JULY 2020

BIOFUELS: A MEDIUM-TERM SOLUTION FOR A LOW-CARBON AVIATION

The aviation sector could cut 40% of its CO2 emissions in France by incorporating 50% of biofuels from 2030, first step towards the new ambition of a zero carbon aircraft by 2035

Executive Summary

Global warming, mainly caused by greenhouse gas (GHG) emissions, is endangering the planet's ecosystems. CO_2 emissions, mainly due to human activity, represent most of the GHG into the atmosphere. With a quarter of global CO_2 emissions, the **transportation sector is the 2nd most emitting**, just after the power and heat production sector. As opposed to the road transport sector, **aviation has only been submitted to few measures aiming at reducing its environmental impact, making it a strategic component for the low-carbon transition.**

Integrating biofuels into aviation fuel is one of the solutions considered to reduce the sector's carbon footprint. Since the first experimental flight took place in 2008, the aviation biofuels sector has developed slowly over the successive certifications of production processes**.** Like road biofuels, aviation biofuels are classified into 3 generations associated with different input profiles. The **more advanced generations (2G - 3G) allow greater carbon savings** and overcome the need to use arable land (1G). However, in the absence of financial support mechanisms, **aviation biofuels remain 2 to 5.5 times more expensive than fossil kerosene**, significantly slowing down their development.

Aviation biofuels are still very marginally used (0.09% worldwide) but, for a few years, the **production volumes have increased** thanks to **supply agreements** between producers and airlines wishing to improve their environmental impact and their public image. Initiatives launched by **States, airports and airlines** spur biofuels use, which can rely on the **supply chain already in place** for fossil kerosene, necessiting only some adaptations.

The **French roadmap** for the deployment of aviation biofuels, unveiled at the beginning of the year, planned their gradual incorporation in until reaching 50% of aviation fuel in 2050. Sia Partners recommendeds **an ambitious but realistic scenario:** incorporating **50% of biofuels from 2030,** thus allowing a **40% reduction in the sector's CO_2 emissions in France, for an average additional cost per ticket estimated at 5€** according to our assumptions*. The scenario proposed by Sia Partners is consistent with the Government's new announcements from the post-COVID-19 recovery plan, aiming in particular to develop a zero carbon aircraft in 2035. In the meantime, **the development of aviation biofuels stands out as an adequate transition solution**, with the acceleration of massive incorporation sooner than the objectives initially set. In this perspective, post-COVID-19 recovery should represent an **opportunity** for the sector, driven by the Government, to rebuild itself in a more sustainable, resilient and respectful way.

** The hypotheses of the case study are detailed in the 3 ᵉ part of the study.*

Content

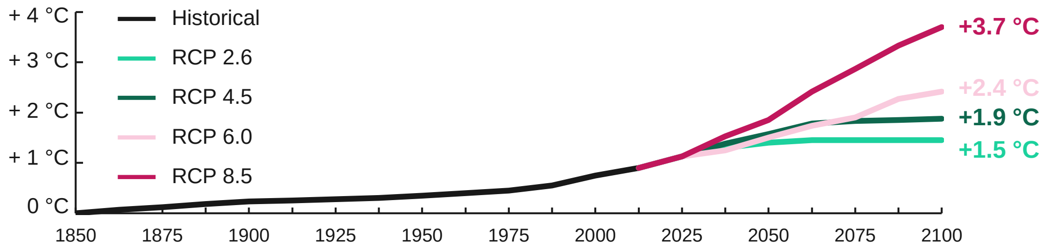
1

The necessity to reduce the aviation sector’s carbon footprint

The necessity to reduce the aviation sector's carbon footprint

Greenhouse Gases (GHGs) produced by human activity continue to disrupt the climate

The IPCC defined climate scenarios (RCP) based on the concentration of GHGs in the atmosphere



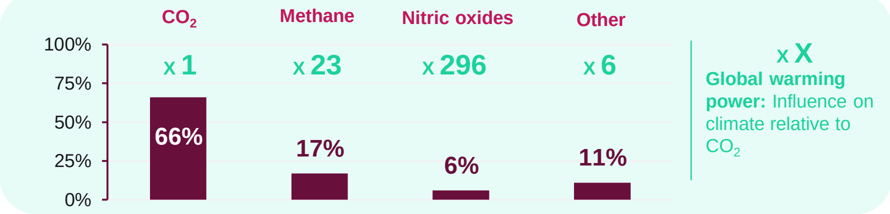
The **RCP scenarios** (*Representative Concentration Pathway*) are defined by 3 main factors related to **GHG concentration in the atmosphere**:

	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
World population growth	-	+	++	+++
Energy intensity	-	+	++	+++
Technological evolution	Breakthrough	Strong	Average	Low

Above a 2 °C increase, impacts are numerous and irreversible

- Risk of economic recession
- Risk of massive population displacements
- Risk of submersion coastal areas
- Increased risk of severe weather
- Risk of famine
- Risk of water shortage

CO_2, although not being the most impacting GHG on global warming*, accounts alone for 2/3 of the GHGs present in the atmosphere



** At a given concentration*

To limit the temperature rise to 2 °C (RCP 2.6 or 4.5), the Paris Agreement, signed in 2015, plans the following actions

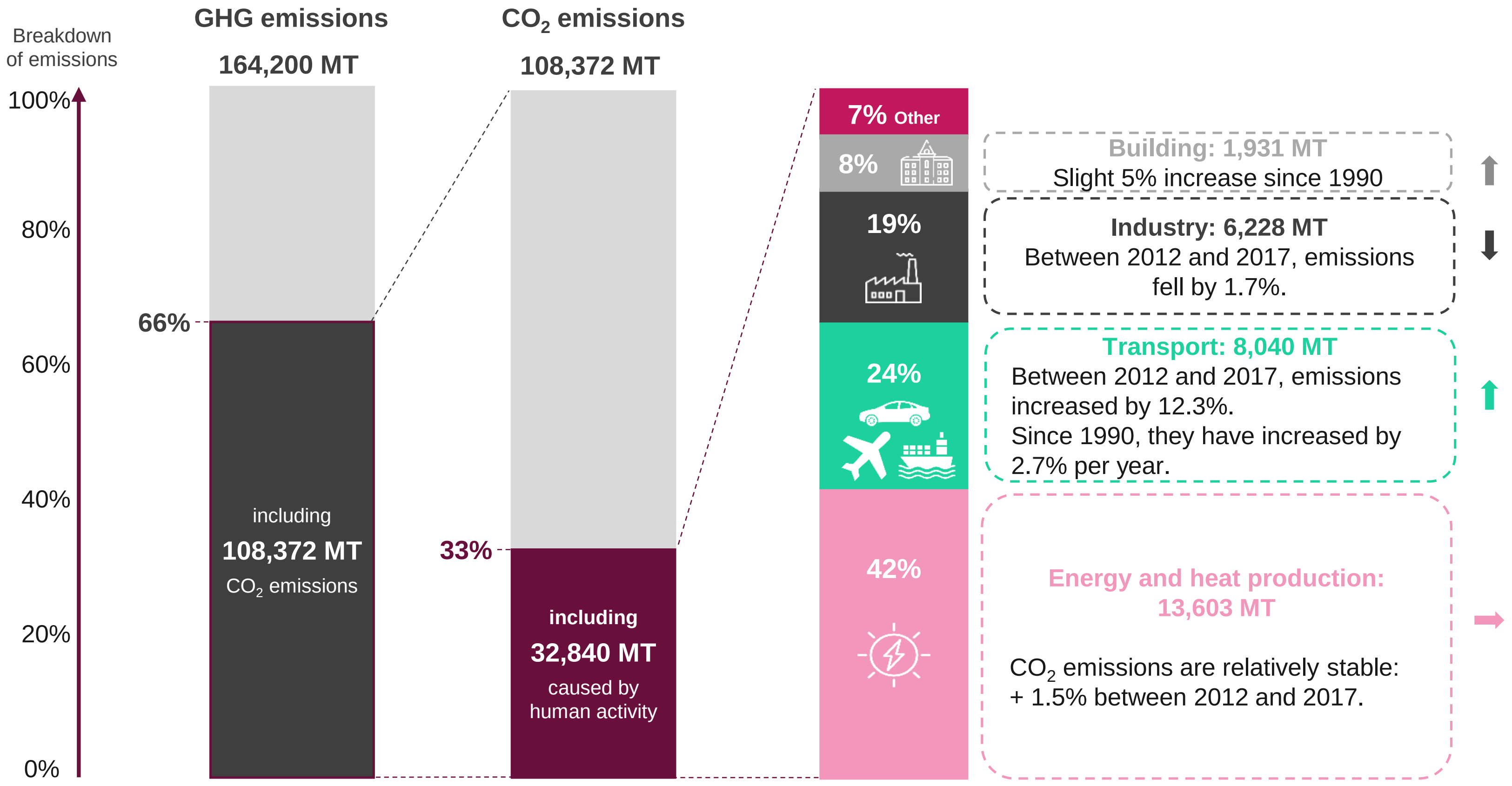
- Mobilization of $100 billion per year by developed countries
- National commitments to limit the warming to 2 °C
- Upward revision of targets every 5 years

The fight against global warming, which is necessary for the preservation of the planet's ecosystems, has driven countries to commit to limiting greenhouse gas emissions through international and regional agreements, and to include them in their national objectives.

Source: Sia Partners analysis from David's Newth and Don Gunasekara data (2019)

The necessity to reduce the aviation sector’s carbon footprint

Big consumer of fossil fuels, transport now accounts for ¼ of CO_2 emissions



World Energy Outlook 2019, IEA (2017 data)

Key figures

45% of GHG emissions are linked to human activities.

1/3 of CO_2 emissions are directly generated by human activities.

1/5 of the greenhouse gas effect is caused by CO_2 emissions related to human activities.

93% of CO_2 emissions are generated by 4 business sectors.

1/4 of global CO_2 emissions are emitted by transport.

The transport sector is decisive in the fight against global warming: it is the 2nd most CO_2 emitting sector and has shown the strongest growth since 2012. National and regional regulatory frameworks are emerging in order to reduce the sector's carbon footprint, mainly for road and maritime transport.

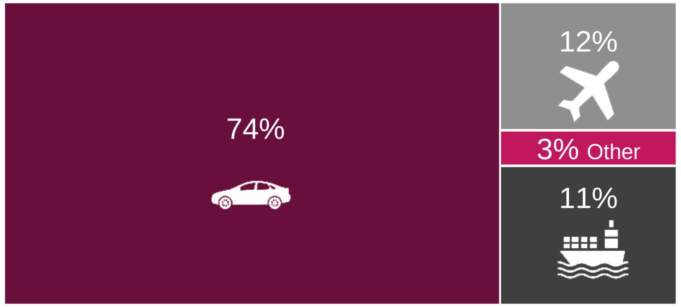
Sources: Sia Partners analysis from the International Energy Agency (IEA) and BP Statistical Review data

The necessity to reduce the aviation sector's carbon footprint

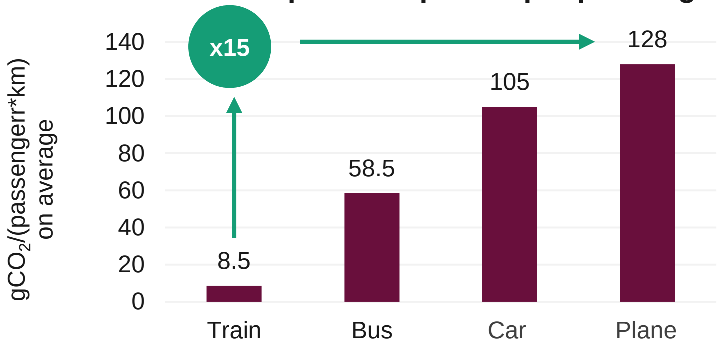
The aviation sector is the most carbon-intensive mode of transportation per kilometer and per passenger

Aviation significantly contributes to CO_2 emissions…

The aviation sector emits 6 times less CO_2 that the road transport sector [1] …



… But the plane is, on average, the most carbon intensive mode of transportation per km per passenger [2]



Use Case: Paris - Marseille

For 4 passengers

115 kg of CO_2
4 passengers in a car (source: ADEME)

272 kg of CO_2
4 tickets (source: Air France)

10 kg of CO_2
4 tickets (source: ADEME)

… And very few measures have been taken to achieve the reduction targets

Measures	Road	Maritime	Aviation
Regulations	• European CO_2 emission standards : 59 gCO_2 / km in 2030 • Prohibition of thermal cars in 2040 in France, planned in Europe	• Reduction of the maximum authorized sulfur rate in fuels, from 3.5% to 0.5% since 1st January 2020 • Maximum Speed Reduction Project	CORSIA system to offset emissions carbon (but only 81 countries participate out of 197)
Alternative fuels	• Electric vehicles (battery or PAC H2) • Natural gas vehicles, biofuels	• Use of LNG • Hydrogen propulsion projects	Some R&D projects around electric or hydrogen aircrafts
CO_2 reduction ambitions	Cut CO_2 emissions of new cars sold in 2030 by 37.5% compared to 2021	Cut global maritime transport GHGs by at least 50% in 2050 compared to 2008	• Stabilize CO_2 emissions at 2020 level • Cut CO_2 emissions by 50% in 2050 compared to 2005 levels

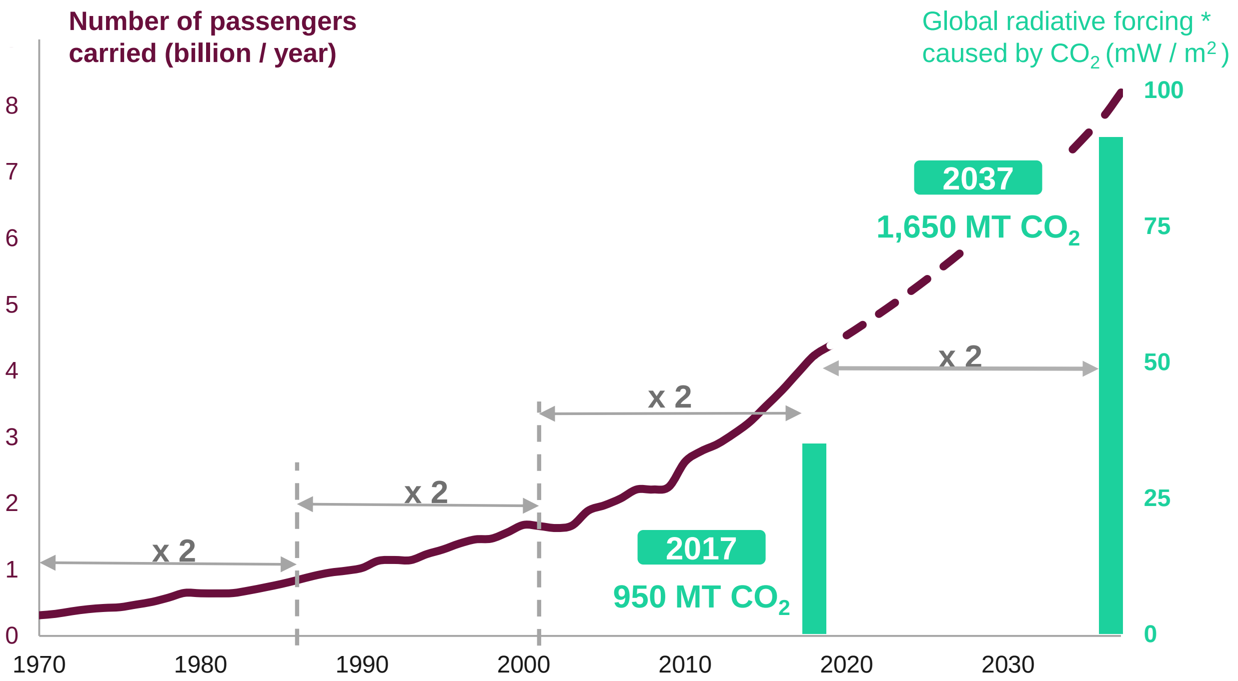
Air transport is more and more scrutinized by public opinion because of its high carbon intensity compared to other transportation modes. The train, for example, is a much lower carbon alternative for short journeys. Compared to the maritime and road sectors, the aviation sector has seen few concrete measures or technological breakthroughs to lower carbon levels, which reinforces the societal awareness.

Sources: (1) IAE (2016); (2) ADEME; Sia Partners analysis using data from EU; ATAG (Air Transport Action Group); ICAO (International Civil Aviation Organization); International Maritime Organization

The necessity to reduce the aviation sector’s carbon footprint

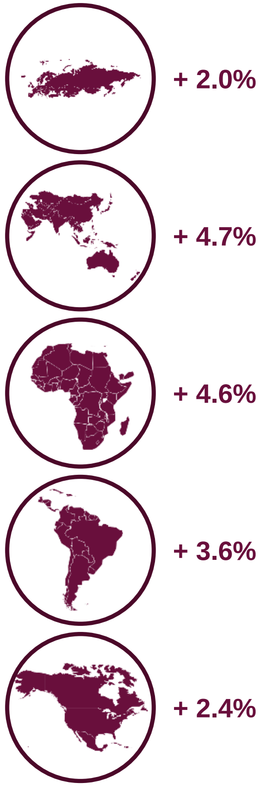
Air traffic growth requires intensified efforts to reduce the sector's carbon footprint

Air traffic growth and impact on global radiative forcing caused by CO_2



Radiative forcing * is the balance between incoming solar radiation and infrared radiation emissions leaving the atmosphere.

Definition of the IPCC



Forecasted annual growth in air traffic between 2017 and 2037 by geographic region

Key figures

x2 of global air traffic between 2017 and 2037.

8.2 billion passengers / year in 2037.

20% of global traffic will be in China in 2037.

x2 of greenhouse effect by 2050.

10% of the anthropogenic greenhouse effect will come from aviation in 2037, compared to 4% today.

5% of global CO_2 emissions in 2037 will be due to the aviation sector, against 2% today.

With 2% of global CO_2 emissions, aviation is already an important cause of the greenhouse effect. The doubling of air traffic expected by 2037 should further accentuate this trend. To stop the worsening of the situation, the entire sector must therefore take action to reduce its carbon footprint per km traveled, beyond the carbon offsetting already used by airlines.

Sources: Sia Partners analysis from the IATA, the World Bank and ICAO data
Predictions made before the COVID-19 crisis that shouldn't jeopardize long-term growth

The necessity to reduce the aviation sector's carbon footprint

Across the world and in Europe, countries and airlines set quantified emission reduction targets

Since the end of 2017, players in the aviation sector have been multiplying announcements and setting quantitative CO_2 emissions reduction targets, mainly on national and European scales, sometimes globally.

United Kingdom

- Carbon neutral industry by 2050 — 2020

easyJet — 2019

- Carbon offsetting of 100% of emissions from all international and domestic flights from 2020
- Launch of a collaboration with Airbus around the electric plane

BRITISH AIRWAYS

- 25% renewable kerosene by 2050 — 2020

Norway

- 30% of aviation biofuel by 2030 — 2019
- Obligation to integrate at least 0.5% biofuel for each flight departing from Norway since January 2020 — 2018

Sweden

- 30% of aviation biofuel by 2030 — 2019

Finland

- 30% of aviation biofuel by 2030
- 50% reduction in CO_2 emissions by 2050

2019

European Union

- 14% of energy from renewable sources overall in transport (road, maritime and air) by 2030, set by the RED (Renewable Energy Directive) - Objective not very restrictive for the aviation sector, only national measures are therefore dimensioning

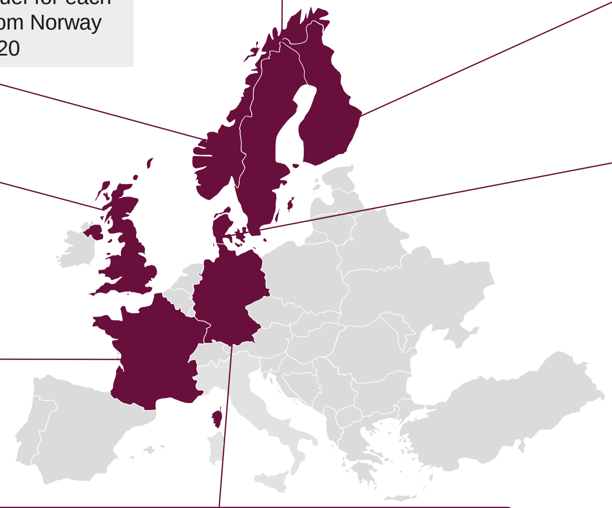
France

- Biofuels share: 2% in 2025, 5% in 2030 and 50% in 2050 (according to the national roadmap)
- Development of a carbon neutral aircraft by 2035

2020

AIRFRANCE — 2020

- 50% reduction in CO_2 pollution per passenger per km in 2025 compared to 2005, i.e. **14.3 MT of CO_2 avoided**
- Carbon compensation of 100% of emissions from all domestic flights from 1 er January 2020
- Fuel consumption below 3 l / 100 km per passenger by 2030
- Incorporation of 2% of sustainable fuel from 2025



Germany

- Carbon neutral airports by 2050 — 2019

Denmark

- Carbon neutral industry by 2050
- Carbon neutral airports from 2020
- Compensation of 100% of CO_2 emissions of the sector from 2020
- Aviation carbon footprint reduced by 30% in 2030 compared to 2017

World

ATAG — 2008

- 1.5% / year improvement in aircraft energy efficiency
- Carbon neutrality in 2020: stabilize CO_2 emissions at 2020 level
- 50% reduction in CO_2 emissions in 2050 compared to 2005 levels

ICAO — 2017

- Carbon neutrality in 2020: stabilize CO_2 emissions at 2020 level
- Share of aviation biofuels: 2% in 2025; 32% in 2040; 50% in 2050 (according to the roadmap)

Public actors / States | Private Actors | 2019 Date of announcement

In recent years, driven by growing awareness about the impact of aviation on climate, more and more countries have set quantified targets for carbon footprint reduction or aviation biofuels incorporation, often more ambitious than the ones set by France. Companies are also mobilizing by offsetting emissions or by setting incorporation targets too. This positioning concretizes the objectives published over ten years ago by ATAG.

Sources: Sia Partners analysis from airlines websites and data from the National Ministries of Ecology, ATAG and ICAO

The necessity to reduce the aviation sector's carbon footprint

Incorporating aviation biofuels in kerosene is one of the solutions considered to reduce the carbon impact of the sector

Different instruments can be mobilized to enable the sector to achieve its carbon emissions reduction target:

Levers	Measures	Goals	Brakes
Regulatory And Financial	Prohibition or limitation of short-haul flights when the train is competitive in terms of travel time (*implementation with Air France, post COVID-19*). System implementation **CORSIA*** , program of **carbon offset and reduction** , (*compulsory from 2027*). Introduction of **carbon emission quota** and creation of an exchange market in order to value carbon. **Tax** on kerosene.	Favor low carbon transport solutions. Financially penalize CO_2 emissions. Reduce CO_2 emissions and contribute to reducing the price gap between biofuels and fossil kerosene.	Not applicable to long-haul that are responsible for approximately **2/3** CO_2 emissions aviation. No short term obligation; only 81 countries subject to it. Creates a lack of competitiveness for the companies concerned (if the scope is not global). Taxes are not discussed at this time.
Societal	**Sensitization** of users on the environmental impact of travel. Development of " flygskam "(= Ashamed of flying, in Swedish).	Promote low carbon transport on relevant routes.	Allow a fairly low gain, especially targets short-haul flights, and countries imbued with a strong environmental culture.
Technological	**Improving energy efficiency** engines and planes **Optimization of flight plans** and improvement of airport infrastructure **Use of alternative propulsion** • **Aviation biofuels** • **E-fuels (synthetic fuels, Power-to- liquid, Power-to- gas)** • **Battery electric** • **Hydrogen fuel cell electric**	Reduce CO_2 emissions in flight **27%** *CO_2 emissions avoided (1)* **6.7%** *CO_2 emissions avoided (1)* **21%** *CO_2 emissions avoided(2)* *(1) By 2050 / (2) If 50% incorporation*	Incremental improvements that do not allow significant gain in the short term. Insufficient solution alone to achieve the objective of reducing CO_2 emissions by 50%. ❯ In place since 2008, market to boost. ❯ Currently being deployed, comercialisation is expected by 2025. ❯ Not very viable for long-haul flights: 180 tonnes of batteries required, 2.5 times the weight of the aircraft. ❯ Technological breakthrough envisaged for 2040, to allow massive electrification of commercial flights (target of 1st H_2 plane in France for 2035).

In addition to setting up incentivizing and sometimes restrictive measures, technological advances are necessary to reduce the carbon footprint of the aviation sector. Alternative fuels are the only solution which should enable airlines to meet their growth targets while reducing their CO_2 emissions in the short and medium term.

** CORSIA = Carbon Offsetting Reduction Scheme*
Sources: Sia Partners analysis from ICAO, Safran and Airbus data.

The necessity to reduce the aviation sector's carbon footprint

The air crisis caused by the COVID-19 pandemic may be decisive for the incorporation of aviation biofuels

The decisions to close borders and to implement containment measures taken by France and European countries in particular could lead to a 36% drop in French air passengers in 2020 and a loss of 12 billion dollars in 2020 for French airlines*.

COVID-19 and its consequences are serious obstacles to the incorporation of aviation biofuel in the short-term…

Global economy

With **the loss of 90% of their turnover** in March and April, airlines are trying to survive the crisis. Once out of the crisis, and for the sake of job retention, companies will probably not be able to invest in the short-term, especially since air traffic will be very severely disrupted until the borders fully reopen.

Cost of kerosene

The collapse in oil prices, caused by the price war between OPEC countries and strengthened by the fall in demand due to COVID-19, accentuates in the short-term the price differential between fossil kerosene and aviation biofuels.

… But could constitute a development opportunity in the medium and long terms

Funding

Given the strategic importance of the air sector for a country and the thousands of jobs at stake, States will most likely intervene via massive loans or entries to shareholders, as France has already done for Air France. **The payment of this aid will, depending on the country, be conditioned to the achievement of environmental objectives** in the medium-term, in response to requests from numerous NGOs and companies. Biofulels, which are part of a logic of local production and strategic and energy sovereignty, would fit perfectly into this framework.

Society

The current crisis seems to strengthen societal awareness. **Health and environment preservation thus become predominant concerns for the general public**. The aviation sector will therefore have to reassure passengers about health safety and take action in favor of the environment. In this context, and in the absence of a realistic medium-term alternative, aviation biofuels will impose as a must for the aviation sector recovery.

The health crisis caused by COVID-19 constitutes an unprecedented and critical event for the sector: restarting the activity and keeping businesses afloat will be major challenges for airlines. Biofuels must be part of the sector's reinvention solution in response to public and government demands.

** IATA forecast, April 2020*

The necessity to reduce the aviation sector's carbon footprint

The French post COVID-19 recovery plan for the aeronautical industry sets a "green" course and supports biofuels

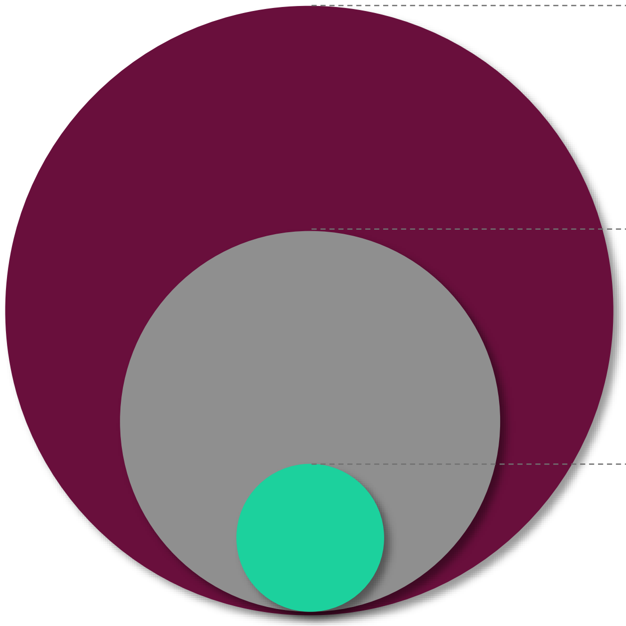
In response to the economic crisis following COVID-19, the French government unveiled a 15 billion euros recovery plan for the aeronautical industry. While a large part of these investments will support the various companies and maintain employment and skills, a significant part will also be directed towards the low carbon transition of the sector, including the deployment of biofuels.

	Industry (8,132 billion €)	Air France (7 billion €)
Investments / Financial support	• €1 billion investment fund to meet capital requirements of companies weakened by the crisis. • Digitalization fund of €300 million to support SMEs. • €1.5 billion in government guaranteed loans. • €832 million orders (armies, gendarmerie and civil security). • €3 billion export guarantee. • **€ 300 million in 2020, then € 600 million in 2021 and 2022, as well as € 400 million of European funds will be invested in R&D and innovation, for the ecological transition of the sector.**	• € 3 billion in direct government loan • € 4 billion loan guaranteed at 90% by the French State
Commitments in favor of ecological transition	• Develop a new flight management system **reducing fuel consumption by 10%** from 2023. • Launch the successor to the Airbus A320 by 2030, with a target of **30% reduction in fuel consumption**, and a **100% capacity of biofuel**. • Launch a **hydrogen airplane** demonstrator in 2026-2028. • Launch a new **hybrid regional aircraft** by 2030. • Launch a **carbon neutral aircraft** in 2035, i.e. 15 years before the objective initially set (2050). This plane will probably be propelled with hydrogen.	• **Limit or delete** flights of less than 2.5 hours. • **Cut 50% of CO_2 emissions** by 2030, instead of 2050 as previously planned. • **Incorporate 2% of sustainable fuel** by 2025, in order to align with the French roadmap for the deployment of aviation biofuels.

The French recovery plan aims to accelerate the ecological transition of the aviation sector with the ambitious objective of developing a zero carbon aircraft by 2035. If, in the long term, hydrogen technologies will probably be the preferred technology, biofuels are essential as a transitory solution towards a low carbon aviation sector and are fully in line with the French recovery plan.

The necessity to reduce the aviation sector's carbon footprint

Aviation biofuels are a credible medium-term solution



2017 IEA data

32,040 MT — **CO_2 from human activity**

*Power generation, transportation, industry and others **human activities contribute significantly to the emission of greenhouse gases**, including CO_2, in the atmosphere.*

8,040 MT — **CO_2 from transportation**

*__Transport__ represents today the **2nd most CO_2 emitting sector**, and the one with the **highest growth.***

950 MT — **CO_2 from aviation**

__Air transport is the transport mode which emits the most CO_2 per kilometer__. It is growing rapidly and only few measures are already in place to reduce emissions.

A limited number of levers can be activated to reduce the carbon footprint of aviation. Technological developments, and in particular **alternative propelling, are effective in reducing in-flight emissions**.
Biofuels are today the most credible solution in the medium-term, since mass electrification seems impossible before 2035.

Given the growth of the aviation sector and current technological limits linked to the use of other alternative propellants, biofuels are an effective and realistic solution in the medium-term, although some challenges must still be considered *. Massive use of this solution could accelerate with recovery planning from the health crisis.

**See part 2

2

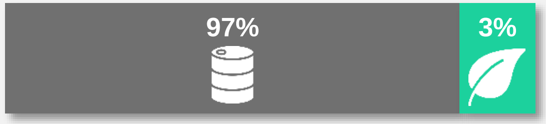
Aviation Biofuels, a sector still under structuration

Aviation Biofuels, a sector still under structuration

With less than one liter per 1000 liters of aviation fuels, biofuels use remains extremely low

The use of biofuels in the aviation sector is practically negligible, unlike its use in the road transport sector and the average use on all transport.

- **Breakdown of conventional fuels / biofuels**



Focus on biofuels
143 billion liters in 2017

Share of biofuels between road and air

The biofuels sector largely favors road transport, in particular because of biofuel integration obligation policies.

- **Distribution of fuels by means of transport**

Focus on aviation fuels
340 billion liters in 2017

Share of biofuels in aviation fuels

Aviation biofuels use is very low compared to conventional kerosene.

Aviation biofuels characteristics

Aviation biofuels must meet strict specifications, in particular they must:

- **Be adapted to the current aviation equipment** (having a long service life)**,** so they can be used in the short and medium term.
- **Be very close to fossil kerosene in terms of composition**, for a similar energy performance .
- **Be certified by ASTM** (*American Society for Testing Material, a standardization body which has published more than 12,000 standards)* for flight safety.

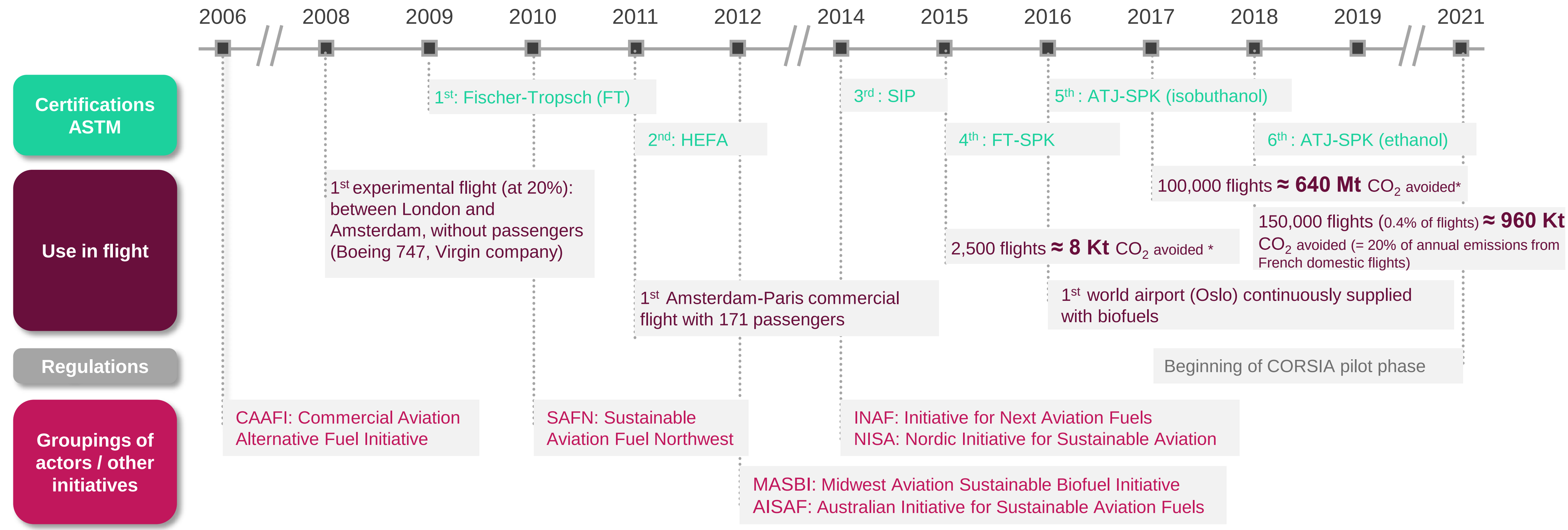
Today, biofuels are almost exclusively used for road transport. With only 0.09% of aviation fuels, the use of aviation biofuels is still marginal and remains far from the incorporation target of 2% by 2025 set by the ICAO.

Sources: Sia Partners analysis from IEA and IATA data

Aviation Biofuels, a sector still under structuration

Despite technological developments, the use of aviation biofuel remained limited by the lack of regulatory frameworks

Since 2008, and thanks to initiatives from airlines and development programs, the aviation biofuels sector has been developing through successive ASTM certifications of production processes.



As of 2018, 150,000 flights worldwide had used biofuels, saving the equivalent of 20% of annual CO_2 emissions due to French domestic flights. However, the lack of favorable regulations for the sector still hampers the democratization of biofuels use in flight. The start of the CORSIA pilot phase should be perceived as a positive signal for the sector.

**For an average flight of 1500 km and 150 passengers with an average incorporation of 15% of biofuel until 2015, and 30% after 2015*
Sources: Sia Partners analysis from ICAO, IATA and ATAG data

Aviation Biofuels, a sector still under structuration

The upstream stages of the value chain concentrate most of the efforts required to develop the sector

While the in-flight use phase is a mastered stage in the value chain, the availability of inputs, conversion to fuel and supply logistics present challenges for the sector.

	Input collection / culture	**Conversion** ⚠	**Transport & distribution**	**Use in flight**
Description	Raw material which will be transformed into fuel: • Oilseeds • Cereals • Wood and forest residues • Used cooking oils • Organic waste • Agricultural residues • Algae, micro algae	Succession of chemical, biological or physical reactions applied to inputs to obtain biofuel	• Upstream transportation to airports • Storage at airports and distribution to airlines • Blending with kerosene, imposed by aviation safety	• Airlines refuel at airport depots. • *Biofuels are compatible with current engines without adaptation.*
Key figures	The inputs are classified in **3 generations**	• **9 existing processes**, of which 6 are certified • **85%** of production comes from a single process (HEFA)*	• Each production process has a maximum blending rate with kerosene, varying from **10 to 50%.** • **5 airports** are permanently supplied with biofuels	**215,000 flights** partially powered by biofuels, as of December 2019
Maturity	● ◐ ○	● ○ ○	● ● ○	● ● ●
	Focus slide 19	Focus slides 20 and 21	Focus slide 22	Focus slide 23

⚠ **The fuel conversion stage is the most complex in the value chain and the least mastered at the moment**

The industry can rely on the existing supply chain for the distribution of kerosene, with downstream stages largely compatible with biofuels. Inputs availability is the subject that raises the most questions among the public today. Technological advances will be necessary on the fuel conversion stage to master more processes and scale up the sector towards mass production.

Sources: Sia Partners analysis from ICAO and IATA data

Aviation Biofuels, a sector still under structuration

Stakeholders from all backgrounds and sizes are involved along the value chain, or have a very close positionning

The value chain of biofuels, and more recently aviation biofuels*, involves at the same time large multinationals, specialized actors and airports.

Input collection / culture

Waste management players

Goal : recover collected waste (2nd generation inputs)

Mainly for road biofuels at that date, rather than for aviation biofuels.

Agrifood specialists / Farmers

Goal : diversify their outlets and their customers

Mainly for road biofuels at that date, rather than for aviation biofuels

Conversion

Oil companies

Goal : green their activities
Average turnover : 2 - 50 billion €

Road biofuels producers

Goal : diversifying the client portfolio
Average turnover : 50 - 500 M €

Aviation biofuels specialists

Goal : to be a leader in the sector
Average turnover : 1 M € (for air biofuel activity)

Transport & distribution

Transporters / distributors

Goal : transport biofuels to airports

Only SkyNRG exclusively distribute aviation biofuels. Other players are mainly involved in fossil kerosene.

Airports

Goal : supply airlines

Precursor airports :
- Oslo
- Los Angeles International
- Bergen
- Stockholm
- Brisbane

Use in flight

Airlines companies

Goal : retain customers and adapt to new needs

Engine manufacturers and aircraft manufacturers

Goal : meet industry commitments and the needs of airlines

Specialized companies are seeking to position themselves as market leaders, while players already in place in the kerosene or biofuels sector are diversifying or undertaking collaboration to seize additional opportunities. Downstream, some airports, in northern Europe in particular, have made the necessary adaptations for the supply of aviation biofuels.

** Non-exhaustive vision*
Sources: Sia Partners analysis from ICAO and IATA data and company websites

Aviation Biofuels, a sector still under structuration

Focus on inputs: 2nd and 3rd inputs generations are promising on medium and long term but have more limited reservoir sizes

Since the certification, in 2011, of the HEFA process using exclusively the inputs of 1st generation, the sector aimed to improve the ecological impact by developing new processes that are compatible with all generations of inputs.

	1st generation: Dedicated energy crops	**2nd generation:** Residues from human activity	**3rd generation:** Algae, microalgae
Types of inputs	• Oilseeds (rapeseed, sunflower) • Beet, sugar cane • Cereals (wheat, corn)	• Wood and forest residues • Agricultural residues (rapeseed stalks, straw, etc.) • Organic waste and cooking oils	• Cultivation of algae in laboratories
Reservoir size	● ● ●	● ● ○	● ○ ○ *
Environment preservation	● ○ ○ Deforestation, competition for arable land	● ● ○ Waste recovery, local loop	● ● ●
Technological maturity	● ● ●	● ● ○	● ○ ○
Associated processes	2 (including 1 certified)	5 (including 4 certified)	3 (including 1 certified)
Economic attractiveness	● ● ○	● ● ●	● ○ ○
Summary	The environmental impact of cultivating inputs is too negative at the moment	The deposit is insufficient at the moment due to the lack of collection in most countries	The costs of growing algae are still too high to allow mass production

If the 1st generation of inputs is widely criticized due to its environmental impact, the 2nd and 3rd generations are more promising, but still respectively lack sufficient inputs and technological mastery to take over the production of aviation biofuels.

** Unlimited deposit in the ocean but very difficult to harvest / In the laboratory, cultivation is very complicated because of the fragility of algae to bacteria and the high demand for water and phosphorus*
Sources: Sia Partners analysis from ICAO and IATA data

Aviation Biofuels, a sector still under structuration

Focus on conversion: The development of processes using inputs of 2G and 3G is essential for the success of biofuels

In order to be used on a commercial flight, biofuels must be produced using a process certified by ASTM. In 2019, 6 processes are certified while 3 others are in the testing phase.

Recent production processes certified by ASTM favor 2nd generation inputs…

Certification date	*Production process*
2009	**FT-SPK** : Fischer-Tropsch Synthetic Paraffinic Kerosene
2010	
2011	**HEFA** : Hydroprocessed Ester and Fatty Acids
2012	
2013	
2014	**HFS-SIP (or DSHC)** : Synthesized Iso- Paraffinic
2015	**FT-SPK / A** : FT-SPK with aromatics
2016	**ATJ-SPK : Isobuthanol** : Alcohol - SPK jet
2017	
2018	**ATJ-SPK : Ethanol** (Alcohol - SPK jet)

… While the sector is moving towards 3rd generation for years to come

3 processes are currently in the testing phase for certification:

- **HDCJ** : Hydrotreated Depolymerized Cellulosic Jet
- **ATJ-SKA** : Alcohol-to-Jet Synthetic Kerosene with Aromatics
- **HFP-HEFA (or HEFA +)** High Freeze HEFA point

Since the creation of the industry, the 1st generation represents 85% of produced volumes

1st generation biofuels are widely dominant on the market due to the greater maturity of technologies and the capacity of input fields.

Distribution of biofuel volumes by generation of inputs

Legend	Generation of inputs mainly used for each process:	1st generation	2nd generation	3rd generation

Due to the greater availability of inputs, the 1st generation is predominant in current production. However, to improve the environmental impact and stop using agricultural inputs, the industry is accelerating the development of 2nd and 3rd generation.

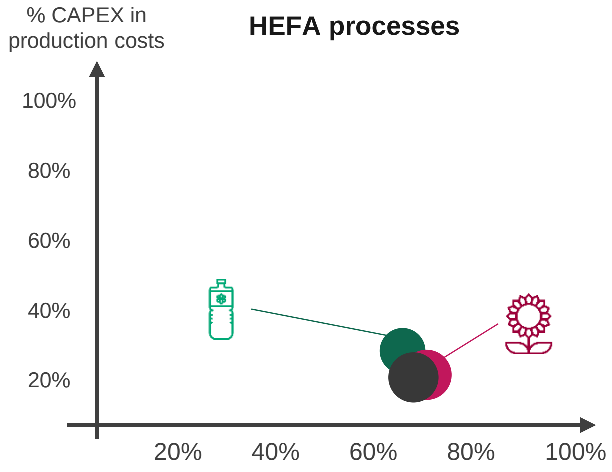
Sources: Sia Partners analysis from ICAO and IATA data and company websites

Aviation Biofuels, a sector still under structuration

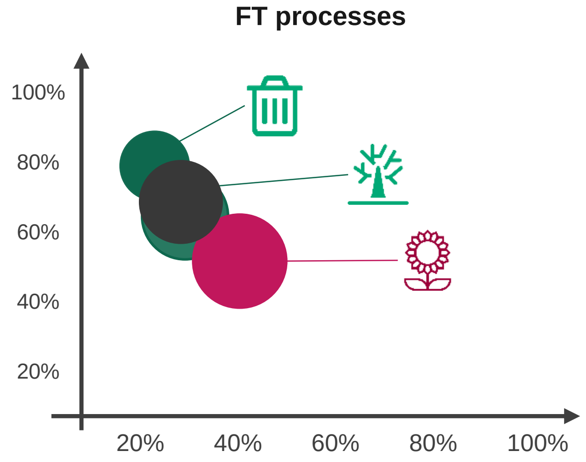
Focus on conversion: Aviation biofuels suffer from a lack of economic competitiveness compared to conventional kerosene

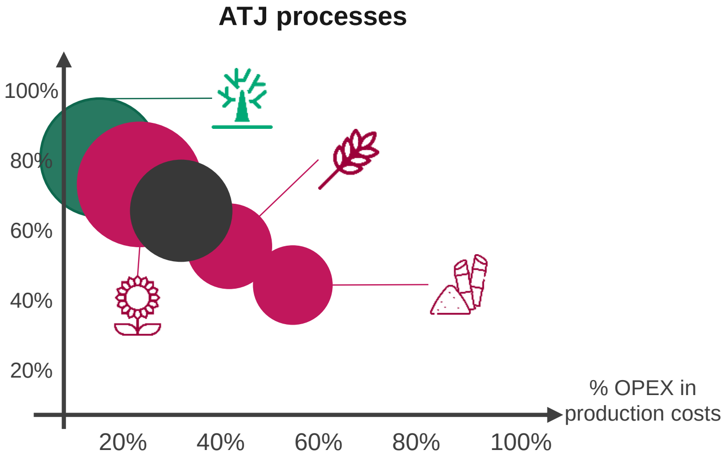
The production costs of aviation biofuels depend directly on the type of input and the process. The breakdown of production costs between CAPEX and OPEX (operations + input purchase costs) is specific to each process.

Costs include CAPEX (installation, equipment purchasing costs, planification) and OPEX (costs of inputs, other operating costs) associated with aviation biofuels production (with plants used for 20 years with a standard production).



- **The cheapest** aviation biofuels, but still twice as expensive as kerosene.
- **Not conducive to economies of scale**: the cost of inputs represents 57% of the cost of production on average.





- With such processes, aviation biofuels are **3 to 5 times more** expensive than kerosene depending on the type of input.
- Require significant CAPEX: 2/3 of production costs, suggesting possible **economies of scale** with increasing production quantities.

Legend

- ● Average process price
- Cost of production / price of kerosene: 5.5 / 3.5 / 1
- **1st generation inputs**: Soybean, palm, sunflower; Sugar; Cereals (wheat, corn, etc.)
- **2nd generation inputs**: Household waste; Agricultural waste; Cooking oil

Economic data are not available for 3rd generation fuels, still in the experimental stage.

Aviation biofuels are currently between 2 and 5.5 times more expensive than kerosene, in particular because of the lack of economies of scale on the production means. Support policies are needed to improve their economic attractiveness to airlines and upscale the production chain.

Sources: Sia Partners analysis from ICCT data (Internal Council on Clean Transportation).
The price of kerosene is based on a pre-coronavirus price per oil barrel.

Aviation Biofuels, a sector still under structuration

Focus on transport & distribution: The existing and efficient kerosene logistics chain can be adapted to the specificities of biofuels

The distribution of aviation fuels is comprised of an upstream part up to airports, and a intra-airport logistics.

Centralized distribution to airports

- Airlines negotiate **supply contracts** (1 to 2 years) with distributors, who then provide transport from production refineries to fuel depots at airports.
- The distribution of kerosene is more centralized than the distribution of road fuels: **180 airports generate 90% of global air traffic** while there are 180,000 service stations in Europe and the USA alone.

Main distributors of aviation fuel

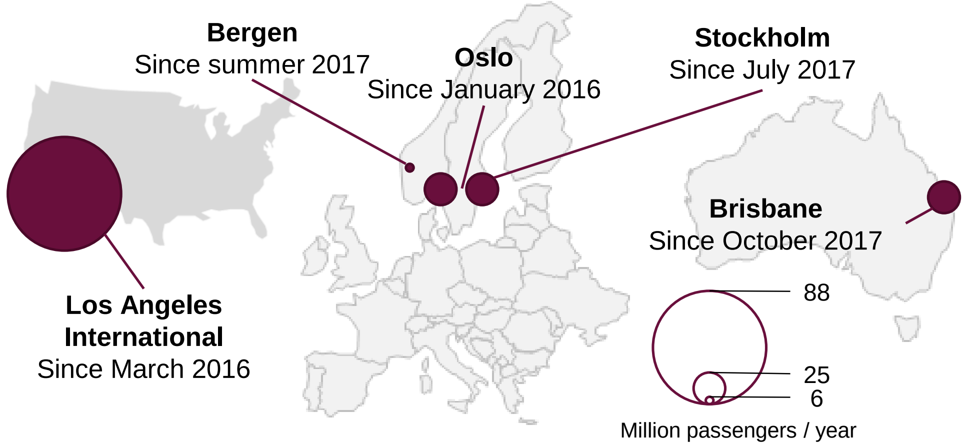
Shell Aviation	72 ML / day
air bp	66 ML / day
ExxonMobil Aviation	64 ML / day
Allied Aviation	60 ML / day
Vitol Aviation	57 ML / day
Total	43 ML / day
Valero	32 ML / day
Gazprom Avia	12 ML / day
SkyNRG	0.25 ML / day

Distributor of aviation biofuel only
Distributor of fossil kerosene only
Distributor of fossil kerosene and biofuel

Adaptations required at airports

- Aviation safety measures impose specific and demanding storage and distribution conditions which are subject to control.
- Managing two different fuel flows at airports is more complex: airports must ensure **fuel traceability.**
- A flow of aviation biofuel requires **mixing infrastructure** with kerosene.

5 airports are permanently supplied with biofuels



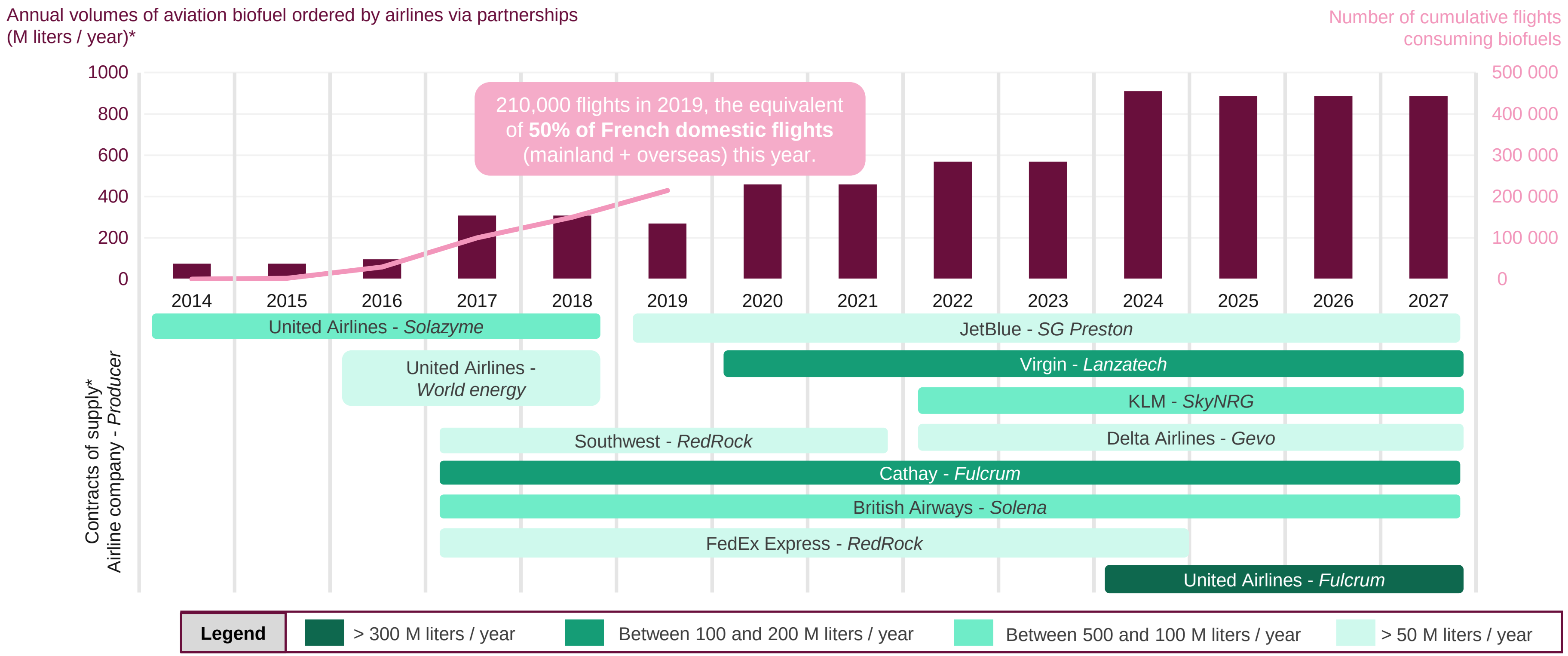
The sector can rely on an existing and efficient logistics chain in which the airports, main component, require only a few specific adaptations to supply biofuels.

Sources: Sia Partners analysis from distributor sites and from IATA and ICAO data

Aviation Biofuels, a sector still under structuration

Focus on in-flight use: A market which is expanding via partnerships between producers and airlines

Working like PPAs (Power Purchase Agreement) for renewable energies, partnerships guarantee producers medium-term income to finance their means of production, while airlines secure long-term supplies, reduce their carbon footprint and improve their image.



Key figures

6 billion liters of aviation biofuel are ensured by contracts over the next 10 years.

In 2017, annual volumes were multiplied by **9.**

300 million liters were delivered in 2017, i.e. as much as in the previous 10 years cumulated (since the 1st experimental flight in 2008).

In total, approximately **12** contracts have been signed by industry players. Some do not reveal the volumes processed.

Current volumes all being ordered through partnerships between airlines and producers, these are the only development lever for the sector and could upscale the market into the production of large volumes. At that date, 850 million liters were ordered for the year 2027, which nevertheless represents only 0.25% of the global annual consumption of aviation.

** Known volumes only, as of December 2019*
Source: Sia Partners analysis from producer and airline websites

Aviation Biofuels, a sector still under structuration

The development of the sector is conditioned to economic, technological and structural evolutions

The sector, penalized by a **lack of economic competitiveness and incentive regulation**, could speed up its development thanks to the implementation of the CORSIA program.

The **2nd and 3rd generations of aviation biofuels** seem to pave the way for production at **reduced environmental impact**. The **quantity of inputs available** could however be a limit to unlock their potential.

Today the sector is structured around many **players from the air, road, agricultural, waste management or biofuel backgrounds**. Airlines place orders with producers through **supply agreements**.

The **upstream value chain** (input collection and production of biofuel) **require significant effort** to develop the sector and airports also must be adapted.

In order to estimate the interest and the feasibility of incorporating up to 50% of biofuel in aviation fuel, we now carry out a case study in France taking into account different parameters: types of biofuels, rate of incorporation, year of study, economic hypotheses.

3

Case study and recommendations

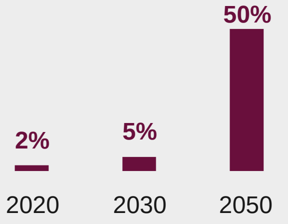
Case study and recommendations

Through three important criteria, the case study aims to assess the French aviation biofuel roadmap

The Ministry of Ecological and Solidarity Transition drew up a roadmap for the sector and set targets for the incorporation of biofuels. The objective of this case study is to estimate the carbon gains, the necessary input sources and the costs associated with this roadmap.

Roadmap

Objectives for incorporating aviation biofuels in France



Identification of 3 criteria to assess the contribution of the use of aviation biofuels

- **Environmental gain**
- **Input availability**
- **Economic impact**

Main calculation hypotheses

Selected journey

French domestic flights

Annual traffic:	158.8 million passengers per 100 km *(source: DGAC)*
Average consumption :	3.76 l / 100 km per passenger *(source: Air France)*

Paris - Marseille route

Distance:	732 km *(source: Air France)*

Technologies

Two types of biofuels, both from 2nd generation, are studied:

1. Process : HEFA
   Inputs: Used oils

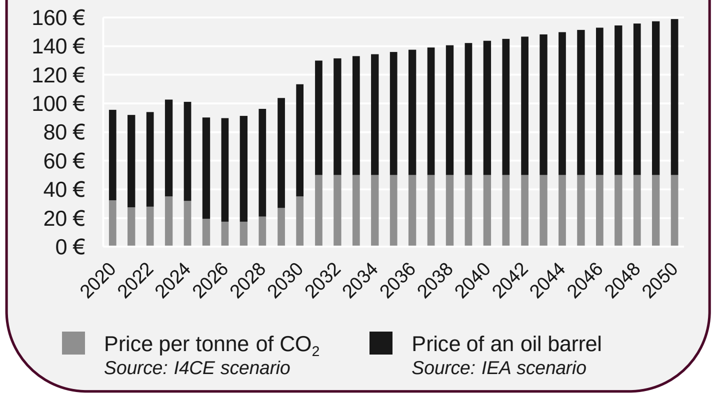
Most used and cheapest process
Mature process therefore figures are available

2. Process : FT-SPK
   Inputs: Municipal organic waste

The most environmentally relevant input
Available figures

Macroeconomics

No tax on kerosene considered



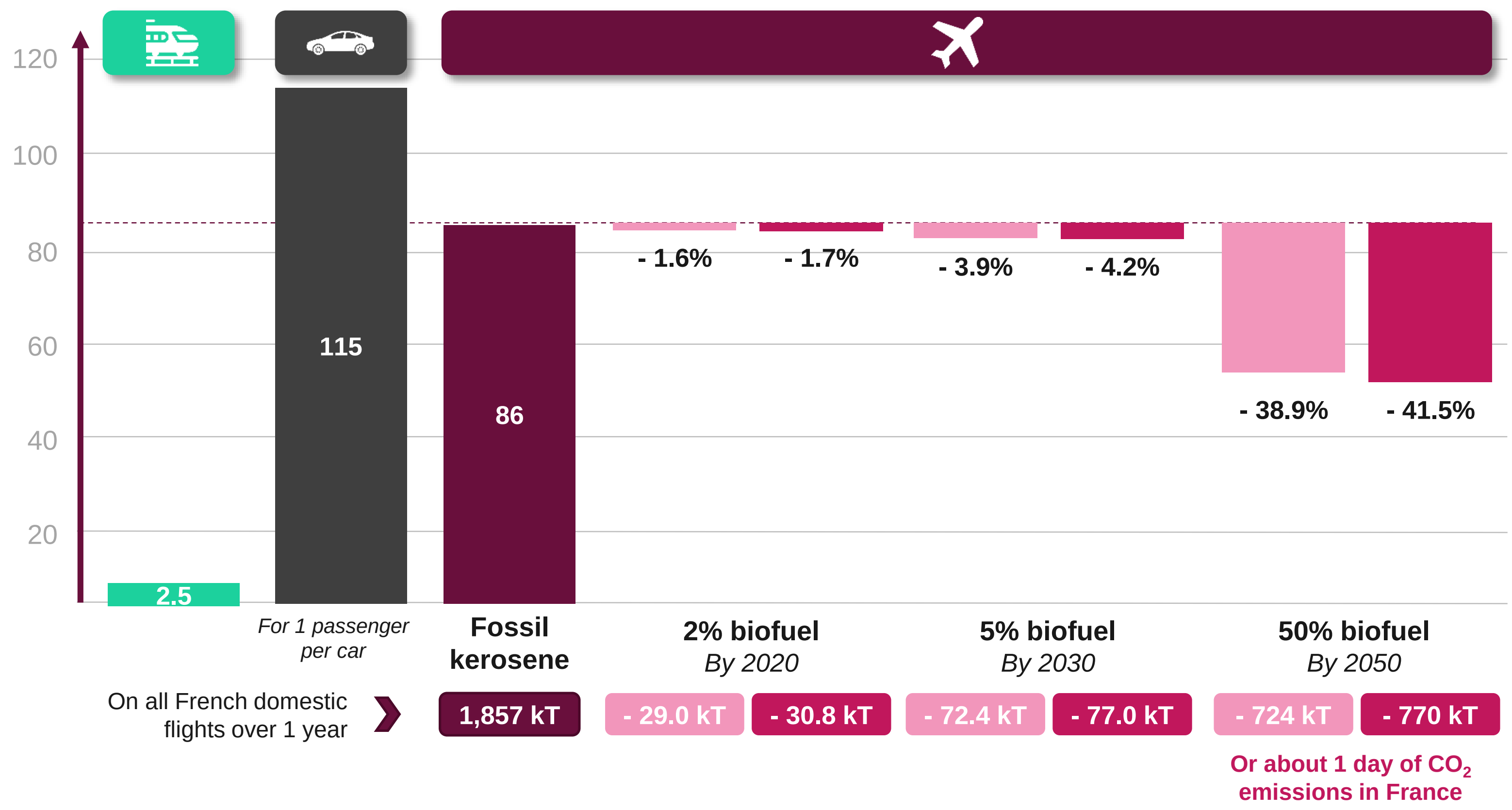
The study focuses on French domestic flights and the case of a Paris-Marseille journey with two biofuel produced from inputs of 2nd generation, with forecasts of the oil barrel and the CO_2 ton prices until 2050.

IEA scenarios on the evolution of the price of oil were carried out before the COVID-19 crisis.

Case study and recommendations

Focus on environmental gain: When used in large quantities, biofuels allows significant carbon gain

CO_2 emissions (kg) on the Paris - Marseille journey for 1 passenger



Key references

With the incorporation of 50% of Biofuel 2:

- On average, a French person would save **140 kg** of CO_2 per year on their air travel.

- The amount of CO_2 saved on a trip from Paris to Marseille represents **2.5 times** French daily CO_2 emissions.

- A Paris-Marseille flight becomes **20 times** more CO_2 emitter than by train instead of 34 times.

Legend

Biofuel 1: HEFA + used oils

Biofuel 2: FT-SPK + municipal organic waste

If incorporating 2 or 5% aviation biofuels is not of major environmental interest, incorporating 50% biofuel from the FT-SPK process *(Biofuel 2)*, on the other hand, reduces CO_2 emissions by more than 40% on a Paris - Marseille flight. Brought back to all domestic flights in France over a year, this corresponds to daily CO_2 emissions from all sectors in mainland France.

The IEA scenarios on the evolution of the price of oil were carried out before the COVID-19 crisis. After the economic crisis linked to COVID-19, discussions are underway around forbidding or limiting flights of less than 2.5 hours. Substituting these planes journeys with train journeys would further reduce CO_2 emissions than using biofuels.

Case study and recommendations

Focus on input availability: Current input sources may be a limiting parameter for the French roadmap

For biofuels to provide significant CO_2 gain, an 50% integration rate is necessary. However, such biofuel production requires large quantities of inputs*.

To incorporate 50% biofuels, the French current inputs reservoirs would not necessarily be sufficient to supply French domestic flights…

Biofuel 1

257 kT
Or 129% of the current reservoir (1)

Biofuel 2

1.93 MT
Or 13% of the current reservoir (2)

… And they would probably be very insufficient to supply all the flights departing from France

- The French flights studied here represent only **15%** of the flights departing from France.
- The inputs studied have **other possible uses** (road biofuels, production of lubricants and production of alternative fuels for oils, production of biogas or biomethane and composting for organic waste ...) which are already supported by financial mechanisms.
- The current reservoirs are gross potential reservoirs. The separate collection of this waste is an important issue, in particular for organic waste, to ensure the availability of these inputs.

Key references

200,000 tons (1) of used oils were generated in 2019 in France
(Source: Ministry of Ecological and Solidarity Transition).

15 MT (2) of municipal organic waste** are generated each year in France
(Sia Partners analysis based on ADEME and La Tribune data).

The current reservoir of used oils does not allow reaching 50% of biofuel of this type on all French domestic flights. A combination of several types of biofuels will therefore be necessary to achieve the objectives of the roadmap.

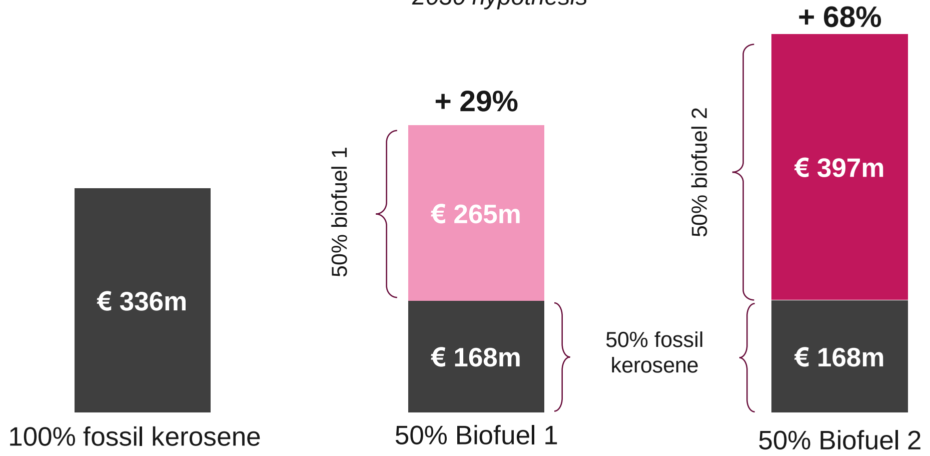
** Calculation of reservoirs is based on the number of French domestic flights carried out in 2019 (without taking into account the flight cancellations planned by Air France for the post-COVID-19 relaunch.*
*** Municipal waste is waste collected by municipalities and therefore generated from households, shops, public services and small industries (excluding large industries).*

Case study and recommendations

Focus on economic impact: more expensive, biofuel generates an additional cost for airlines, yet transferable to passengers

The additional cost of incorporating 50% of biofuel would be very difficult to assume for the airlines alone ...

Fuel budget for all French domestic flights
2030 hypothesis

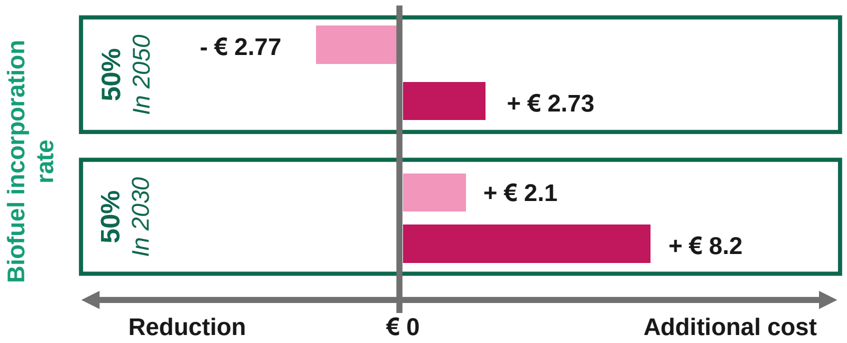


In 2019, Air France - KLM group generated a € 290 million net income.

Incorporating 50% of biofuel induces a significant additional cost for all airlines in an already ultra-competitive market. *This additional cost will be further accentuated by the fall in oil prices following the COVID-19 crisis.*

… But the economic impact on ticket price would be relatively acceptable for travelers

Impact on ticket price (Paris – Marseille flight)
Roadmap scenario: 50% in 2050 / Sia Partners scenario: 50% in 2030



The price per ton of carbon and kerosene is forecasted to be much higher in 2050 than in 2030, making biofuel less competitive in 2030 than in 2050.
The high price of carbon in 2050 even allows an economic gain when using Biofuel 1.

On average, ticket price for a Paris – Marseille flight is 120 €.

If the cost of biofuel is passed on to ticket price, this would generate an additional cost of up to 2.3% for the traveler on a Paris - Marseille flight in the roadmap scenario.

Legend	Fossil kerosene	Biofuel 1: HEFA + used oils	Biofuel 2: FT-SPK + municipal organic waste

The additional cost of integrating biofuel, while being difficult for airlines to support, could be passed on directly to the passenger ticket price while remaining acceptable, even with a 50% incorporation rate. The decisions will also depend on possible supporting policies to the sector.

Study based on pre-COVID-19 kerosene prices
Sources: the cost of producing biofuel is based on a study by Internal Council on Clean Transportation + extrapolation from Sia Partners which includes economies of scale

Case study and recommendations

50% of aviation biofuels in 2030: an ambitious but achievable scenario, consistent with the French post COVID-19 recovery plan

In order to reach the objective of 50% of aviation biofuels on all French domestic flights, while being compatible with realistic available inputs sources and limiting costs as much as possible, Sia Partners recommends using the following combination of biofuels types:

All kerosene consumed on French domestic flights = **50% fossil kerosene** + **27%* Biofuel 1: HEFA + used oils** + **23% Biofuel 2: FT-SPK + municipal organic waste**

- 27%* Biofuel 1: *Use of used oil deposits within a reasonable limit (60%)*
- 23% Biofuel 2: *Biofuel 2 supplementation to reach 50% of aviation biofuel*

The **consequences** and **earnings** of this solution are:

	Environmental interest	Input availability	Economic impact
Key figures	**745 kT** of CO_2 avoided equivalent to a **40%** cut of CO_2 emissions	**140 kT** used oils equivalent to **60%** of the gross reservoir **880 kT** municipal organic waste equivalent to **6%** of the gross reservoir	**125 million euros** of additional cost for airlines on all French domestic flights *Or* **€5 of** additional cost per ticket on average (*Sia Partners estimation*)
Comments	The amount of CO_2 avoided represents approximately: • the **daily emissions** in France • the annual emissions of **150,000 French people** • the **half of weekly emissions from the French industrial sector**	Such biofuel demand can be covered by existing input sources without compromising other uses.	The measure would be costly but it can be passed on to the price of tickets and comprises several economic advantages: • Local job creation • Increased energy sovereignty • Price stability

Incorporating 50% of aviation biofuel by 2030 on all French domestic flights would reduce CO_2 emissions by 40% for an average additional cost estimated at €5 per ticket and per passenger, provided that support measures are put in place to allow significant upstream investments.

Study based on the pre-COVID-19 price of kerosene and which does not take into account possible cancellations of flights lasting less than 2 hours 30 minutes (as announced in the recovery plan for the sector). Sources: the cost of producing aviation biofuel is based on a study by Internal Council on Clean Transportation + extrapolation from Sia Partners which includes economies of scale

Case study and recommendations

The Sia Partners scenario is fully in line with the French recovery plan for the aeronautics sector, with significant environmental gain in the medium term

The case study, based on the hypotheses of the French roadmap, makes it possible to draw conclusions and lessons for the development of the sector:

Plurality of inputs: Several types of biofuels associated with different inputs must be combined to meet demand. The abolition of some specific domestic flights would make it possible to reduce these necessary inputs quantities. Gross inputs reservoirs are also sought for other uses, such as road transport, which yet has more effective alternative solutions to reduce their carbon footprint.

Minimum incorporation rate: The environmental gain is significant only from a 50% incorporation rate of biofuel. Therefore, the French roadmap unveiled at the start of the year does not entail any real environmental gain in the medium term (by 2030). However, the objective, announced in the post-COVID-19 recovery plan, of a carbon neutral aircraft by 2035, must materialize through significant support for the sector and environmental gain.

Investments: The biofuels massive integration objectives require deploying new production units* with high CAPEX. To ensure these investments, strong signals must be sent to investors to reassure them of the market potential (legislation, subsidies on the price difference between kerosene and biofuel, "Green premium" on tickets, etc ..)

Political choices: Political will is required to adopt financial and regulatory measures favoring the generalization of biofuel. In addition, a strategy will have to be put in place for the use of gross reservoirs, in order to prioritize and favor aviation biofuel among the outputs, at the expense of other uses such as road biofuels (for which the public authorities can mobilize other solutions alternatives).

In order to reduce the carbon footprint of the aviation sector in the mid-term in an absolute and non-relative way (without the use of compensation mechanisms), Sia Partners recommends the implementation of an ambitious scenario for 2030, consistent with the objectives of the French post COVID-19 recovery plan. The objective set by the government to develop a carbon neutral aircraft using hydrogen in 2035 demonstrates the interest of boosting the biofuel sector as a transitional solution before 2035.

** To date, only one refinery in France: La Mède.*

Contacts

Charlotte DE LORGERIL

Partner

Mail: charlotte.delorgeril@sia-partners.com

Tel: +33 6 24 73 18 34

@cdelorgeril

Benoît MAHE

Manager

Mail: benoit.mahe@sia-partners.com

Caroline LE GALL

Supervising Senior Consultant

Mail: caroline.legall@sia-partners.com

Jean-Sébastien TURC

Consultant

Mail: jean-sebastien.turc@sia-partners.com

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