65 million passengers.

The following Table 5 provides a summary of the main information that will characterize the VNO Airport.

Airport overview		SAF information		Transport and distribution at a glace	
Passengers [Mln/y]	30	SAF supplier	Orlèn S.A.	Near port	No
Flights [x1000/y]	N/A	SAF pathway	HEFA	Near railway station	<3 km
Fuel needs [MlnL/y]	2,000	SAF blend	2%	HRS	Yes

Table 5 - CPK Airport data and profile.

In line with its commitment to sustainable development, CPK Airport has devised a comprehensive strategy covering a broad spectrum of areas. The airport has achieved readiness for net-zero CO_2 emissions since its inaugural year.

Furthermore, CPK Airport has formulated a robust fuel strategy encompassing hydrogen, Sustainable Aviation Fuel (SAF), and electric solutions. Presently, the airport's primary focus lies on exploring scenarios associated with hydrogen utilization.

It has also initiated surveys with airlines expressing interest in gathering information about SAF. This proactive approach underscores CPK's dedication to advancing environmentally friendly practices and embracing innovative fuel alternatives in aviation operations.

The following paragraphs contain a detailed description of the SAF supply chain for each phase, considering production and blending, transport and storage, and final distribution within the Warsaw airport grounds.

Production & Blending

The following Figure 19 shows the SAF suppliers' routes to the CPK Airport.

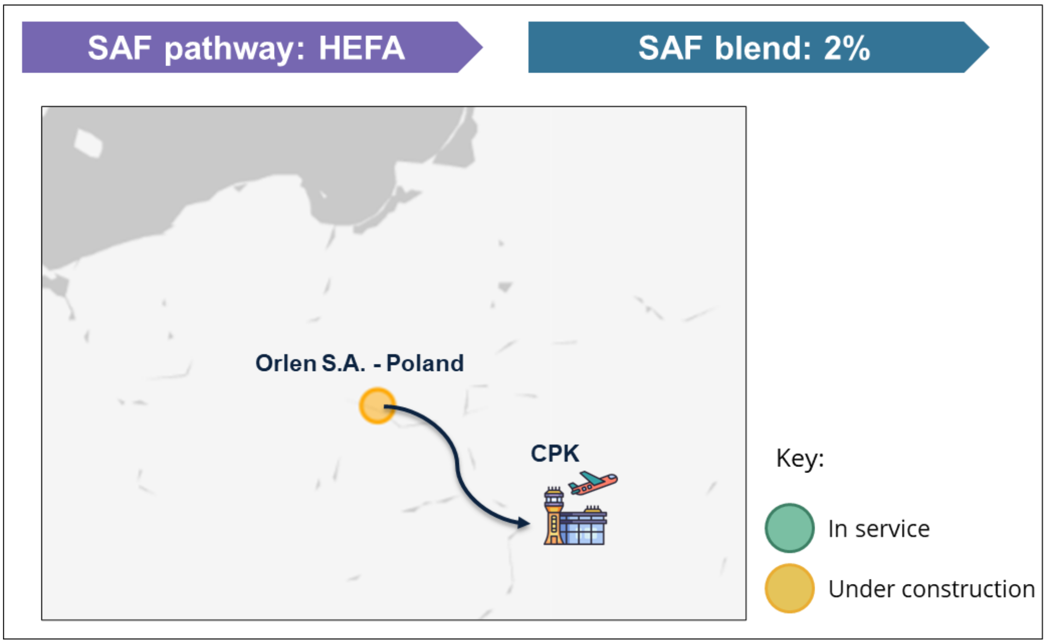

Figure 19 - CPK Airport SAF suppliers' route.

The main SAF supplier for CPK airport is Orlen S.A., they have a plant currently under construction in Plock by the Vistula River in central Poland, located around 80-100 km from the airport, and will provide SAF trough hydrotreated vegetables oils and cooking oils to airlines starting from 2025. This plant will produce around 0.4 billion liters per year of SAF from 2025.

Orlen S.A. will be to blend any percentage of mix, CPK Airport plans to request blended SAF with traditional JET A-1in the percentage of 2%, or in any case depending on the legislation and market conditions.

Transport & Storage

CPK Airport will be supplied with blended SAF fuel trough a dedicated railway and in the event on any disturbances in the railway delivery, alternative supplies will be able with road tankers, they will work to build a pipeline system to directly connect the refinery with the airport and obtain SAF already blended with a percentage in accordance with local regulation (i.e., 2% of blending).

The fuel farm will be dimensioned based on the number of fuel tanks required. Actually, in accordance with the Master Plan[14] it will be necessary to provide 5 aviation fuel tanks. They are planning to not storage blended SAF in a dedicated tank.

Distribution inside airport perimeter

The main assumption for the distribution of SAF is to maximize the use of aircraft refueling trough the HRS. Fueling will take place via a dispenser which will connect HRS with aircraft on aprons. Other aprons may be served using specialized airport tanker trucks.

Supply Chain Layout

Below a representative diagram of SAF's supply chain from production to final use in the airport.

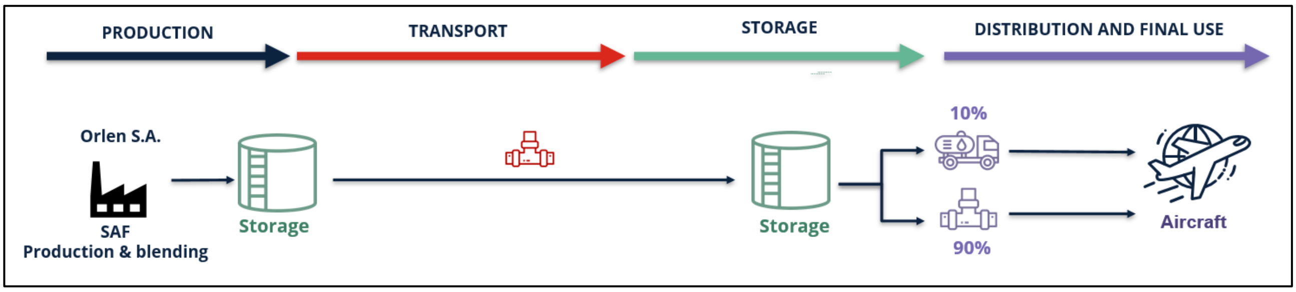

Figure 20 - CPK Airport Supply Chain Layout.

3 Examples of SAF experiences in other Airports

This section aims to share the experiences of some major airports located in Europe, United States and Asia in terms of infrastructure solutions adopted for delivering SAF that characterize their supply chain and ways to support the development and use of SAF itself at a local level. This can be an inspiration for other airports looking to introduce the use of SAF as they can adapt and replicate these experiences according to their own needs.

3.1 Amsterdam Schiphol Airport (AMS)

SAF is supplied to Amsterdam Airport Schiphol by Neste as of December 2020 following the acquisition of a minority stake in Aircraft Fuel Supply (AFS), the airport's fuel storage company. This sustainable fuel, produced from used cooking oil, is exclusively used by KLM Royal Dutch Airline (so called KLM) for flights departing from Schiphol. As the predominant airline at the airport, KLM offers customers enrolled in its Corporate and Cargo SAF program the opportunity to purchase drop-in fuel. Additionally, KLM supplements all flights departing from AMS with 0.5% SAF, funded by a surcharge on passenger airline tickets ranging from €1 to €12 based on journey distance and travel class[15]. KLM has secured purchase agreements with various SAF providers, demonstrating its commitment as the world's first airline to invest significantly in sustainable kerosene. As a further incentive mechanism for the deployment of SAF, Schipol Airport provides airlines refueling with SAF at it with subsidies of € 500 per metric tonne for biofuels and €1,000 per metric tonne for e-fuels. Furthermore, Schiphol has also facilitated Neste, their SAF supplier, in acquiring a share of AFS (airport fuel distributor as mentioned above), to ensure a steady SAF supply[16].

The SAF blend, fully certified to meet ASTM D 7566 specifications for aviation fuel, maintains the same quality and safety standards as conventional fuel. It seamlessly integrates into existing infrastructure at Amsterdam Airport Schiphol, including pipelines, storage facilities, and hydrant systems, with no modifications required.

The main parameters characterizing the airport are indicated in the following Table 6.

Airport overview		SAF information		Transport and distribution at a glace	
Passengers [Mln/y]	61.9	SAF supplier	Neste Oil	Near port	25 km
Flights [x1000/y]	442	SAF pathway	HEFA	Near railway station	25 km
Fuel needs [MlnL/y]	N/A	SAF blend	N/A	HRS	Yes

Table 6 - AMS Airport data and profile.

3.2 Brussels Zaventem Airport (BRU)

Since January 1st, the NATO pipeline that supplies Brussels Airport with kerosene has been open for the transport of Sustainable Aviation Fuel (SAF)[17], marking a significant milestone in eco-friendly aviation. The inaugural batch of SAF, ordered by Brussels Airlines, was commemorated with a symbolic first flight from Brussels to Malaga. Brussels Airport, the sole Belgian airport fully supplied with kerosene via the NATO pipeline network, had long sought the capability to receive SAF through this pipeline. Consequently, sustainable aviation fuels can be efficiently supplied via NATO's Central Europe Pipeline System (CEPS). The Neste SAF utilized by Brussels Airlines is derived from 100% renewable waste and residual raw materials, including used cooking oil and animal fat waste. For the pilot project, Brussels Airlines purchased 2,000 barrels of 1,000 liters each, containing a blend of 38% SAF, which equates to approximately 2 million liters or 2,000 m³. This volume enables the carrier to operate almost 400 flights from Brussels Airport to Barcelona with an A320 aircraft. The SAF was transported by Brussels Airlines from Neste's blending facilities in Ghent via the CEPS pipeline to the fuel storage facility at Brussels Airport, facilitating the airline's first SAF-operated flights on January 1st. SAF plays a crucial role in reducing the aviation industry's ecological footprint, aligning with European Commission goals to mandate 2% SAF usage by 2025 and 5% by 2030. Brussels Airport and its partners in the Stargate project aim to achieve 5% SAF usage by 2026. The availability of SAF through existing airport infrastructure and the NATO pipeline optimizes supply logistics. Efforts to promote the collection of raw materials for SAF production include a population survey and awareness campaign within the Stargate project. Furthermore, priority will be given to promoting the use of SAF at Brussels Airport, focusing on small-scale blending of biofuel with kerosene at high blending ratios to meet partner demands while minimizing the need for large-scale blending facilities stairs.

The main parameters characterizing the airport are indicated in the following Table 7.

Airport overview		SAF information		Transport and distribution at a glace	
Passengers [Mln/y]	22.2	SAF supplier	Neste Oil	Near port	No
Flights [x1000/y]	N/A	SAF pathway	HEFA	Near railway station	<3 km
Fuel needs [MlnL/y]	N/A	SAF blend	38%	HRS	Yes

Table 7 - BRU Airport data and profile.

3.3 London Heathrow Airport (LHR)

London Heathrow Airport has taken significant strides in integrating Sustainable Aviation Fuel (SAF) into its existing infrastructure and airline fleets. SAF has already been introduced at Heathrow, with the first SAF flight departing from the airport in June 2021. Currently, 60% of the airport's airlines, based on capacity, have committed to converting at least 10% of their fuel supply to SAF by 2030[18]. In 2022, Heathrow became the first airport globally to initiate a SAF Incentive Program, covering up to 50% of the additional cost of SAF to alleviate financial burdens on airlines. With an ambitious objective to triple the percentage of SAF usage at the airport to around 1.5% by 2023, Heathrow aims to become one of the world's leading airport users of

SAF. The SAF Incentive Program will undergo annual reviews, with any adjustments discussed with airlines through the standard consultation process on airport charges. New government policies planned in the UK, starting from 2025, are expected to further incentivize the production and utilization of SAF. Delivery of SAF to Heathrow is verified based on evidence of receipt at the airport or delivery into a pipeline connected to the airport, based on a mass balance approach.

The main parameters characterizing the airport are indicated in the following Table 8.

Airport overview		SAF information		Transport and distribution at a glace	
Passengers [Mln/y]	79.2	SAF supplier	N/A	Near port	No
Flights [x1000/y]	454	SAF pathway	N/A	Near railway station	<3 km
Fuel needs [MlnL/y]	N/A	SAF blend	N/A	HRS	Yes

Table 8 - LHR Airport data and profile.

3.4 San Francisco International Airport (SFO)

San Francisco International Airport (SFO) has consistently led the way in environmental stewardship, setting benchmarks not only within San Francisco but also among the nation's premier airports. As part of its five-year strategic plan, SFO aims to reduce greenhouse gas emissions and achieve carbon neutrality by 50%. In particular, the increasing use of SAF as aviation fuel will contribute to the achievement of these challenging goals. The main supplier of SAF to SFO is the World Energy (AltAir Fuels) refinery located in Paramount, California, which has additional facilities currently under construction near the airport itself. Notably, the production of SAF occurs at a separate site from the blending process, with transportation between these sites facilitated by tanker trucks or ships. Once blended, the SAF is transported to storage facilities via the Kinder Morgan Santa Fe Pacific Pipeline System (KM SFPP). Two potential sites for conventional fuel storage have currently been identified: the SFO Fuel Farm with a capacity of 45.5 million liters and the Shell facility with a capacity of 29.8 million liters. Transportation from these storage sites to the airport is via direct connections to the SFO fuel system.

SFO is currently leading globally in SAF uptake, receiving an estimated nearly 5 million blended gallons, particularly notable during the peak of the Covid pandemic. This uptake was facilitated by airlines such as Lufthansa, Alaska, Jet Blue, American, Amazon, and now DHL, Delta, and Signature, all committing to increased SAF utilization. These efforts are supported by two key producers, Neste and World Energy, with the latter operating in Southern California.[19]

The main parameters characterizing the airport are indicated in the following Table 9.

Airport overview		SAF information		Transport and distribution at a glace	
Passengers [Mln/y]	25.5	SAF supplier	World Energy	Near port	23 km
Flights [x1000/y]	377	SAF pathway	HEFA	Near railway station	3.5 km
Fuel needs [MlnL/y]	4,540	SAF blend	N/A	HRS	Yes

Table 9 - SFO Airport data and profile.

3.5 Seattle-Tacoma International Airport (SEA)

Seattle-Tacoma International Airport made history as the first airport operator in the United States to establish a clear timetable and objectives for transitioning all airlines at Seattle-Tacoma International Airport (SEA) to commercially competitive SAF. The primary objective is to ensure that every flight fueled at SEA incorporates at least a 10% blend of SAF by 2028. To achieve this, two potential SAF production methods from six suppliers were assessed, both involving the blending process and subsequent certification at the storage site. For smaller volumes in the initial phase, transportation from the production site to the storage site will be facilitated by tanker trucks, while traditional JET-A1 will be transported via the Olympic Pipeline. Storage operations will be managed by Sea-Tac Airport Fuel Farm, boasting a capacity of 19 million liters per year of SAF. Plans for constructing rail access and expanding site capacity are under economic evaluation to accommodate future growth. Conversely, for larger volumes in the long term, transportation from the production site to the storage site will utilize rail transport, with traditional JET A-1continuing to be transported via the Olympic Pipeline. Subsequently, transportation from the storage site to the airport will be facilitated by pipeline.

The main parameters characterizing the airport are indicated in the following Table 10.

Airport overview		SAF information		Transport and distribution at a glace	
Passengers [Mln/y]	58.8	SAF supplier	N/A	Near port	20 km
Flights [x1000/y]	417	SAF pathway	HEFA	Near railway station	<3 km
Fuel needs [MlnL/y]	2,271	SAF blend	10%	HRS	Yes

Table 10 - SEA Airport data and profile.

3.6 Singapore Changi Airport (SIN)

Singapore, a leading aviation hub in the Asia-Pacific region, designates Singapore Changi Airport as its primary reference point. Neste's refinery expansion in Singapore has effectively doubled its production capacity, now reaching 2.6 million tons annually, with the potential to produce up to one million tons of sustainable aviation fuel (SAF). SAF production occurs at Neste's refinery in the Tuas area of Singapore, where it is blended with conventional fossil jet fuel and certified to meet jet fuel specifications at the blending terminal in Singapore. Subsequently, the blended fuel is delivered to customers at Changi Airport. The refinery expansion includes enhanced raw material pre-treatment capacity on-site, enabling the facility to process more challenging waste and residue raw materials efficiently. Additionally, Neste has entered into an agreement to acquire a stake and become a minority shareholder in Changi Airport Fuel Hydrant Installation Company Pte Ltd (CAFHI), which oversees fuel storage and infrastructure at the airport.

The main parameters characterizing the airport are indicated in the following Table 11.

Airport overview		SAF information		Transport and distribution at a glace	
Passengers [Mln/y]	58.9	SAF supplier	Neste Oil	Near port	32 km
Flights [x1000/y]	328	SAF pathway	HEFA	Near railway station	<3 km
Fuel needs [MlnL/y]	N/A	SAF blend	N/A	HRS	Yes

Table 11 - SIN Airport data and profile.

3.7 Main considerations

In light of what emerged from the supply chain valuation of the fellow's airports and the examples provided, it is evident that the distinction between large and small airports, in addition to being based on the number of passengers and air traffic, is determined by the volumes of processed fuel and transport ways (Figure 21), which are also closely linked to their geographical location.

Figure 21 - Modes of transport for large and small volumes of fuel.

Considering this differentiation, it is conceivable to postulate that during an initial phase characterized by low SAF volumes, the infrastructure of small airports, predicated on truck transportation, may already be conducive to SAF integration. As SAF volumes processed escalate, influenced by prevailing regulations, larger airports furnished with pipeline infrastructure and HRS distribution systems are anticipated to experience greater facilitation.

4 Scalability and replicability of the identified solutions

This Chapter is aimed at identifying key drivers that can express guidelines in terms of scalability of the solutions derived from SAF's airport supply chain analyses described previously depending on whether both large and small airports are considered. In fact, both airport typologies may have a significant increase in the production capacity of SAF as this is the result of the progress inherent in the use of the SAF itself. In this regard, worldwide SAF production is expected to reach 1,875 billion liters in 2024, which is a threefold increase compared to the 600 million liters generated in 2023[20].

Regarding their infrastructure, for large airports one of the main drivers in evaluating scalability are the method by which SAF is stored in the fuel farm and the solutions adopted for final distribution. In this type of airport, from an infrastructural point of view, the main advantage in the introduction of the SAF is obtained when the blended SAF is mixed with traditional JET A-1, as no modifications to the supply chain compared to the current situation are necessary. In the initial phase, it may be easier to supply SAF to large airports with suitable infrastructure for its introduction, particularly via pipeline, which is the most efficient method for transporting high volumes of SAF.

Regarding the distribution system for final use these types of airports are typically equipped with a Hydrant Refueling System (HRS) for aircraft refuelling. An optimal solution for large airports with this system and able to handle high volumes of SAF could be the adoption of Mass Balance solution for the final distribution (Figure 22). Mass Balance allows attributing the environmental benefits of SAF to the entire volume of fuel produced and is efficient when the airport's goal is to procure SAF without allocating specific quotas of SAF for a particular airline.

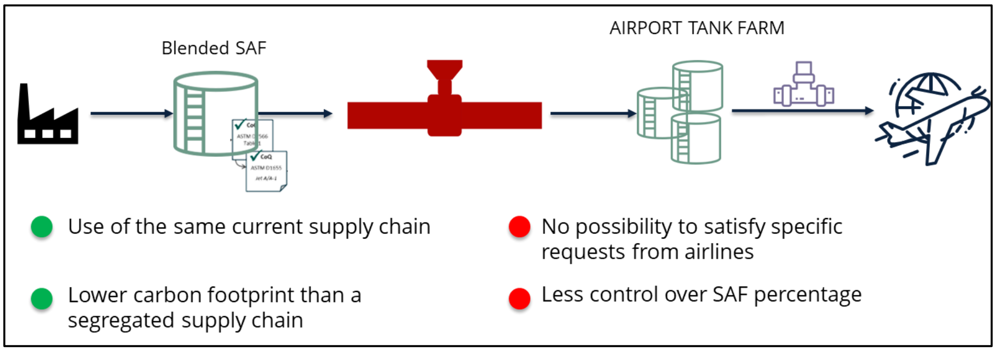

Figure 22 - Mass balance solution for large airports.

However, the scenario shifts if there are particular requests from airlines, i.e. in the event that a certain company requests SAF at a specific percentage physically transported, without the use of the Book and Claim method (see Figure 23). This necessitates a dedicated tank for SAF, potentially leading to infrastructure modifications. Moreover, dedicated SAF storage and refuelling via truck become necessary, although this solution is more suitable for small airports.

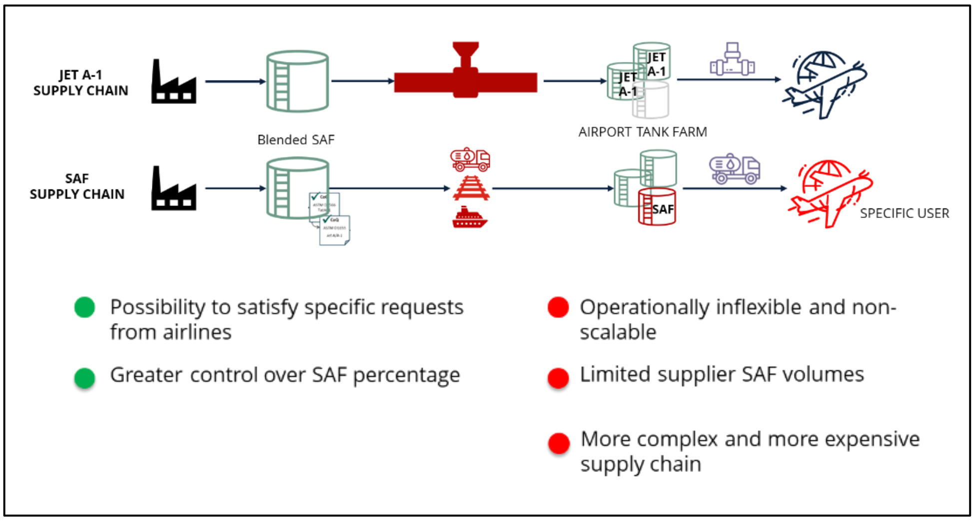

Figure 23 - Segregation solution for large airports.

As reported, the case of Copenhagen serves as an example for large airports that need to integrate SAF.

On the other hand, in reference to their infrastructure, small airports are typically characterized by a supply chain focused on handling small volumes of fuel, with trucks being the primary mode of transportation and distribution. For this kind of airports, segregation solution is simpler, which consist of segregating SAF in a dedicated tank within the fuel farm and subsequently distribute it via refuelling trucks (Figure 24). This approach ensures efficient delivery and integration of SAF within the existing operations of the airport.

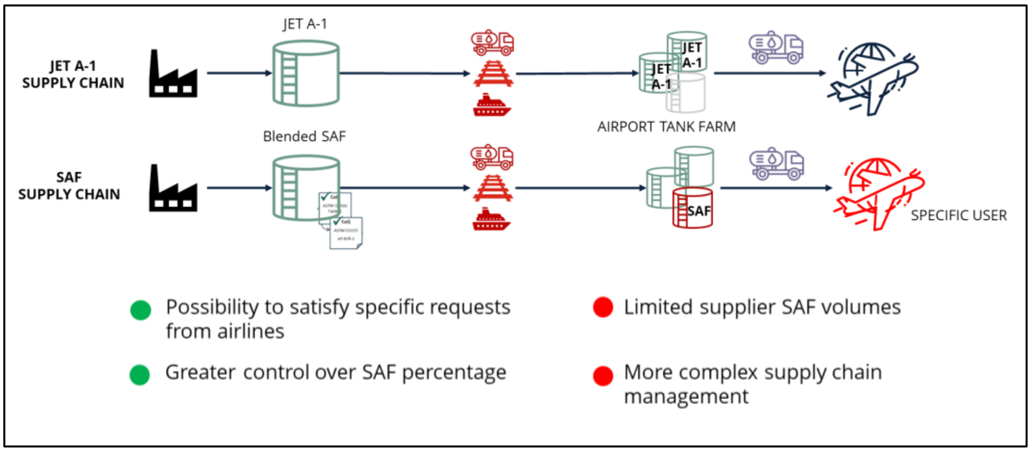

Figure 24 - Segregation solution for small airports.

Another solution for small airports may be to store the blended SAF arriving at the airport in conventional JET A-1 tanks, mixing it to distribute it whit a Mass Balance mode trough refuelling trucks (Figure 25). This solution previously indicated for large airport can also be convenient for small airport from an infrastructural point of view since no relevant modifications are necessary.

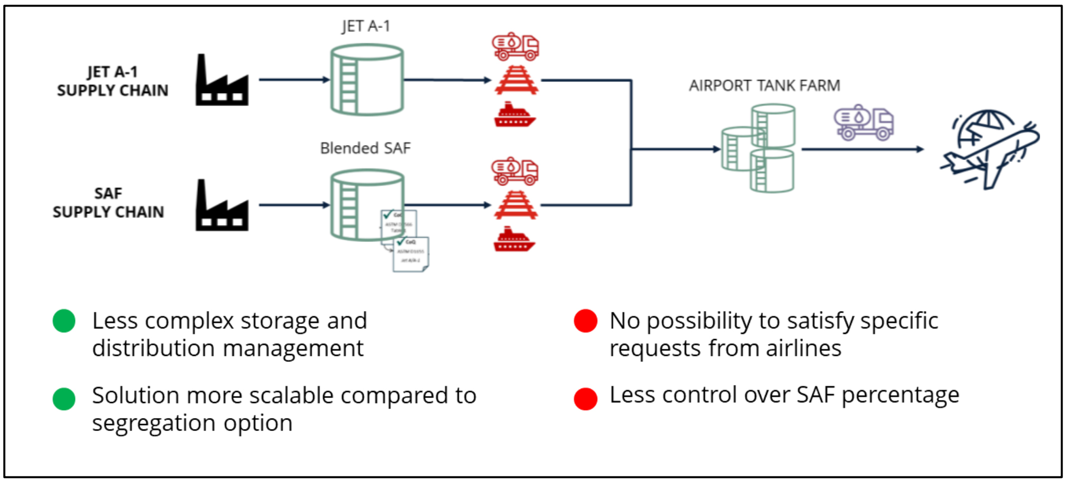

Figure 25 - Massa balance solution for small airports.

In cases where it is no possible to physically supply the small airport with SAF, Book and Claim emerges as an alternative for airlines seeking a quota of SAF. This method allows airlines to claim and utilize environmental credits associated with SAF, even if physically supplying SAF to the airport is challenging. As reported, the case of Vilnius serves as an illustrative example for small airports seeking to integrate SAF into their operations, highlighting potential strategies and approaches for effectively incorporate SAF despite logistical constraints.

Exploring how airports are adapting to manage the increasing volumes of SAF provides valuable insights into the industry's current status and emerging best practices. Additionally, a further fundamental aspect is to analyse the geographical distribution of SAF producers in Europe and worldwide as it has a direct impact on the accessibility and distribution of sustainable fuel in various regional markets. Understanding these factors is essential to develop effective strategies and facilitate the transition towards a more sustainable aviation sector. Geographical location plays a pivotal role, especially concerning global emissions. From this perspective, establishing a SAF supply chain that integrates emissions considerations throughout the process involves selecting SAF suppliers and producers located as close as possible to the airport.

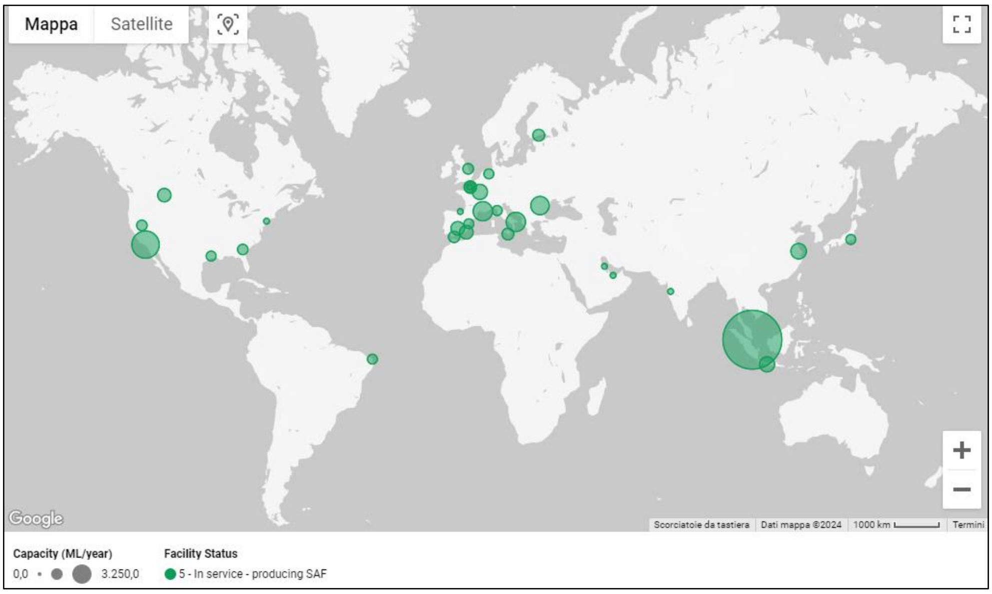

Figure 26 – Active SAF producers in the world[21] - Green facilities can also be sites where the blending process takes place.

Focusing on Europe (as shown in Figure 27), it is possible to appreciate that there are a very limited number of refineries currently marketing SAF (17 facilities) with an announced capacity of 3.3 billion liters/year. The non-capillary geographic location is certainly a bottleneck that will need to be resolved soon.

Figure 27 - Active SAF producers in Europe - Green facilities can also be sites where the blending process takes place.

Therefore, analysing future developments related to the opening of new refineries or the expansion of existing ones (Figure 28), it is possible to note that there will be a rapid development in the production of SAF both in Europe and in the rest of the world.

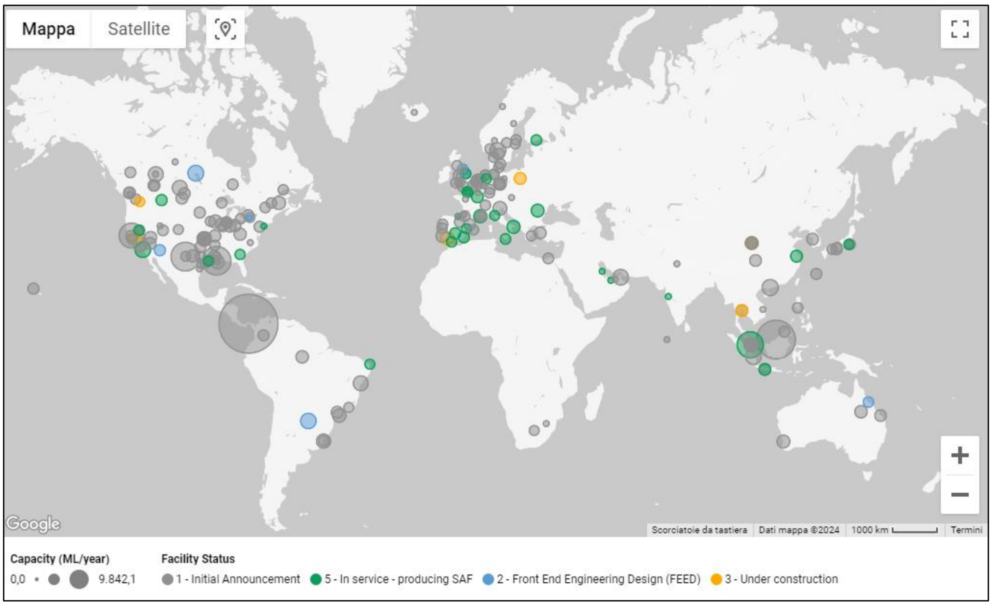

Figure 28 – All SAF facilities in the world: active producers and new ones under construction, designed or announced - the facilities reported may also be sites where the blending process takes place.

The future production capacity declared[IV] for the soon-to-open refineries will be equal to about 76.6 billion litres/year[V], with an increase of 880% compared to current values, for a total production capacity of 85.3 billion liters/year (as indicated in the Table 12).

	Current situation (2024)	Next future (by 2030)	Absolute variation	Percentage change
Number of facilities	31	266	+235	+760%
Announced capacity (billion liters/year)	8.7	85.3	+76.6	+880%

Table 12 – Comparison between current numbers of facilities and announced capacity and futures ones in the world.

In particular, the United States are going to be leaders in SAF production, with 79 future facilities and 32% of total production, the first European country in terms of volumes will be Sweden with 9 facilities and 3.7% of total SAF production, followed by the Netherlands with 11 facilities and 3% of total production. This could be an important point because Central Europe is served

[IV] Information is based on publicly-available announcements and there is no certainty of the effective implementation of the facilities announced as future openings.
[V] Since it is difficult to obtain detailed information on future production of SAF or Lower Carbon Aviation Fuels (LCAF), the numbers reported as future capacity include both production items. LCAF is a fossil-based aviation fuel that features a smaller carbon footprint than conventional kerosene and meets the CORSIA Sustainability Criteria (at least 10% less CO_2 emissions than traditional fuel).

by the Central Europe Pipeline System (CEPS)[VI], and it would be interesting to explore the use of this transport system to supply Central European airports with SAF.

Focusing again on Europe (see Figure 29 and Table 13[VII]), in the next few years we will have 95 facilities able to produce SAF with an announced capacity of 15.1 billion liters/year.

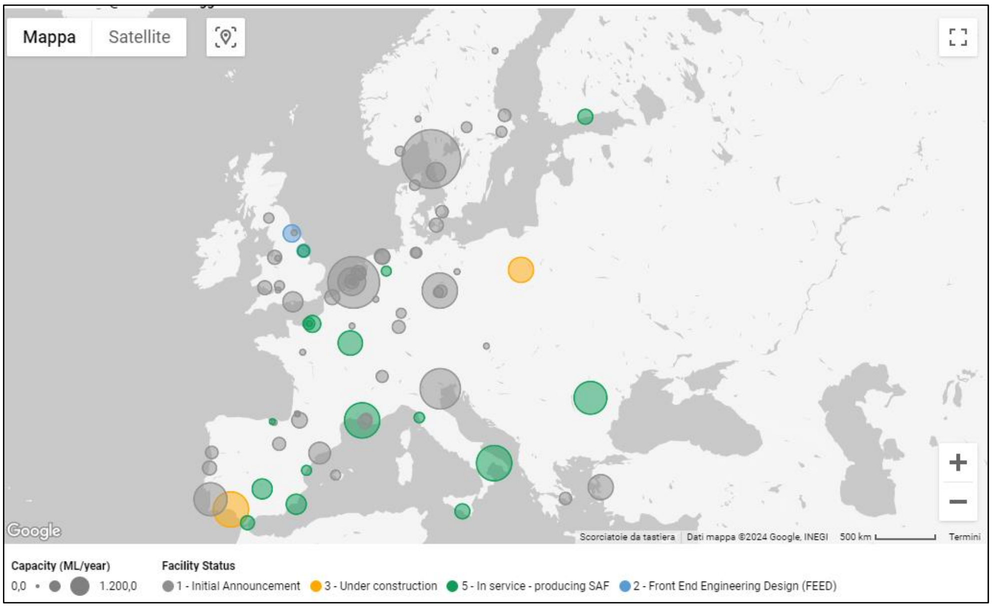

Figure 29 – All SAF facilities in Europe: active producers and new ones under construction, designed or announced - the facilities reported may also be sites where the blending process takes place.

The main countries will be Sweden and the Netherlands with 3.13 and 2.64 billion liters/years of projected capacity both. In the third place will be France with 1.74 billion liters/years of projected capacity, followed by Spain (1.59) and Italy (1.51).

	Current situation (2024)	Next future (by 2030)	Absolute variation	Percentage change
Number of facilities	17	95	+78	+460%
Announced capacity (billion liters/year)	3.3	15.1	+11.8	+360%

Table 13 – Comparison between current numbers of facilities and announced capacity and futures ones in Europe.

[VI] The Central Europe Pipeline System (CEPS) is the largest petroleum pipeline system in NATO and crosses the host nations of Belgium, France, Germany, Luxemburg and the Netherlands, it delivers jet fuel to major civil airports such as Brussels, Frankfurt, Luxembourg, Schiphol and Zurich.

[VII] Since it is difficult to obtain detailed information on future production of SAF or Lower Carbon Aviation Fuels (LCAF), the numbers reported as future capacity include both production items. LCAF is a fossil-based aviation fuel that features a smaller carbon footprint than conventional kerosene and meets the CORSIA Sustainability Criteria (at least 10% less CO_2 emissions than traditional fuel).

Regarding the countries where the airports covered by this study are located, there will be a refinery that will produce SAF also in Poland and Denmark, while no SAF refinery is yet planned in Lithuania. The development of new infrastructure capable of providing SAF is moving in the right direction, although progress still needs to be made to ensure simple and sustainable provision for a greater number of airports.

In addition to the issues discussed so far and which influence the supply chain of SAF for airports, it must be kept in mind that at the present an important constraint for the massive implementation of SAF is related to its cost.

Now, in fact, the neat SAF costs from 2 to 3 times the traditional JET A-1 and has higher volatility (see Figure 30).

Therefore, to better understand the real cost of the SAF, it would be appropriate to compare it with the cost of the JET A-1 to which the environmental costs in terms of CO_2 emissions should be added. Considering the CO_2 emission cost related to the current EU-ETS[VIII] scheme, it is possible to consider an environmental cost of about 161 €/tjet A-1[IX] to be added to the cost of the fuel market. It is an extra cost of more than 25% compared to the market price which should be added to the current jet A-1 cost.

Figure 30 – Neat SAF cost compared to Jet A-1 cost. Credit: Reuters graphics[22].

[VIII] The EU Emissions Trading System (ETS) is a cornerstone of the EU's policy to combat climate change and its key tool for reducing greenhouse gas emissions cost-effectively. It is the world's first major carbon market and remains the biggest one. The EU ETS works on the 'cap and trade' principle. A cap is a limit set on the total amount of greenhouse gases that can be emitted by the installations and aircraft operators covered by the system. The cap is reduced annually in line with the EU's climate target, ensuring that emissions decrease overtime. The cap is expressed in emission allowances, where one allowance gives the right to emit one tonne of CO_2eq (carbon dioxide equivalent).

[IX] The calculation was performed considering an emission factor for the A-1 jet of 3.15 tCO_2/t, an environmental cost of €64/tCO_2 (EU-ETS EUA market on data 9th of April 2024) and an 80% emission reduction for the use of SAF.

The cost of producing and marketing SAF is influenced, among other things, by the availability of the raw material and the distance between the place of production and supply, in addition to the fact that new plants must be depreciated. Consequently, a reduction in SAF costs can be expected in the future and further investigation into SAF cost scenarios themselves would be interesting.

5 Conclusions

In conclusion, this document provides a comprehensive overview of the various solutions that both large and small airports[X] can adopt to integrate SAF into their supply chains. It emphasizes the importance of tailoring strategies to suit the unique needs and capabilities of each airport, considering factors such as existing infrastructure, fuel volume requirements, and geographic location.

The analysis underscores the increasingly pivotal role of airports within the supply chain, serving as key facilitators in the distribution of SAF. This necessitates the provision of efficient fuel infrastructure and continual improvements to ensure the effective management of sustainable fuel resources.

Large airports, with their capacity to handle significant fuel volumes, have an advantage in SAF integration, particularly if equipped with a Hydrant Refueling System (HRS) and pipeline connections to producers or external depots. This enables them to seamlessly blend SAF with traditional JET fuel using the mass balance distribution model, facilitating a smooth transition to sustainable aviation practices without extensive infrastructure modifications.

Conversely, small airports, reliant on truck-based fuel supply infrastructure, may find optimal solutions in segregating SAF within their existing tank farms. While this approach may require modifications to the supply chain to accommodate dedicated SAF tanks, it represents a viable pathway towards SAF integration for smaller facilities. For small airports as well, it is possible to employ the mass balance approach for SAF distribution, but since fuel transportation mainly occurs via trucks, segregating blended SAF is more facilitated upstream in the supply chain for these airports. An open solution that remains to be validated depending on current regulations is the Book and Claim system, which would allow airlines to request SAF certification even if it is not physically present at the airport.

Thus, the infrastructure of small airports may be more suitable if the demand for SAF is low, as truck transport allows for optimal management of small volumes and facilitates SAF segregation with less complexity. On the other hand, if the demand for SAF were to become high, larger airports would have better infrastructure to facilitate the introduction of SAF on a larger scale, because the use of pipelines and HRS distribution systems allows for the processing of much higher volumes of SAF.

Furthermore, addressing geographical disparities in SAF production through the expansion of producer networks globally and in Europe is crucial. By increasing the number of producers, the aviation industry can mitigate logistical challenges associated with transportation and reduce emissions resulting from long-distance transport. Additionally, a thorough examination of SAF costs relative to conventional JET A-1 fuel is essential. Presently, limited producer numbers

[X] The distinction between large and small airports in defining SAF infrastructure is closely linked to the methods by which SAF is transported and distributed and especially the volumes involved.

contribute to relatively high SAF prices. However, anticipated rises in demand driven by mandatory SAF requirements, such as those outlined in initiatives like ReFuel Aviation, may drive economies of scale and potentially lower SAF costs over time. Detailed cost analyses will be pivotal in assessing the economic feasibility and competitiveness of SAF adoption within the aviation sector.

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