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Decarbonizing Aviation:
All Aboard

REPORT JANUARY 2022

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There is no desire more natural than the desire for knowledge

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RECOMMENDATION N°1 (World)

Accelerate the development of disruptive technologies and increase the incremental reduction in aircraft energy consumption.

a. Accelerate incremental changes in consumption reduction;

b. Maintain investment dynamics for disruptive technologies, especially for: new aircraft shapes, new engines (including electrification), hydrogen-powered aircraft;

c. Prepare the certification model for disruptive innovations;

d. Establish mechanisms to ensure competitive costs for lower-emitting equipment (financing new infrastructure, compensating for the additional costs associated with new equipment, etc.).

RECOMMENDATION N°2 (France/EU/World)

Facilitate financing for the replacement of old equipment with newer, lower-emitting equipment within the framework of the EU Taxonomy and/or using surcharge mechanisms.

RECOMMENDATION N°3 (France/EU/World)

Implement means of reducing energy consumption for aircraft operations.

- Flight: accelerate the implementation of the Single European Sky, the digitalization of air traffic control, the use of satellite tracking for transatlantic flights, and the development of flight formations to boost wake energy recovery.
- Ground: limit the use of APU when connected to the terminal, optimize taxiing and towing when relevant.

RECOMMENDATION N°4 (France/EU/World)

Promote intermodality for the start/end of trips, notably by ensuring connections between the main rail stations and the terminals to facilitate transitions, and by implementing integrated passenger transport pathways.

RECOMMANDATION n°5

Clarify the definition of SAF and ensure their use to achieve emission reduction goals.

a. (World) Establish SAF sustainability criteria shared by all countries and defined by ICAO, both in terms of the reduction of their life cycle emission levels, and the type of feedstock used.

b. (France/EU) Include hydrogen in the definition of SAF to allow the development of all sectors contributing to the decarbonization of air transport.

c. (EU/World) Expand the SAF blending mandate to all geographical regions, based on the European Refuel EU model; in Europe, be more ambitious than the 63% target for 2050 provided by Refuel EU Aviation, depending on the activation rate and the efficiency of the various decarbonization levers.

RECOMMANDATION n°6

Support supply to create a competitive SAF market in Europe.

a. (France/EU) Finance functional prototype projects for various technologies, including biofuels and synfuels, using EU ETS funds.

b. (France/EU) Set up Calls for Proposals (guaranteed price) and ensure the competitiveness of SAF produced in Europe during the first years (subsidies), in order to boost sector development in Europe and secure the launch of the first production units.

c. (EU) Dynamically adapt the SAF blending trajectory as defined in the framework of Refuel EU Aviation, in order to avoid plateau effects and to be consistent with the industrial environment; in this respect, an increase in the 2030 target could be considered.

d. (EU) Maximize production volumes, provide incentives (e.g., tax credits) to offset the cost premium between SAF and kerosene for blends above base requirements.

RECOMMANDATION n°7 (EU/World)

Limit distortions of competition between hubs/airlines.

a. In the short term, set up a European compensation mechanism applicable to all journeys departing from the EU. It should be proportional to the distance traveled by each passenger to subsidize the SAF blending at no additional cost compared to kerosene, thus avoiding competitive distortions and limiting risks of carbon leakage for journeys outside the EU not subject to the same SAF blend requirements.

b. In the medium term, allow for different speeds of implementation of SAF blend ratio requirements between countries/geographical regions without distorting competition between hubs/airlines; back SAF blending mandates at the point of departure for each passenger and throughout their journey.

c. In the long term, implement homogeneous SAF blend ratios at ICAO level.

RECOMMANDATION n°8 (France/EU)

Promote synthetic fuel to stimulate the development of a large-scale hydrogen production chain:

- Synfuel opens up a large volume market for hydrogen production in the short term and allows for the implementation of large-scale production facilities, which are essential for lowering costs;
- Synfuels make it possible to bypass the problems of transporting and storing hydrogen when there are no dedicated infrastructures;
- The synthetic fuel manufacturing process circumvents the issue of feedstock availability because it uses only air, water and electricity;
- Investments could then be used for the distribution of hydrogen to airports when hydrogen-powered aircraft are entered into service;
- The production of synthetic fuel also allows for the development of CO_2 capture technology.

RECOMMANDATION n°9 (EU)

In the short term, set up a mechanism to limit the distortion of competition related to connecting traffic between Europe and the rest of the world subject to the EU ETS, for example by maintaining a fraction of free allowances to ensure balanced competition with flights subject to the CORSIA system.

RECOMMANDATION n°10 (World)

Strengthen existing carbon quota systems and develop new mechanisms to extend their coverage to air traffic emissions not covered as of yet:

a. Encourage the implementation of ETS-type market mechanisms for domestic emissions in countries and regions outside Europe;

b. In the medium term, ensure the alignment of carbon allowance systems with each other and with the industry's “Net Zero” objective.

RECOMMANDATION n°11 (World)

Implement a massive investment policy for decarbonized energies that goes beyond the replacement of production methods currently used, in order to meet the new needs of transport players by 2050.

GLOSSARY

ACI: Airports Council International
ADEME: French Environment and Energy Management Agency
IEA: International Energy Agency
ASD: AeroSpace & Defense Industries Association of Europe
ATAG: Air Transport Action Group
ATM: Air Traffic Management
A4E: Airlines For Europe
BPI: Public Investment Bank (also known as Bpifrance)
CANSO: Civil Air Navigation Services Organization
CDO: Continuous Descent Operations
CII: French Innovation Tax Credit
CIR: French Research Tax Credit
COP: Conference of the Parties
CORAC: French Civil Aeronautics Research Council
CORSIA: Carbon Offsetting and Reduction Scheme for International Aviation
EASA: European Union Aviation Safety Agency
EEA: European Economic Area
ERA: European Regions Airline Association
EREA: European Research Establishments in Aeronautics
EU ETS: European Union Emission Trading Scheme
FAB: Functional Airspace Block
FABEC: Functional Airspace Block European Central
FEGP: Fixed Electrical Ground Power
GIFAS: French Aerospace Industry Grouping
GPU: Ground Power Unit
HEFA: Hydroprocessed Esters and Fatty Acids (Oil processing industry)
HEP: Hybrid Electric Propulsion
IAEA: International Atomic Energy Agency
IATA: International Air Transport Association
ICCT: International Council on Clean Transportation
IRENA: International Renewable Energy Agency
ICAO: International Civil Aviation Organization
PAC: Fuel Cell (=Pile à Combustible)
PBN / RNP (improved navigation): Performance Based Navigation / Required Navigation Performance
Project NextGen: Next Generation Air Transportation System
PCA: Pre-Conditioned Air unit
ANSP: Air Navigation Service Providers
PtL: Power to Liquid
RISE: Revolutionary Innovation for Sustainable Engines
RPK: Revenue Passenger Kilometer
SAF: Sustainable Aviation Fuels
EU ETS: European Union Emission Trading Scheme
SESAR: Single European Sky Air Traffic Management
SETI: Single Engine Taxi In (landing procedure)
SETO: Single Engine Taxi Out (take-off procedure)
TRL: Technology Readiness Level
VTOL: Vertical Take-Off and Landing
WEF: World Economic Forum

I

MASSIVELY WEAKENED BY THE CRISIS, THE AIR TRANSPORT SECTOR REMAINS CRUCIAL FOR EUROPE'S ECONOMY, TOURISM AND STRATEGIC FUTURE

1. Air transport is an essential sector for Europe's strategic sovereignty, the mobility of people and, more broadly, economic and human development

The first characteristic of air transport, compared with other transport modes, is that it essentially cannot be replaced by alternative means of transportation for long and very long-distance travel. The development of air travel has made it possible to connect any points in the world in less than a day, whereas the same journey would have taken several days or even weeks at the beginning of the 20th century. In this sense, the development of air transport has revolutionized the mobility model of Western societies and has been one of the elements which fostered the important globalization movement that characterized the second half of the 20th century. In addition to intercontinental links, for a number of geographical regions – particularly islands – air routes are now a near-vital need. For example, Indonesia, which is a very insular territory, carries each year a number of passengers (in domestic flights) equivalent to 15% of its population.

It should be mentioned that air travel is not exclusively used for business trips, and family travel accounts for a significant portion of flights (approximately 20% before the crisis). For France, besides tourism, air transport is essential to maintain a close connection with the 2.5 million French people living abroad, and with the 2.7 million French people living in the overseas territories and departments.

Air transport therefore plays an essential role in the mobility model of modern societies, and more generally in the functioning of our societies and their economies. It is a catalyst and gas pedal for connectivity, innovation and productivity. ATAG indicates that a 10% increase in air traffic would imply a 0.5% growth in GDP per capita long term.[1]

One economic sector to which air transport makes the greatest contribution is tourism. It accounts for several hundred million jobs worldwide and about 10% of global GDP. The level and growth of the tourism sector is directly dependent on people's ability to travel, and more specifically to fly. According to ATAG, the bulk (58%) of international transit tourists use air travel, while aviation supports an estimated 44.8 million tourism jobs worldwide, contributing approximately $1 trillion to global GDP.

Moreover, the importance of air freight should not be overlooked: while it represents only 1% of the overall volume of freight worldwide, it accounts for 35% of the value of freight in strategic sectors such as the pharmaceutical industry.

The aviation industry is one of the largest in Europe. According to ATAG, in 2018 the sector directly employed around 2.7 million people in Europe – the majority of whom are employed at airports. To these direct jobs must be added indirect and induced jobs, as well as jobs in the tourism sector for which

1 Air Transport Action Group: a coalition of organizations and companies in the air transport sector, with some 40 members, including the main aircraft manufacturers (Airbus; Boeing; Comac), engine manufacturers (GE; Pratt & Whitney; Rolls-Royce; Safran) and airline representatives. One of ATAG's goals is to address sustainability issues in the industry.

air transport is largely necessary. Overall, the contribution of air transport represented 13.5 million jobs in 2018 at the European level and contributed $991 billion to GDP.

Aeronautics is one of the main industrial sectors in France. GIFAS estimates that 194,000 people work in its member companies (mainly in the Paris region and the Southwest). In addition to GIFAS member companies, there are an estimated 350,000 direct industrial jobs in the aerospace industry in France.[2] Hence, France is home to a large number of players and this sector is one of the country's main industries. With sales of around €74 billion in 2019, of which two-thirds are exports, the aeronautics industry is one of the main contributors to the French trade balance.

Direct non-industrial jobs must also be added to the direct industrial job count – indirect and induced jobs as well as tourism jobs, which is a particularly important sector in France. Taking ATAG data into account, we can estimate that the positive impact of air transport in France represents several million jobs and several hundred billion euros.

Moreover, one of the most spectacular developments of the second half of the 20th century is the strong democratization of air transport, made possible by the significant drop in ticket prices. Since 1950, ticket prices have been divided by 7 and by half since 1980. In 2019, 4.5 billion passengers were thus transported by air (of which 58.4% were domestic passengers). As mentioned, the sharp drop in ticket prices has made air travel more accessible: the vast majority of people in developed countries have flown at least once in their lives, and nearly half have flown in the last 12 months (US and UK data). Finally, it should be pointed out that the cost reduction for air travel has been implemented at a time when the industry is bearing the cost of its infrastructure, unlike most other modes of transport.

2 Groupement des Industries Françaises Aéronautiques et Spatiales (GIFAS), website (Observatory/Employment & Training).

2. Domestic and international air traffic has been strongly impacted by the COVID-19 Crisis, putting pressure on the sector and its strategic scope which must be supported

The aviation industry has been particularly affected by the COVID-19 heath crisis. The first consequences were felt as soon as the various social distancing measures and epidemic prevention rules were put in place, notably the lockdowns implemented around the world. In April 2020, more than 64% of the global fleet had been grounded, and traffic was reduced by 94.4% compared to April 2019. Over the course of the year, passenger-kilometers were down 64.5%.

The first players to be affected by the decline in traffic were airports and airlines: the latter suffered heavy losses in 2020, estimated at $137.7 billion by IATA (compared with an average annual profit of around $30 billion before the health crisis). However, the repercussions of the crisis have been mitigated thanks to strong public support. IATA estimates that between the beginning of 2020 and August 2021, governments have granted $243 billion to companies to bolster their liquidity. This has helped limit the number of airline bankruptcies, which in 2020 were rather similar to the pre-crisis period (~45 bankruptcies per year). Governments have used various tools to support companies (capital increase, subsidies, loans, etc.), some of which will have to be repaid after the crisis. Moreover, airline companies borrowed heavily to cope with the cash flow hemorrhage caused by the decline in activity. As a result, their debt has increased by about 50%, from $430 billion in 2019 to $650 billion in 2021. Airports have also seen their economic model largely challenged by the crisis, insofar as they are highly dependent on air traffic (airline fees, parking, shops, etc.).

In France, the government has implemented significant measures to support the entire economy, including the air transport sector (government-backed loans, furlough), as well as specific measures (such as accelerated military orders) and direct support to Air France-KLM. On the whole, the State has mobilized some €20 billion for the industry, which has limited the number of company bankruptcies in the sector and maintained skills. At the same time, the modernization and diversification fund has mobilized nearly one billion euros and has helped to partially maintain investment dynamics.

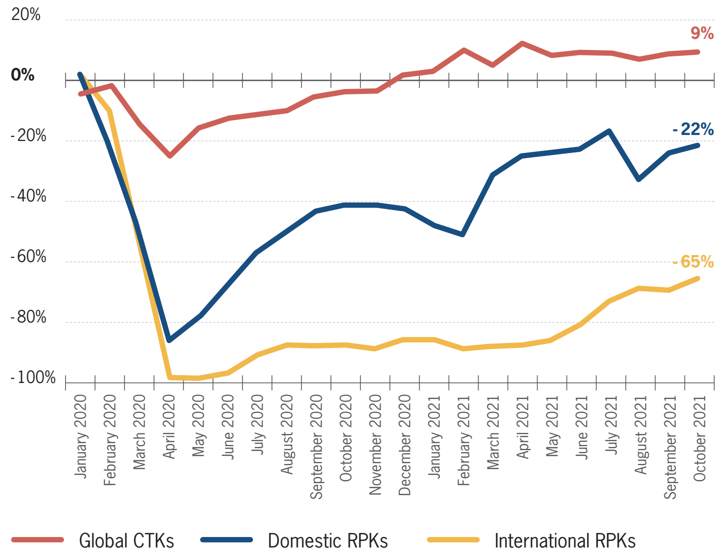
Overall and worldwide, the share of economic activity linked to air transport threatened by the health crisis is estimated at $1,700 billion by ATAG. Several million jobs have been impacted in the sector (2.3 million according to ATAG), a 21% decrease compared to the pre-health crisis situation. Airlines have plans to reduce their workforce and make savings.

From an industrial standpoint, the crisis was also heavily felt in 2020, with a notable 55% drop in aircraft deliveries compared to 2018 (also due to the 737 MAX crisis). The order volume has also been affected, mainly for long-haul aircraft. As a result, manufacturers have largely reduced production rates (by around 40%), with significant consequences for the industry's entire subcontracting chain.

While wide-spread vaccination against COVID-19 seems to offer a way out of the crisis, a full return to normalcy is yet to come following the appearance of new variants of the virus, and the implementation of new restrictive measures by governments to face the new waves of contamination. As represented in the graph below published by IATA, the situation is mixed:

Air traffic trends as of early 2020

(Unit: revenue passenger kilometer or cargo ton kilometer for freight)



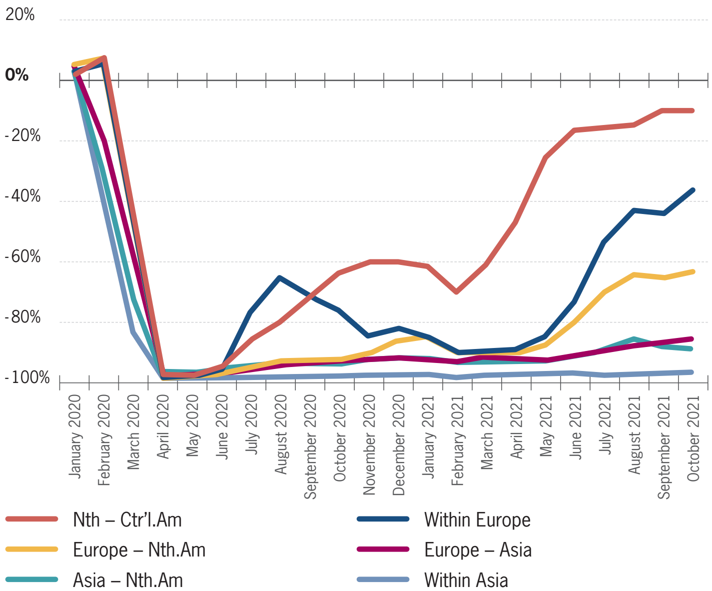
Source: IATA.

It shows that (i) the health crisis has had almost no impact on freight volumes, (ii) domestic traffic is showing a gradual but partial recovery and was 22% lower in October 2021 than in January 2020, and (iii) international transport is still heavily slowed down, at 65% below the January 2020 level.

There also remains a strong disparity in terms of traffic recovery depending on the geographical regions considered, as shown in the graph below.

Air traffic trends as of early 2020 by geographical connection

(Unit: in passenger kilometers)



Source: IATA.

Asia seemingly continues to be the continent most affected by the decline in traffic – while traffic levels in Europe and the United States are closer to those observed pre-crisis. Two factors explain these dynamics: the first is the difference in sanitary measures implemented in various countries, making the flow of passengers more complex; the second is the implementation of "Zero-Covid" policies in several Asian countries, making travel particularly difficult.

Finally, air traffic recovery prospects also differ according to the type of travel considered. While family travel (visiting relatives) will be the first to recover, business travel is more at risk, especially due to the development of teleworking and corporate budget cuts.

This uneven situation is noticeable in airlines' financial results. While not achieving pre-health crisis profits, the industry overall returned to profitability in the third quarter of 2021, for the first time since the last quarter of 2019, and despite the general increase in costs related to inflation and rising oil prices.

Therefore, the extent of the crisis combined with the uncertainty of full traffic recovery are very weakening factors for the sector, and it is difficult to assess the extent of the crisis' long term effects. The challenge of decarbonization is thus all the more daunting, insofar as it will require – as detailed in the rest of this report – very significant investments.

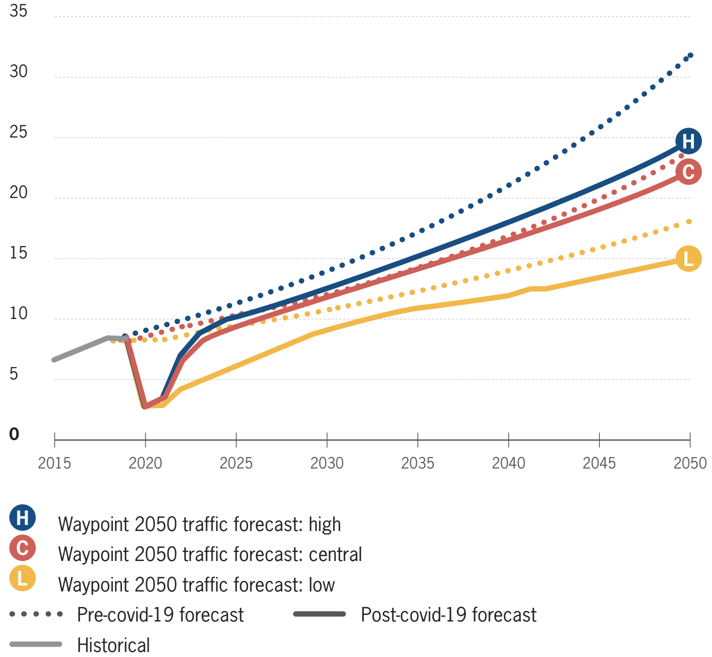
3. As a result, 2050 traffic forecasts have been reduced

In these uncertain times, forecasting is particularly difficult. At the beginning of the summer of 2020, consensus in the industry was that traffic would return to 2019 levels by 2023. Today, this objective has been postponed by one year and a return to the pre-crisis situation is not expected before 2024.

In the longer term, ATAG has revised the outlook for air traffic growth, with its central traffic forecast used for the Waypoint 2050 report being about 8% lower in 2050 than in a world without Covid. This forecast (see chart below), with significant margins of uncertainty, points to an average annual increase in air traffic of 3.1%, compared with 5.3% growth per year since 1990. This forecast implies a decrease of 8% in the level of traffic by 2050 compared with the forecast made before the health crisis.

ATAG forecasts for world air passenger traffic recovery

(Revenue passenger kilometers (RPKS))



Note: 8% reduction in 2050 traffic for central forecast

Source: Waypoint 2050, p17.

Traffic recovery dynamics and medium-term growth in global air transport will depend on several still uncertain factors, including (i) the actual date of recovery from the health crisis, when air traffic will return to its pre-health crisis level, (ii) the overall economic situation and the long-term impact of the health crisis on GDP growth in economies around the world, (iii) a possible reduction in leisure traffic due to concerns about the health status of destinations and the potential downside of quarantines, and (iv) a reduction in business/intra-corporate traffic in the medium term, due to new ways of operating (remote meetings, teleworking) and budget cuts.

II

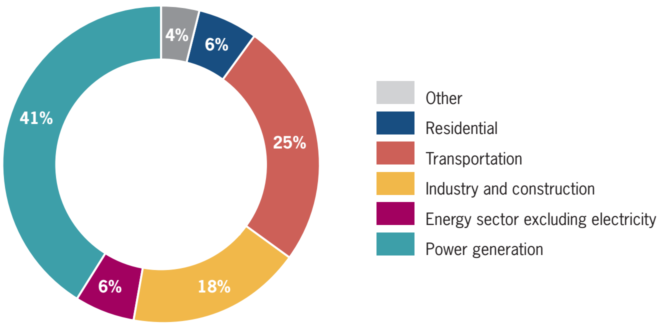
SECTOR PLAYERS HAVE DRAWN UP AN AMBITIOUS PLAN FOR DECARBONIZATION

1. Despite steady growth in air traffic since 1990 (~5% per year), the sector's level of CO_2 emissions has been contained thanks to aircraft improvements

First, the importance of air transport decarbonization should be put into perspective by recalling (i) the share of air transport emissions in total global emissions and (ii) the past trajectory of emissions growth.

According to ATAG, in 2019 air transport consumed 363 million liters of kerosene, which produced 914 million tons of CO_2. The sector's emissions thus represent 2-3% of total global emissions, and 10% of the transport sector's emissions – a level lower than shipping. Approximately 80% of emissions come from flights traveling more than 1,500 km (medium and long-haul).

Global CO_2 emissions share by sector

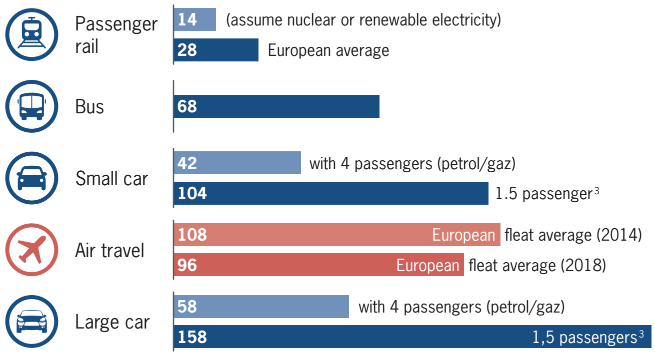


Note: Air transport accounts for 2% to 3% og global CO_2 emissions (~10% of the transport sector's CO_2 emissions).

Source: Ministry of the Ecological Transition, Key climate figures, 2018.

Comparing CO_2 emissions between different modes of transport

(Grams of CO_2 per passenger kilometre)



Source: Waypoint.

Compared to other transport modes, it seems clear that air transport is very efficient in its use of fuel, and thus in the carbon intensity associated with its consumption: per passenger-kilometer, air transport emits quantities of CO_2 comparable to automobile transport. However, this comparison has its limits insofar as each mode of transport responds to mobility needs that may be very different.

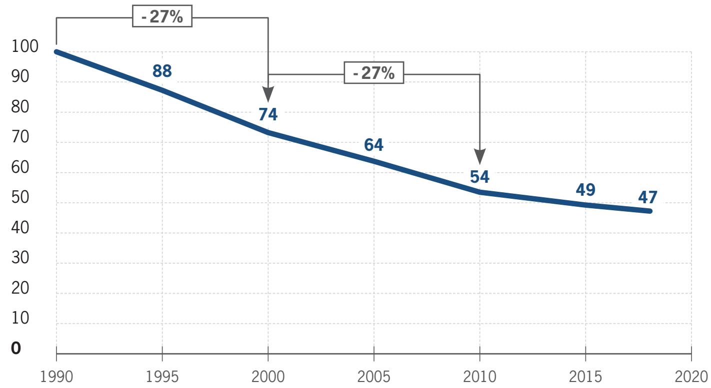
The energy efficiency of air transport has been made possible by continuous progress in aviation technology. Upgrades in aircraft and engine design have reduced fuel consumption per seat by 82% since 1960. Combined with improvements in operations and infrastructure, this continued progress has halved CO_2 emissions per passenger-kilometer since 1990, and has prevented the emission of 11 Gt of CO_2 since 1990.

3 Average occupancy of cars is around 1.5. These figures do not include embedded emissions from construction and maintenance of infrastructure, wich are less important for aviation.

Although this was mainly driven by a desire to lower costs, particularly for kerosene, this ongoing work in the industry has led to a reduction in its carbon footprint, despite the significant growth in the number of passengers carried. Today, aviation is a very efficient means of transportation, with emissions per passenger-kilometer comparable to those of private cars.

World fleet energy performance trends

(Unit: CO_2 / Revenue Tonne-Kilometer, base 100 in 1990)

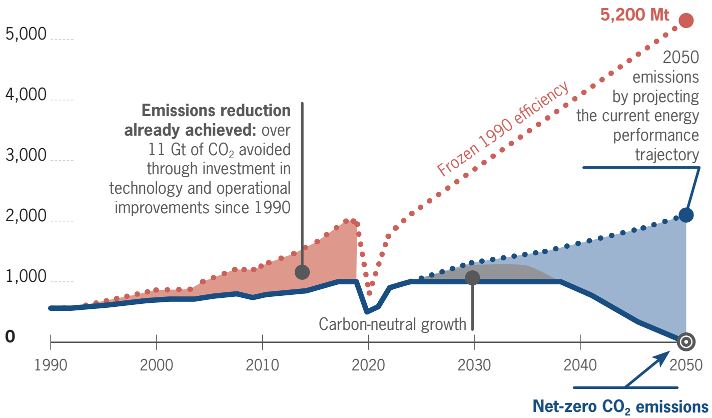


Source: IATA, fuel fact sheet, 2019.

A particularly revealing observation regarding the efforts already made by the industry to reduce its environmental impact is the decoupling of the increase in passenger numbers from the increase in emissions. Since 1990, the sector's CO_2 emissions have increased annually by 2.49%, while air traffic has grown by 5.33%.

World air transport CO_2 emission trajectories

(CO_2 millions of tonnes)



Source: Waypoint 2050 p14.

Therefore, the challenge for the industry is to take a further step in decoupling the volume of passengers carried from CO_2 emissions. In the absence of additional efforts, it is likely that air transport will continue to increase its emissions, in line with the increase in air traffic.

2. Growing environmental demands on air transport are prompting the main players to commit to an ambitious plan aimed at achieving carbon neutrality by 2050

Environmental pressure placed on air transport has accelerated considerably in recent years. The industry is under attack for both its emissions and its image, and the public's assessment of the industry's emissions is often greatly overestimated. This pressure has important consequences on the sector's image. For instance, the surveys conducted annually by ADEME indicate that 51% of French people say they are giving up flying for leisure, compared with only 36% in 2018.

In addition to these shifts at the individual level, calling for increased efforts from the industry, the major groups are also faced with growing restrictive climate measurement and reporting obligations, and are under pressure from both governments and investors.

Accelerating the reduction of aeronautics' environmental impacts is a major challenge for the industry, particularly insofar as (i) the high level of maturity of technologies implies a high cost for future incremental innovations, (ii) the introduction of disruptive technologies also require significant investments, and (iii) the industry's investment and profitability cycles extend over several decades, which implies limited fleet renewal.

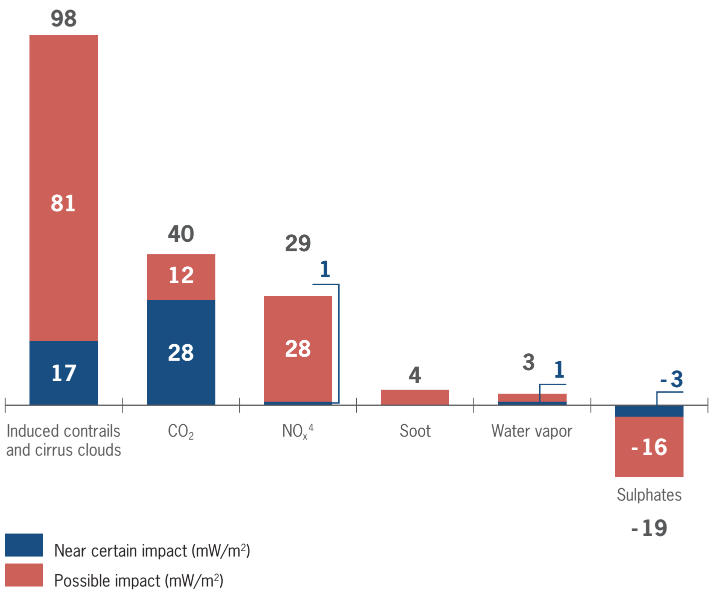
The industry has recently committed to achieving carbon neutrality by 2050. The purpose of this report is to identify and review the levers for achieving this target. In addition, some individual players have made commitments in the context of their carbon trajectory (AirFrance has indicated that it is aiming for a well below 2°C trajectory as part of the Science bases target model, and Airbus has announced the development of a hydrogen aircraft by 2035).

3. Environmental impact goes beyond the issue of CO_2

It should be noted that while this report focuses on reducing aviation CO_2 emissions, aviation also produces other types of greenhouse gases such as nitrogen oxides (NOx). Although not all gases have the same impact on the climate, CO_2 is the most notable greenhouse gas because of its lengthy lifespan (~100 years) compared to other greenhouse gases (e.g., about 1 day for NOx, or 10 years for methane produced by agriculture).

Impact of aviation products in terms of effective radiative forcing

(Unit: mW / m^2)



Source: Atmospheric Environment, Volume 244, The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018[5]. Archery Strategy Consulting analysis.

4 Net effect of NO_x emissions, part of wich are absorbed by the reaction with methane and water vapor in the upper atmosphere.

5 Atmospheric Environment, Volume 244 (D.S. Lee, D.W. Fahey, A. Skowron, M.R. Allen, U. Burkhardt, Q. Chen, S.J. Doherty, S. Freeman, P.M. Forster, J. Fuglestvedt, A. Gettelman, R.R. De Leon, L.L. Lim, M.T. Lund, R.J. Millar, B. Owen, J.E. Penner, G. Pitari, M.J. Prather, R. Sausen, L.J. Wilcox).

When airplanes fly through certain areas of the atmosphere, they leave contrails behind. The impact of these contrails (and the hazy cirrus clouds they sometimes generate) on climate change is still very uncertain. More research is needed to assess the exact impact of contrails on the greenhouse effect. Similarly, other gases emitted by aviation may have a positive or negative impact on the greenhouse effect.

Overall, the non-CO_2 impacts on global warming – which are subject to a higher level of uncertainty to date – could be more important than the CO_2 impacts. However, there is a methodological advantage in favoring the analysis of CO_2 impacts over non-CO_2 impacts, due to the precision of (i) the measurements of CO_2 emissions and their impacts and (ii) the forecasts of future emissions according to the levers activated in each scenario.

In addition, certain measures implemented to address CO_2 emissions can be considered to also have an impact on “non-CO_2 aviation” emissions (e.g., reduction of fuel consumption, optimization of flight and ground operations). In this respect, the alternative fuels presented later in this report contain fewer aromatics than fossil fuels (kerosene), which helps to limit the formation of condensation trails. Furthermore, there are other measures currently being studied to reduce non-CO_2 impacts, which are not addressed in this study. With regard to contrails, the optimization of flight plans to avoid formation zones (horizontal and/or vertical trajectory deviation) are being studied. Regarding NOx, research is underway to optimize flight levels to limit NOx emissions.

It should also be noted that global warming, and the resulting changes in temperature, humidity and wind, can induce positive or negative feedbacks on all the environmental impacts of aviation.

Finally, some measures that have a positive impact on a given environmental factor may also have a negative impact on another, highlighting a need for a global approach: even if this study focuses on the sector’s CO_2 emissions for reasons of methodological efficiency, all environmental externalities will have to be taken into account and mitigated, including other greenhouse gases as well as potentially negative impacts on air quality, water quality and biodiversity. This analysis also applies to all modes of mobility and their infrastructures.

For instance, the figure below presents a comparative analysis of the impacts associated with the creation of a new rail line (project cost: 14.3 billion euros)[6] and the use of existing means of transport – air and car – to connect Paris to Toulouse. This analysis shows the importance of taking all environmental consequences into account for each mode of transport, and can be compellingly reworked according to the geographic, demographic and economic context of a project.

6 La Tribune, *LGV Bordeaux-Toulouse: L'empreinte environnementale du GPSO scrutée à la loupe* (november 2021).

Comparing the environmental impacts of rail transport (HSR) and air transport

	Impact	HSR (Great South West Railway Project)	Airplane	Automobile
CO_2 emissions	**Creation of infrastructure**	**~3 MteqCO_2** • 327 km of HSR (Bordeaux-Toulouse section and Bordeaux-Dax section, with 55 km shared) • Development South of Bordeaux • Development North of Toulouse • New stations (Agen, Montauban, Mont-de-Marsan)	**Pre-existing** *at the airports of Bordeaux and Toulouse*	**Pre-existing** *Highway A10 (Paris-Bordeaux) Highway 162 (Bordeaux-Toulouse)*
CO_2 emissions	**Operating passenger lines**	**4 kg CO_2 / passenger** (Paris-Toulouse emissions by TGV)	**130 kg CO_2 / passenger** *(Paris-Toulouse emissions by plane)*	**40 kg CO_2 / passenger** *(Paris-Toulouse emissions by automobile)*
Other effects	**Ground surface area**	4,830 hectares of which: • 1,230 ha of agricultural land • 2,850 ha of silvicultural areas (forests)	**Pre-existing** at the airports of Bordeaux and Toulouse	**Pre-existing** Highways A10 / A62
Other effects	**Biodiversity**	**Important,** subject to compensation measures	**Limited**	**Important**
Other effects	**Noise emissions**	**Important** (moderate level over a long distance)	**Important** (mainly near airports)	**Important** (Moderate over a long distance)

Replacing part of the air traffic with rail traffic would **save ~0,3 Mteq$_{CO2}$ / year,** equivalent to an emissions **amortization period for the ~10 year transition process**

Source: Rapport de la commission d'enquête préalable à la déclaration d'utilité publique du Grand Projet Ferroviaire du Sud-Ouest[7]; Archery Strategy Consulting analysis.

7 GPSO / LN Inquiry Commission Report (March 2015).

Moreover, these comparative analyses between modes of transport must be carried out in a prospective manner. Indeed, it takes more than 15 years to develop a new high-speed line, which will require very large investments and have a strong impact on soil and biodiversity. However, by this time (2035), “Zero carbon” air alternatives should be available (e.g., hydrogen aircraft), which calls into question the trade-off between the creation of a new high-speed line and the use of air transport.

Lastly, emissions caused by the sector (e.g., in the tourism sector, which is very dependent on air transport economically) must be subject to specific actions in order to reduce their environmental impact.

III

DECARBONIZATION LEVERS EXIST AND MUST ALL BE ACTIVATED TO ENABLE THE AVIATION INDUSTRY TO MAKE ITS TRANSITION

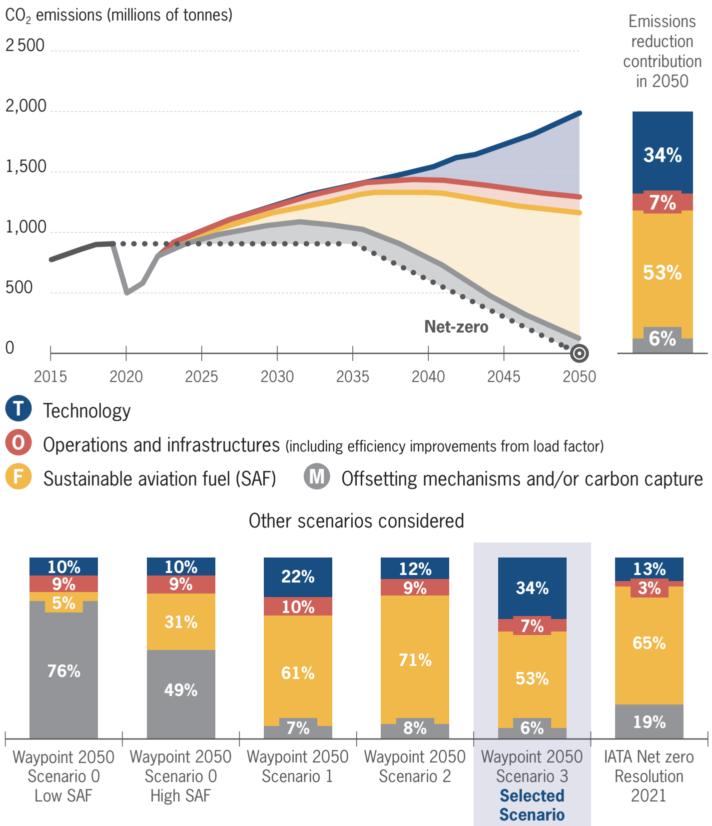
In order to fulfill its commitment to achieve carbon neutrality by 2050 – a commitment reiterated in Glasgow at COP 26 in November 2021[8] – the airline industry, under the aegis of ATAG, has considered several decarbonization scenarios in its *Waypoint 2050* study.[9]

8 COP: the Conference of the Parties is an international climate conference that brings together each year the signatory countries of the United Nations Framework Convention on Climate Change (UNFCCC). The 2015 edition (COP 21), hosted by France, adopted the Paris Agreement, which commits all countries in the world to reduce their greenhouse gas emissions and keep global warming below 2°C by 2100. While significant progress was made at the 2021 edition (COP 26) organized by the United Kingdom (e.g., global commitment on methane), additional efforts will be needed in the coming years to comply with the Paris Agreement (e.g., coal phase-out).

9 ATAG, *Waypoint 2050 - A vision of net-zero aviation by mid-century* (2nd edition, September 2021).

World air transport decarbonization scenarios

Scenario 3 – Waypoint 2050



Source: Waypoint 2050 p26, ATAG, IATA[10], Fly Net Zero p5 à p8.
Archery Strategy Consulting analysis.

10 International Air Transport Association, *Fly Net Zero – Airline commitment to Net Zero 2050* (octobre 2021).

Four main levers for improvement are identified to achieve the decarbonization goals:

- Technological developments (e.g., aircraft aerodynamics, engines) and their integration into the fleet;
- Optimization of flight and ground operations (e.g., flight path, aircraft maintenance);
- The use of Sustainable Aviation Fuels (SAF) (e.g., biofuel produced from forest residues or microalgae);
- The use of compensation measures (e.g., forestry, natural carbon sinks, CO_2 capture/storage).

The scenarios differ in their use of the various improvement levers:

- The baseline scenario (scenario 0) is a continuation of current efficiency trends in technology without accelerating improvements; regardless of the level of SAF blending considered (5% to 31%), success in meeting the neutrality objectives mostly relies on CO_2 capture or carbon mitigation measures (49% to 76%);
- In scenario 1, technological improvements are boosted by the integration of disruptive technologies (22%), in particular with the fleet transitioning to hybrid/electric aircraft and using innovative architectures from 2035/40; the objective of carbon neutrality is achieved through the use of large quantities of SAF (61%);
- In scenario 2, technological improvements include new aircraft configurations but no significant switch to electric or hybrid engines; the objective of carbon neutrality is once again achieved through the use of SAF in very large quantities (71%);
- In scenario 3, use of technological developments is more significant (34%), with electric aircraft up to 100 seats (regional), zero emission aircraft (powered by decarbonized hydrogen)[11] for the 100-200 seat segment (short and medium haul), and non-conventional aircraft with hybrid-electric propulsion for larger aircraft; the weight of SAF remains the driving force in this scenario to achieve carbon neutrality (53%).

11 Decarbonated hydrogen is defined as that created by renewable (e.g., wind) or low-carbon (e.g., nuclear) means of production.

This report therefore includes the conclusions of the detailed Waypoint 2050 analysis: it choses to focus on **scenario 3**. The decarbonization trajectory selected is therefore based on the following mix of improvement levers:

- ~34% on technological developments;
- ~7% on the optimization of flight and ground operations;
- ~53% on the use of alternative fuels (SAF);
- ~6% on mitigation measures.

This scenario is the most proactive in terms of technological progress and is in line with recent announcements by aircraft and engine manufacturers:

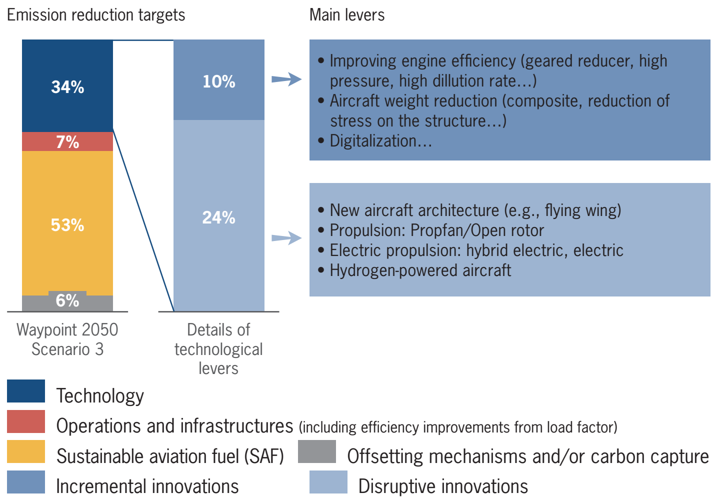
- Hydrogen-powered aircraft project announced by Airbus to be put into service by 2035;
- The RISE (Revolutionary Innovation for Sustainable Engines) functional prototype announced by CFM International offers a 20% reduction in fuel consumption compared to the LEAP engines used on the Airbus A320neo and Boeing 737 MAX; combined with changes to other aircraft components, a 30% reduction in fuel consumption is possible for medium-haul aircraft;
- Ultrafan functional prototype announced by Rolls-Royce with a 25% fuel saving compared to the first generation Trent engines.

Moreover, this scenario appears to offer the best balanced between the two main levers (technological developments and SAF): it takes into account the inherent limitations of SAF production by 2050: limited availability of economically exploitable inputs for biofuels, and significant generation of decarbonized electricity for the production of synthetic fuels.

1. Implementation of disruptive technological innovations is essential to reduce aircraft consumption

Technological developments include **two types of evolution: incremental and disruptive.** They are distinguished essentially by their level of technological maturity (TRL)[12] to date and the depth of the change compared to the historical 10 architecture of the aircraft.

Technological contributions to the emissions reduction target



Source: Waypoint 2050; Archery Strategy Consulting analysis.

12 The TRL (Technology Readiness Level) measurement system is used to assess the maturity level of a technology. The scale has 9 maturity levels (from 1 to 9 – low to high): the higher the level (close to 9), the more mature the technology is to be marketed.

1.1. Incremental innovations

RECOMMANDATION 1A (World)
Accelerate incremental changes in consumption reduction.

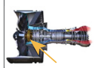
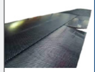
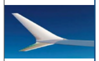
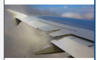
Incremental developments are based on **mastered architectures and technologies** that will contribute to the achievement of the emission reduction targets (~10% of the ~34%):

- Optimize **engine efficiency** (use of geared engines, engines operating at higher pressure, installation of larger rotors…);[13]
- Improve **aircraft structure** (composite materials, winglets, adaptable flaps…), in order to improve aerodynamics or lighten weight;
- Increase use of **digitalization** (deployment of sensors, calculations…), allowing an optimized use of aircraft.

The concept of these developments is now well understood and their implementation in new aircraft is only a matter of time. The earlier they can be implemented in fleets, the greater their impact on emissions. Therefore, it is essential to maintain efforts in incremental innovations in order to secure their early roll-out.

13 A visible module at the inlet of the turbojet engine, consisting of blades or vanes that suck in and compress the air within the engine, and whose size strongly impacts its fuel consumption.

Overview of incremental innovations

Technology	Description	Maturity	Perimeter	Illustration
Gearbox motors E	**Using a gearbox to separate the speeds of the turbojet engine components:** optimizes engine efficiency	In progress: the Pratt & Whitney engine	SH MH LH	
Composite structures for wings and fuselage	**Increasing the use of composite materials that are lighter** than the metals currently used: reduces the weight of the aircraft and therefore fuel consumption	Already used to varying degrees	SH MH LH	
Winglets	**Modifying the wingtips to reduce the drag induced by the wingtip vortices:** improves aircraft aerodynamics	Widespread except on some older models	SH MH LH	
Lighter loads on the wings	**Using adaptive flaps to limit the level of stress on the wings and thus reducing the weight of the aircraft:** lightens the aircraft and reduces fuel consumption		SH MH LH	
Integrated Aircraft Health Monitoring	**Using sensors to detect damage to the structure and identify maintenance/repair needs more quickly:** reduces structures and therefore weight thanks to tailored maintenance cycles		SH MH LH	
Advanced digitalization of flight controls	**Increasing and improving on-board computers:** optimizes commands & controls and navigation which reduces fuel consumption		SH MH LH	
High pressure reactors E	**Operating engines at higher pressures to improve** engine performance: reduces aircraft weight and improves turbojet efficiency	TRL 8	SH MH LH	

…/…

Overview of incremental innovations

Technology	Description	Maturity	Perimeter	Illustration
Riblets	**Creating grooves on aircraft walls:** reduces frictional drag, thus increases the efficiency of the aircraft and reduces fuel consumption	TRL 8	SH MH LH	
Fuel cells for auxiliary systems	**Replacing auxiliary power units** (supplying electricity to various aircraft systems) **running on kerosene with a hydrogen-powered fuel cell:** reduces kerosene consumption	TRL8 – tests spécifiques à prévoir pour aviation	SH MH LH	
Ultra High Bypass Ratio engines (UHBR) E	**Installing larger rotors:** increases dilution rates and therefore decreases fuel consumption	TRL 5	SH MH LH	

TRL level [1;3]: Research

TRL level [4;6]: Under development

TRL level [7;9]: Being deployed

Commercialized; Can be more widespread / improved

TRL: Technology Readiness Level = Maturity of the technology

E Engine technology

SH Short-haul MH Medium-haul LH Long-haul

Source: Waypoint 2050; Archery Strategy Consulting analysis.

1.2. Disruptive innovations

Other more radical developments, or disruptive innovations, are essential to achieve the CO_2 reduction objectives (~24% of the ~34%). These innovations will tackle the engine on the one hand, and the structure of the aircraft on the other.

Motorization

First, regarding the engine, technological developments can be made in three main areas: design, hybrid/electric motorization and use of hydrogen as fuel.

Overview of disruptive innovations in motorization

Technology	Description	Maturity	Perimeter	Illustration
Open rotor	**Placing the rotor outside the nacelle:** increases dilution rates and reduce consumption		SH MH LH	
Hybrid electric propulsion	**Combining and/or alternating electric and thermal propulsion:** reduces fuel consumption amplified by a possible reduction in the size of combustion engines and therefore in weight		SH MH LH	
Electric propulsion	**Using electric motors to activate traditional thrusters** (or a series of small rotors) powered by batteries or fuel cells: eliminates fossil fuel consumption		SH MH LH	
Hydrogen Aircraft	**Using hydrogen as fuel** (either in a thermal reaction to power traditional engines, or in a chemical reaction to power a fuel cell that powers an electric motor): eliminates fossil fuel consumption		SH MH LH	
Reactors integrated in the fuselage Boundary Layer Ingestion	**Placing the engines at the back of the fuselage** so that the fan absorbs the air passing through the fuselage: reduces part of the drag		**TBD**	

Source: Waypoint 2050; Archery Strategy Consulting analysis.

Engine design

The design objective is to break with traditional reactors and develop new architectures. One of the most advanced projects focuses on the use of a propfan (Open rotor). CFM International has officially launched the CFM RISE technology development program in 2021, which will feature an Open rotor.[14/15] The new design is expected to reduce fuel burn and CO_2 emissions by more than 20% compared with the current generation of LEAP engines,[16] while maintaining comparable cruise speed (~0km/h95) and noise performance. LEAP has already achieved fuel burn and CO_2 emissions reductions of about 15% compared with the previous generation of engines (CFM56).[17]

Hybrid/electric aircraft

Numerous hybrid or electric aircraft concepts are under development, some of which are intended for commercial-scale operation. This is the case for several French startups such as VoltAero (Cassio 1 hybrid electric 4-seater), Mauboussin (Alerion M1H hybrid electric two-seater) or Ascendance Flight (VTOL hybrid electric 4-5-seater),[18] but also for large groups such as Airbus (VTOL CityAirbus Nextgen electric 4-seater).

Given this momentum, electric propulsion could begin to enter the small aircraft market (2 to 6 passengers) by 2025. These aircraft could be viable alternatives in certain areas, such as flying cabs or medical transportation in congested cities. Although these aircraft are not included in the scope of the Waypoint 2050 analysis, they are a necessary step to subsequently developing these technologies for commercial-sized aircraft (for regional transport).

14 Joint venture between the American engine manufacturer GE and the French engine manufacturer Safran (Safran Aircraft Engines).
15 Revolutionary Innovation for Sustainable Engines.
16 Successor to the CFM56 engine that powers the latest generation of short-haul programs (A320neo, B737max, C919).
17 Safran, *LEAP-1A: a new generation engine for the A320neo family* (website).
18 Vertical Take-Off and Landing: vertical take-off and landing aircraft, designed to bypass the need for runways.

However, scaling up electric technologies for short-range (up to ~90 minutes, 100 seats or so), all-electric or hybrid civil aircraft currently poses a number of challenges:

- Although battery technology has evolved rapidly in recent years, in part due to an accelerated deployment in the road vehicle market, the energy density of a conventional lithium-ion battery (~250 Wh/kg) is still insufficient to power an aircraft even though it is reaching the levels required by small aircraft (750 to 2,000 Wh/kg). Whether through advances in this technology or through alternative technologies (e.g., lithium-sulfur), it is reasonable to expect that an energy density of 800 Wh/kg could be achieved by 2050;
- While liquid fuel allows the aircraft to get lighter as it flies and burns fuel, batteries do not get lighter as energy is consumed: this limiting factor further restricts the aircraft's range and restricts the use of batteries to very short trips;
- Although the fire safety of lithium batteries has improved significantly in recent years, it will still be essential to have stringent testing and certification processes in place to ensure that electric aircraft meet the very high safety standards of commercial aviation.

As an alternative to electric batteries, fuel cells can produce electricity on board from hydrogen. But here again, their low energy density (1 to 2 kW/kg) currently limits their application to functional prototypes for very small aircraft. There are many projects, including one by Californian company ZeroAvia, which has flown a small aircraft (Piper Malibu M) equipped with an electric motor and a fuel cell.

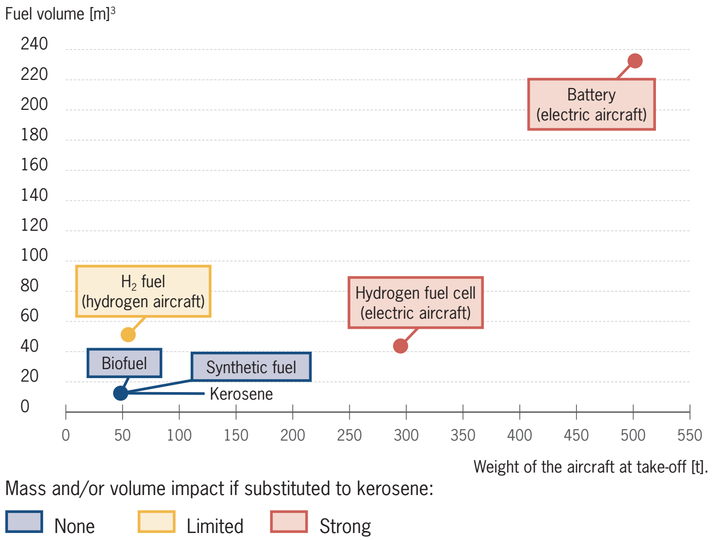
Given the significant challenges tied to the development of larger all-electric aircraft, hybrid electric aircraft may be a technically feasible intermediate step towards full electrification. This hybrid electric propulsion can be achieved by combining a turbojet engine (or turboprop) with an electric propulsion chain (series or parallel). This concept has already been used for over 20 years in the automotive industry.[19]

19 The first mass-marketed hybrid car was the Toyota Prius, which was introduced in 1997.

In this overview of technological solutions aimed at replacing conventional kerosene, a fundamental issue remains the impact of weight and volume carried in the aircraft: to date, only the replacement of kerosene by an alternative fuel (biofuel or synfuel) is neutral in terms of aircraft weight at take-off or volume occupied by the fuel, all other things being equal. The use of H_2-fuel impacts the volume available in the aircraft and limits aircraft range, and the use of hydrogen fuel cells or batteries adds considerably to the weight of the aircraft. In addition, battery volume is much greater than kerosene volume.

Aircraft propulsion system impact by volume and mass

(for a 200 passenger aircraft traveling a distance of 2,000 km)



Source: Clean Sky 2, Fuel Cells and Hydrogen[20], *analyses Archery Strategy Consulting.*

Based on current knowledge, it seems unlikely that fully electric aircraft with more than around 100 seats will be technically feasible and enter service by 2050. While the technical challenges remain for the 50-100 seat segment, activity is growing in the sub-19 seat segment, which accounts for less than 1% of total fuel consumption (CO_2 emissions) in global aviation.

For the medium- and long-haul aircraft segments, only hydrogen and synthetic fuels are accessible technologies.

Hydrogen aircraft

Unlike the fuel cell, where hydrogen (H_2) is used as fuel and coupled with the combustive O_2 to generate electricity, the objective here is to use H_2 as a direct fuel for a turbojet engine.

In terms of fuel, hydrogen appears to be one of the best candidates to decarbonize future aircraft and is one of the solutions favored by aircraft manufacturers for 2035, because it provides more energy than most common fuels and, unlike carbon-based fuels, it only produces water during combustion. Furthermore, while the infrastructure network (transportation and storage) does not exist today, aviation fuel distribution is highly centralized and can easily supply a small number of airports while covering a significant portion of global air traffic (in 2017, the top 100 airports generated nearly half of the world's air passenger traffic).[21]

This configuration requires technological developments, the main challenge being the transportation of hydrogen on board an aircraft in sufficient quantity, because although it is about three times lighter than kerosene, H_2 is about four times bulkier for the same on-board energy use. To create this space, the industry is considering placing tanks in the rear fuselage, which would be lengthened. This would not only affect the aerodynamic performance of the

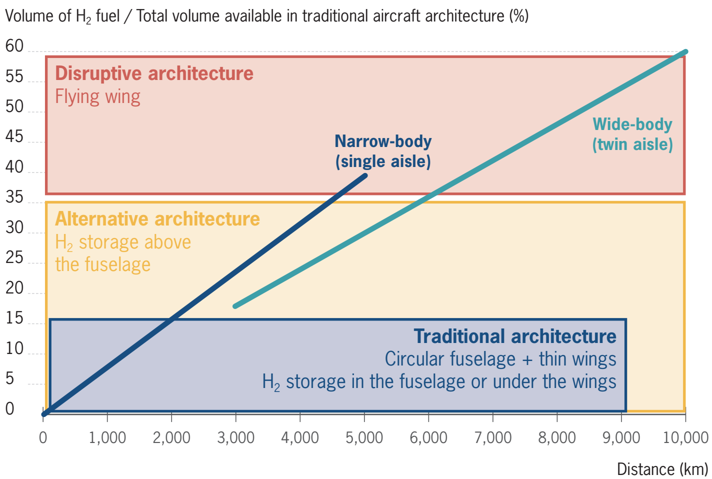
20 *Clean Sky 2 and Fuel Cells and Hydrogen* are public-private partnerships, the former to develop technologies to reduce noise and CO_2 emissions and other gases in aviation, and the latter to develop fuel cell and hydrogen technologies. Both are funded by the European Commission, industry and research centers/universities.

21 Airports Council International (ACI).

plane, but it would also be necessary to store H_2 in liquid form to gain space (at -253°C). However, storing such a volume of H_2 at -253°C and maintaining it at this temperature will require the use of a cryogenic system and a specific tank structure, which gives rise to several challenges: thermal insulation, resistance to vibrations and shocks, contained weight, tightness to avoid hydrogen leakage (transience), etc.[22] If these properties are mastered individually, the challenge is to combine them within a single solution.

Under these conditions and with the classical first generation aircraft architecture, a range of about 2,000 km seems possible. Beyond that, alternative architectures (storing H_2 above the fuselage) or even disruptive architectures (flying wing) will have to be considered.

Hydrogen volume needed according to distance traveled

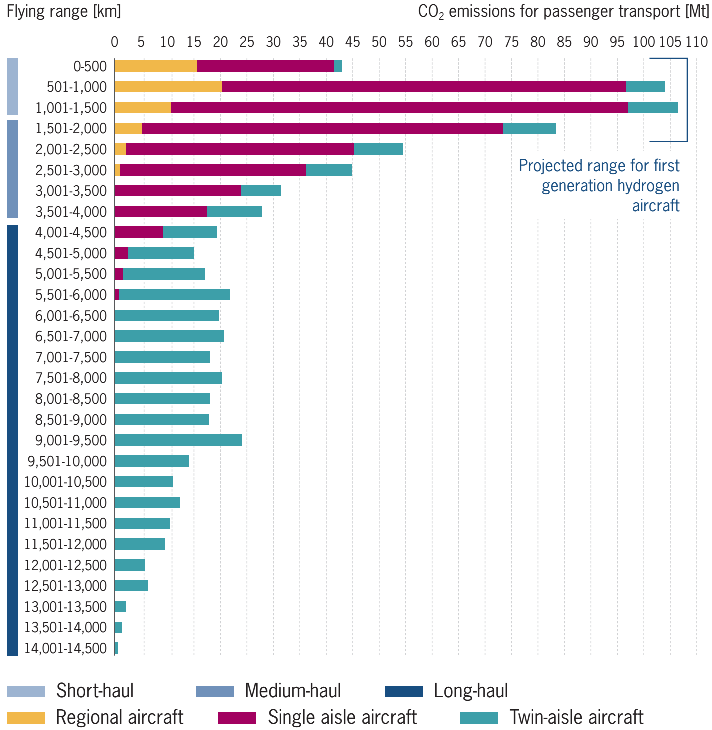


Source: Archery Strategy Consulting analysis.

22 Property of hydrogen which, at this temperature, passes through materials.

This range would be sufficient to cover ~42% of aviation emissions (largely regional and single-aisle aircraft).

Aircraft CO_2 emission levels according to range worldwide



Source: ICCT[23], CO_2 emissions from commercial aviation; Archery Strategy Consulting analysis.

23 International Council on Clean Transportation: a non-profit organization dedicated to producing impartial technical and scientific reports for environmental regulators.

Technological levers focused on short- and medium-haul aircraft

The decarbonization trajectory will differ greatly depending on the passenger segment considered. While the use of SAF is now possible for all segments, the use of the aforementioned technologies (battery electric, hydrogen fuel cells, hydrogen fuel) is very uneven.

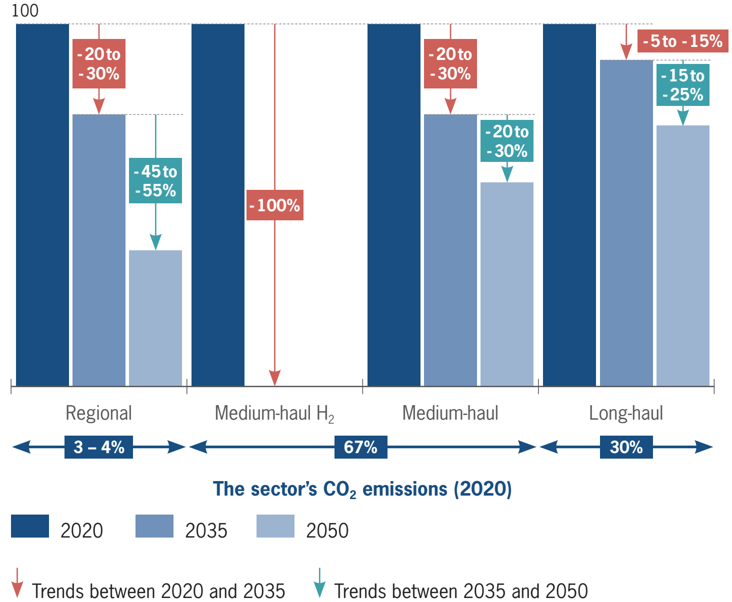
- Regional flights (9-10 and 50-100 seats), which account for ~3-4% of the sector's CO_2 emissions (worldwide), could rely on (hybrid) electric propulsion and hydrogen fuel cells to gradually decarbonize;

- Short- and medium-haul flights (100-250 seats), which account for ~67% of CO_2 emissions (worldwide), could benefit from a kerosene alternative with hydrogen propulsion, and from significant performance improvements;

- Finally, long-haul flights (250+ seats), which account for the remainder (~30% of global CO_2 emissions), will have no alternative but to rely entirely on SAF.

Expected reduction in kerosene consumption by aircraft class

(Kerosene consuption – base 100 in 2020)

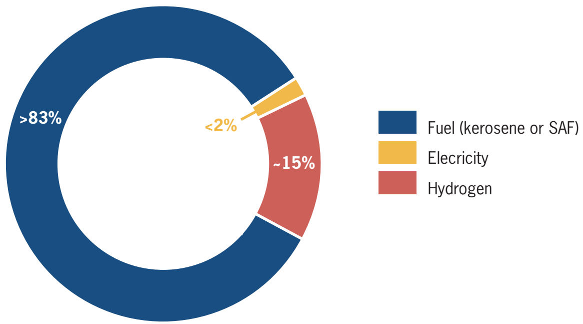


Source: Destination 2050; Waypoint 2050; Working Group; Archery Strategy Consulting Projection.

Consequently, while the aviation industry is mobilizing to make increasingly efficient and low-carbon aircraft viable, a very large proportion of commercial aircraft (>80%) will continue to be powered by conventional engines, fueled by conventional (kerosene) or alternative (SAF) fuels. This is particularly true for long-haul flights, for which no alternative seems to be available by 2050.

Breakdown of global aviation energy demand by fuel type in 2050

Global aviation energy demand in 2050: ~600 Mtoe

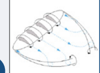


Source: Waypoint 2050; Archery Strategy Consulting analysis.

Aircraft structure

The main technological developments in aircraft structure aim to improve aerodynamics and lift. The considered modifications target both the wings (size, curvature, number, etc.) and the body of the aircraft (connection of the wings to each other, integration of the wings into the fuselage, etc.).

Overview of disruptive structure innovations

Technology	Description	Maturity	Perimeter	Illustration
Laminar flow control	**Modifying the aircraft skin to optimize airflow:** maintains efficiency over time and therefore reduces fuel consumption	TRL 7	SH MH LH	
Improvement of wing curvature	**Optimizing the curvature of the wings during flight to improve the efficiency of the aircraft:** improves lift and thus aircraft efficiency	TRL 6	SH MH LH	
Strut-Braced wing / Truss-Braced wing	**Increasing wingspan supported by masts:** reduces drag and increases efficiency		SH MH LH	
The Canard configuration	**Installing lifting surfaces at the front of the aircraft** (in front of the wings): eliminates tail drag (lifting surface at the back) and improves efficiency	Advanced for military use, not civil use	SH MH LH	
Blended Wing Body	**Changing the body of the aircraft to integrate the wings to the fuselage** (no clear differentiation between the two): improves the lift/drag ratio and thus the aircraft's efficiency		SH MH LH	
Box Wing	**Changing the body of the aircraft to connect the wings together** and encompass the fuselage: reduces drag and therefore fuel consumption		SH MH LH	

TRL level [1;3]: Research

TRL level [4;6]: Under development

TRL level [7;9]: Being deployed

Commercialized; Can be more widespread / improved

TRL: Technology Readiness Level = Maturity of the technology

SH Short-haul MH Medium-haul LH Long-haul

Source: Waypoint 2050; Archery Strategy Consulting analysis.

Funding innovation

RECOMMANDATION 1B (World)

Maintain investment dynamics for disruptive technologies, especially for: new aircraft shapes, new engines (including electrification), hydrogen-powered aircraft.

The sector's manufacturers are massively investing in R&D using their own funds. For example, aircraft manufacturers Airbus and Boeing invested more than €3 billion in equity in 2019, while engine manufacturers Safran and Rolls-Royce self-financed more than €1 billion in R&D the same year. [24]

Companies in the aeronautics sector also have access to several forms of public subsidies to finance innovation.

The European Union launched an aviation research and innovation program, *Clean Aviation*, at the end of 2021, as part of the European Green Deal presented in 2019 (the overall goal is to reduce greenhouse gas emissions in Europe to zero by 2050). The program focuses on three main areas of research: hybrid and fully electric concepts, ultra-efficient aircraft architectures, and disruptive technologies to run aircraft on hydrogen. Running from 2021 to 2031, this public-private partnership between the EU and the European aviation sector will have a total budget of more than €4.1 billion, of which €1.7 billion will be funded by the EU.[25] Clean Aviation is the successor to the Clean Sky 1 and 2 PPPs (launched in 2008 and 2014, respectively), which supported research and innovation to reduce CO_2, NO_x and noise emissions.

24 Airbus: 2019 Annual Report | Boeing: 2019 Annual Report and website Innovation tab | Safran: 2020 Annual Report | Rolls-Royce: 2019 Annual Report; Level of R&D investment reported at Group level.

25 European Union, Clean Aviation, *Clean Aviation seeks scientific advice* (23 November 2021).

In France, the main mechanisms are: corporate tax credit through the research tax credit (CIR) or the innovation tax credit (CII); the possibility of repayable advances and subsidies granted by various organizations, such as Bpifrance or regional funds.[26] In 2008, the French government created CORAC,[27] an organization to oversee innovation in the aerospace industry. This body is chaired by the Minister of Transport and brings together all the players in the sector (aircraft manufacturers, engine manufacturers, systems manufacturers, equipment manufacturers, specialized SMEs), in order to define the sector's research program in line with objectives based on the major environmental themes, safety and competitiveness (e.g., digitalization of the supply chain). Practically speaking, CORAC provides financial support for functional prototype projects aimed at reducing emissions (atmospheric pollutants, noise), improving safety in the face of growing air traffic, or supporting the emergence of new forms of mobility (e.g., flying cabs). For instance, the EcoPulse hybrid aircraft project led by Airbus, Daher and Safran received €11 million in funding in 2019.[28] While CORAC previously had an annual budget of €135 million, it has been entrusted with the management of an exceptional budget through the "France 2030" plan, which provides €4 billion in support for the automotive and aeronautical industries.[29] With this unprecedented budget, the Government is demonstrating its determination to succeed in developing low-carbon aircraft by 2035.

It should be noted that all these innovation support measures are separate from the Ace Aéro Partenaires fund (Ace Capital Partners, a subsidiary of Tikehau Capital). This fund, launched in 2020 and dedicated to the rescue and restructuring of the French aeronautics industry, should enable the emergence of a stronger ecosystem of subcontractors in an industry that still has a large number of hyper-specialized SMEs. This ecosystem will be essential to guarantee the production of new generation aircraft. By the end of 2021,

26 Public Investment Bank.

27 French Civil Aeronautics Research Council.

28 The first flight planned for 2022.

29 Government, *France 2030 Plan: €30 billion investment in advanced technologies* (October 2021).

the fund will have invested €200-250 million of the €750 million raised from the French government (€200 million) and prime contractors (Airbus, Safran, Dassault, Thales).[30]

Certification

RECOMMANDATION 1C (World)

Prepare the certification model for disruptive innovations.

Certification is a long and highly standardized process (individual testing of the various parts making up the aircraft, tests on the ground or on other aircraft, wind tunnel tests, simulator tests, use of prototypes for tests, etc.), in which the tests are carried out by the manufacturers under the control of the certification authorities.

For some functions, a large part of the certification is based on the experience acquired by the manufacturer through large volumes of past flights with aircraft using said functions. This will not be possible for certain disruptive innovations for which it will be important to determine very early on in the aircraft definition process which demonstration elements are expected to ensure the certification of these new aircraft.

These expected demonstration elements will also have to be shared between all the certification agencies worldwide, at the risk of seeing an aircraft certified in only one part of the world. Furthermore, there is no doubt that in the case of a disruptive innovation, agencies in different geographical areas will request an independent analysis of the aircraft.

30 GIFAS, *Consolidation strengthens in aeronautics* (October 2021).

Mechanism ensuring the competitiveness of lower emission equipment

RECOMMANDATION 1D (World)

Establish mechanisms to ensure competitive costs for lower-emitting equipment (financing new infrastructure, compensating for the additional costs associated with new equipment, etc.).

To support some of the anticipated innovations, such as hybrid/electric or hydrogen aircraft, there will be a need to adapt existing airport infrastructure to provide high power electricity or hydrogen. Future low-emission aircraft may therefore face barriers to deployment due to the investments required to adapt infrastructure, as is the case in other industries (e.g., electric cars). This is especially true since the number of H_2 aircraft flights from the same airport on which to amortize this additional cost is likely to be very limited when these aircraft are launched: it is not possible to pass on the full cost of the new infrastructure to these few daily flights, at the risk of heavily impacting their operating costs.

Moreover, the economic model of these new aircraft could be affected: a battery charging time or H_2 refueling time longer than for kerosene aircraft refueling will reduce the number of daily rotations that they can be perform.

It will therefore be necessary to anticipate these potential pitfalls alongside the development of these new generations of aircraft, and to set up mechanisms to ensure their competitiveness as soon as they enter service (e.g., airports, airlines, etc.).

2. Equipment renewal is a short-term lever, easily activated, benefiting quickly from technological evolutions

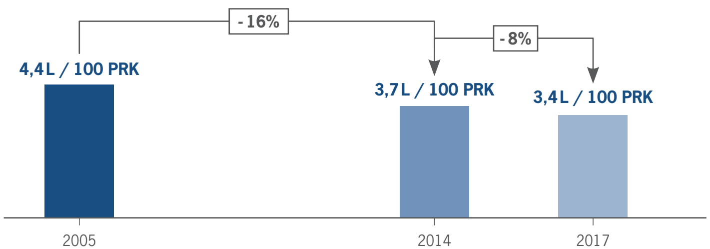
RECOMMANDATION 2 (France/EU/World)

Facilitate financing for the replacement of old equipment with newer, lower-emitting equipment within the framework of the EU Taxonomy and/or using surcharge mechanisms.

2.1. The equipment renewal challenge

The average fuel consumption per commercial flight is trending downward thanks to new, more efficient aircraft (from 4.4 L / 100 RPK in 2005 to 3.4 L / 100 RPK in 2017).[31]

Average fuel consumption trends per commercial flight



Source: European Aviation Environmental Report 2019, p7[32].

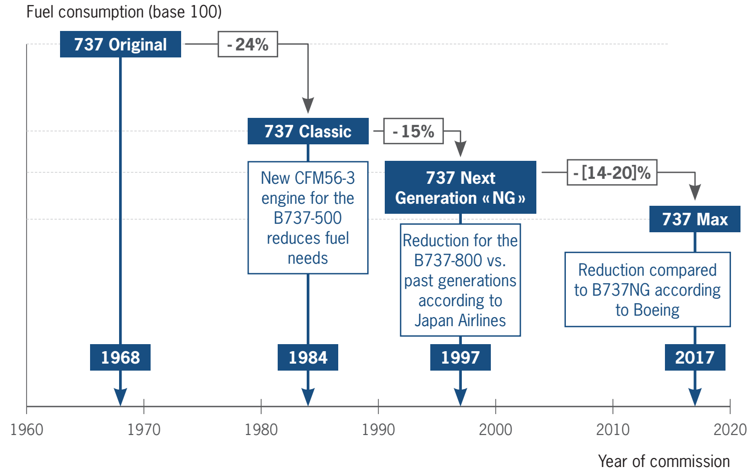
31 Revenue Passenger-kilometer (RPK): industry metric that calculates the number of kilometers traveled by paying passengers.

32 EEA, EASA, and Eurocontrol, *European Aviation Environmental Report* 2019 (January 2019).

The renewal of aircraft thus makes it possible to harness the beneficial effects of technological developments in favor of reducing fuel consumption and by extension CO_2. The older the fleet in service, the greater the potential for lowering CO_2 emissions.

In practical terms, aircraft manufacturers renew their models every 15 to 20 years, each generation results in an increase in fuel efficiency. Over the past 50 years, the Boeing 737 family has significantly improved its operational efficiency, with fuel savings estimated at around 50% for the 737 MAX (4th generation, launched in 2017) compared to the “Original” B737 (launched in 1968).

Overview of the four generations of Boeing 737 and the estimated fuel savings between each generation

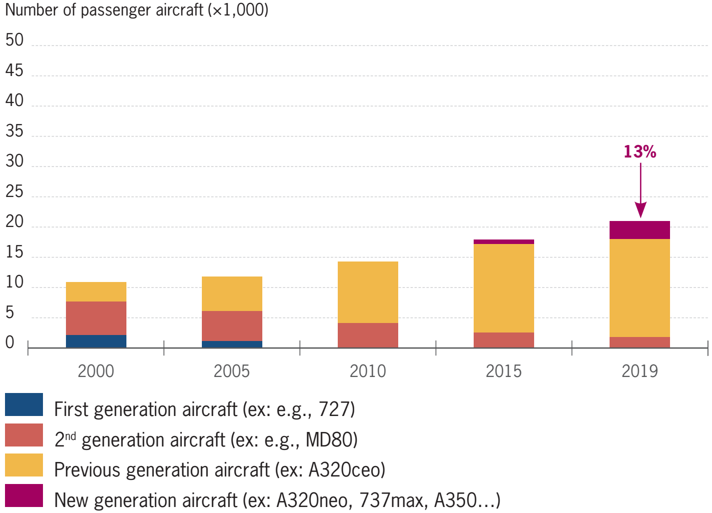


Source: Boeing, Japan Airlines, CFM International, Archery Strategy Consulting analysis.

On average, airlines replace their aircraft 22.5 years after delivery to the first customer.[33] Moreover, most airlines depreciate their aircraft over a period of 20 years (or 25 years for some aircraft).[34]

Thus, it is common to see aircraft in airline fleets that are more than a generation behind the newest models. These accounted for about 5% of the fleet in service in 2019.

Share of various aircraft generations currently part of the global fleet



Source: Airbus, Global Market Forecast 2021-2040 p13.

Aircraft renewal is a very efficient and immediate lever. For example, a theoretical immediate renewal of the 87% of old generation aircraft would lead to

33 Destination 2050.
34 Air France (2014 Annual Report) | Lufthansa (2014 Annual Report) | easyJet plc (2014 Annual Report).

a reduction in emissions of over 10%. The issue of aircraft withdrawn from the fleet remains to be defined on a case-by-case basis: they could either be decommissioned or put back on the second-hand market, thus fueling the withdrawal of even older and therefore higher CO_2-emitting aircraft.

By acquiring 100 new A320neo aircraft at the end of 2021 (for KLM and Transavia), the Air France-KLM Group has reaffirmed that renewal is the “first lever to cut CO_2 emissions, with immediate effect.”[35]

As the impact of CO_2 emissions is cumulative (emissions emitted in year N remain in year N+1), the impact on global warming must be addressed over the whole period and not only in 2050. A regular renewal of the fleet, compatible with the economic model of the industry (while maintaining their capacity to invest in innovations), should make it possible to contain emissions over the period 2020-2050.

This measure must be balanced with the challenges facing manufacturers, particularly in the engine sector, where a significant portion of profitability comes from maintenance operations, which are less important for recent fleets than for older fleets. The profitability for these players is key to financing investments in new technologies.

To encourage airlines to invest in lower-emission aircraft, governments should consider implementing incentive mechanisms such as tax incentives to accelerate the investment replacement rate: to this end, the French Finance Bill for 2022 proposes to “introduce a tax incentive mechanism for investments made by airlines renewing their fleet by opting for aircraft that allow for a reduction of at least 15% of carbon dioxide emissions compared to the aircraft they replace.”[36] Such a system had already been considered for 2021 with an additional depreciation rate of 30%.[37]

35 Air France-KLM, *Air France-KLM orders 100 A320neo aircraft for KLM and Transavia* (December 2021).
36 Senate, *Budget Bill 2022* (November 2021).
37 Senate, *Budget Bill 2021*.

Financing an additional depreciation tax rate mechanism

Principle: the additional depreciation allows a company to deduct from its taxable income an amount (%) of the purchase value of an asset. The deduction, spread over the period of use, is added to the accounting depreciation.
Scope: this provision is applicable in the country where the company is fiscally domiciled (e.g., France). It can be extended to several geographical areas (e.g., EU Member States).
Cost: 65M€ in year 1 and up to 1.3 M€ per year on a European scale at cruising speed, starting at 20 years.

Assumptions:
- Authorized additional depreciation: 30% (for the example considered in France)
- Corporate income tax: 25% (as of 2022 in France)
- Value of an aircraft: 70 M€ (catalog cost – before rebate granted by the aircraft manufacturer – which can vary from ~100M€ for a single-aisle aircraft to ~400M€ for a superjumbo)
- Amortization period: 20 years
- Aircraft fleet in 2040 in Europe (vs. 2019): 9,140 (5,220) – Aircraft deliveries (2021-2040): 8,705

2.2. European taxonomy

European regulations are evolving while Europe is intent on achieving carbon neutrality by 2050. Various levers have been put in place through a comprehensive plan, the European Green Deal,[38] announced by the European Commission in 2019. One of the pillars, the Sustainable Finance Action Plan, aims to redirect capital investments towards so-called sustainable activities.

In this context, the taxonomy makes it possible to establish a European classification system for sustainable activities. It aims to classify economic activities according to their impact on the environment, i.e., their level of sustainability, defined according to the contribution of the activity to one of the EU's six environmental objectives, including climate change mitigation. Four types of activities are derived from this classification: Sustainable, Transitional (if no low-carbon alternative exists but emissions match the sector's best performances), Enabling (activity producing high emissions but necessary for the development of sustainable activities), Other. The purpose of this taxonomy is to label financial products intended for Sustainable, Transitional or Enabling activities, in order to make them visible by contrast to Others.

In order to allow the replacement of older aircraft, the European taxonomy must ensure that it does not limit the financing of fleet renewal by impacting all aircraft in the same way. To do this, it is important that the taxonomy distinguish between two cases:
- The acquisition of newer aircraft to replace older, more polluting models (for example, replacing the A320ceo with the A320neo), within a stable fleet, which will help reduce CO_2.
- The acquisition of new aircraft to expand the fleet, which does not contribute to reducing CO_2.

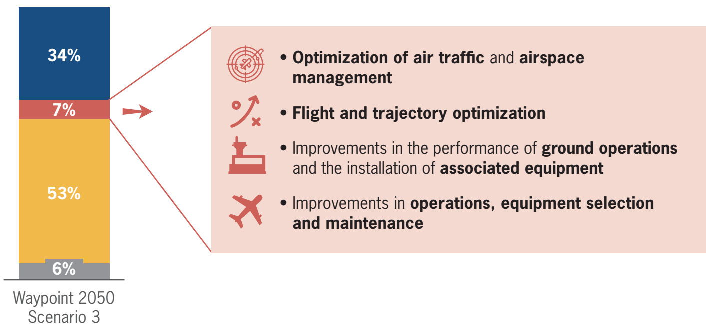
The stakes of the taxonomy are colossal: if aviation obtains the European label for part of its activities, then aircraft owners (airlines, leasing companies) would be able to finance themselves more easily on the markets. If not, financing would be much more difficult and the sector's strategy for achieving carbon neutrality would be affected.

38 Green Pact for Europe.

3. Levers for optimizing consumption in-flight and on-ground must be activated in the short and medium term

3.1. Flight and ground operations optimization

Operational improvements aimed at reducing CO_2 emissions



- Technology
- Operations and infrastructures (including efficiency improvements from load factor)
- Sustainable aviation fuel (SAF)
- Offsetting mechanisms and/or carbon capture

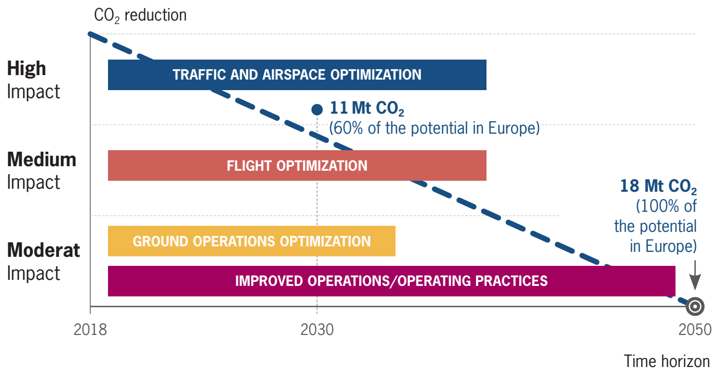
Source: Waypoint 2050.

Improving operational efficiency can help reduce CO_2 emissions and achieve the goal of carbon neutrality by 2050. While this alone will not be sufficient to achieve the goal, the resulting practices can often be implemented more quickly than aircraft technology developments, which are limited by the rate at which new aircraft enter the fleet. Their implementation could contribute to a

40 Pacte vert pour l'Europe.

reduction in Europe of 11 Mt CO_2 in 2030 (~60% of potential) and 18 Mt CO_2 in 2050 (~100% of potential).

Four contributions to the CO_2 reduction target



Source: Destination 2050 p8.

RECOMMANDATION 3 (France/EU/World)

Implement means of reducing energy consumption for aircraft operations.

- Flight: accelerate the implementation of the Single European Sky, the digitalization of air traffic control, the use of satellite tracking for transatlantic flights, and the development of flight formations to boost wake energy recovery.
- Ground: limit the use of APU when connected to the terminal, optimize taxiing and towing when relevant.

In a highly regulated, complex and often locally organized air transport operating environment, a large number of players are collectively responsible for the safety and efficiency of air transport and influence air transport operations, the efficiency of the operational process and, consequently, the environmental performance of the aviation sector: airlines, air navigation service providers (ANSPs), airports, ground handling agents, aircraft manufacturers, etc.

The reduction aim of this 2nd lever will be implemented through 4 categories of practices, contributing in a heterogeneous way to the targeted objective:
- Traffic and airspace optimization;
- Flight and trajectory optimization;
- Ground operations optimization;
- Improved operations and operating practices.

Traffic and airspace optimization

Air traffic and airspace management aims to ensure safe and efficient flights, balance the demand for flights with available airspace capacity, and provide aeronautical information for airspace users. Improvements in this category primarily involve configurations and use of the airspace in which airlines operate. This category of practices could have a high impact on reducing CO_2 emissions.

Overview of air traffic and airspace optimization practices

Practice	Description	Accessibility	Carriers
Airport Collaborative Decision-Making (A-CDM)	**Centralizing and sharing operational information** (via digital tools) between airlines, air traffic control, ground handling services: limits taxiing time, waiting time and associated fuel consumption		**Airports / ANSP / Airlines**
Continuous Descent / Climb	**Deploying continuous climb and descent practices thanks to more tailored traffic management avoids tiered flight phases** which put more strain on the engines: reduces fuel consumption		**Airlines / Airports / ANSP**
Flexible use of military airspace	**Making military airspace available,** when not in use, in order to allow civilian aircraft to navigate in it when needed: optimizes trajectories and therefore reduces fuel consumption		**State / ANSP**
Single European Sky	**Reducing the fragmentation of European airspace by harmonizing practices and systems** (or by making them interoperable so that they can communicate with each other) **and by creating airspaces which reflect travel flows rather borders:** optimizes routes and therefore reduces consumption		**States / ANSP / European Union**
SESAR	***Single European Sky ATM (Air Traffic Management)* Research, the technological and industrial counterpart of the Single European Sky:** aims to develop adapted, harmonized and/or interoperable management systems		**States / ANSP / European Union**

…/…

Practice	Description	Accessibility	Carriers
Reducing the laps between aircraft at takeoff	**Optimizing aircraft separation rules to increase runway capacity** and operational flexibility while maintaining appropriate safety levels: reduces fuel consumption prior to takeoff		**ESA / DGAC (French Civil Aviation Authority)**
Initiatives to improve air traffic outside the EU	**Modernizing air traffic management, particularly in the United States with the NextGen project, which makes extensive use of satellite** and real-time route **data:** optimizes traffic		**United States / ANSP / Airlines / Airports**
Performance-based Navigation (PBN)	**Using satellite technology for landing trajectories** to optimize landing and airways used, especially in case of airport congestion: reduces fuel consumption during landing	Blueprint by country	**Airlines / Airports / ANSP**
Required Navigation Performance (RNP)	**Reinforcing Performance Based Navigation (PBN) by adopting the Required Navigation Performance (RNP) specification, which is more specific** and allows the controller to bring the airways closer together because it is safer: optimizes trajectories	Blueprint by country	**Airlines / Airports / ANSP**
More flexible tracks	**Taking advantage of more accurate navigation systems** (PBN/RNP) **to establish a new route with air traffic** control in case of weather changes: optimizes trajectories and therefore reduces fuel consumption		**Airlines / ANSP / Airports**

…/…

Practice	Description	Accessibility	Carriers
Airport congestion management	**Deploying tools** (sensors and software) to visualize and analyze boardings, departures, regional air traffic… **allowing departures when the runway is accessible ≠ currently departures happen when the aircraft is ready:** limits taxiing and associated fuel consumption		**Airlines / ANSP / Airports**
Trajectory-based Operations (TBO)	Projecting aircraft trajectories ahead of time in order to predict and plan optimized approach intervals (based on PBN systems; time-based traffic management systems; information exchange systems between infrastructures and aircraft): optimizes routes which reduces fuel consumption		**Airlines / Airports / Manufacturers / ANSP**

Long-term development and/or deployment
Medium-term deployment and / or retrofit
Can currently be deployed

ANSP: Air Navigation Service Providers

Source: Waypoint 2050, Destination 2050; Archery Strategy Consulting analysis.

Implementing the *Single Sky*

In response to the ever increasing air traffic in Europe and to the air traffic control inefficiencies identified by Eurocontrol, the EU launched the Single European Sky program, which aims to enable European airspace to accommodate more traffic, while reducing costs and improving performance.

The implementation is based on a set of measures: [41]

- The development and application of air traffic management regulations, particularly in terms of safety, interoperability of systems and procedures, and fees.

41 Ministry of the Ecological Transition (2017).

- The establishment of functional airspace blocks (FABs) formed through agreements between States, aimed at managing airspace according to traffic flows rather than borders: there are currently 9 FABs in Europe. The FABEC (Functional Airspace Block European Central), which accounts for ~55% of flights in European airspace, includes France, Germany, Belgium, Luxembourg, the Netherlands and Switzerland. FABEC has, for instance, enabled the creation of shorter routes in major cities, resulting in fuel savings.
- An air navigation services performance system, either European with binding objectives set by the European Commission, or local at State or FAB level.
- The designation of Eurocontrol as Network Manager.
- The SESAR technology program to modernize Europe's air traffic management system (ATM),[42] including digitization and automation of associated activities; investment in SESAR over the period 2015-2024 is expected to be nearly €3 billion,[43] and is expected to save 540 thousand metric tons of jet fuel and 1.7 million metric tons of CO_2 by 2030. The SESAR project is the European equivalent of the NextGen project in the United States.[44]

All of these measures should optimize the organization and use of European airspace, resulting in fuel savings and thus reducing CO_2 emissions.

Since December 2021, aircraft flying at an altitude of nearly 6,000 meters in airspace managed by the Bordeaux, Brest and Paris centers (i.e., nearly half of French airspace) have been able to fly "free route": this practice, which allows airlines to choose the best route for each flight by bypassing historical air routes, should help reduce CO_2.

42 Single European Sky Air Traffic Management.
43 International Airport Review, *SESAR deployment drives efficient*, modern ATM (November 2021).
44 Next Generation Air Transportation System.

Centralizing and sharing operational information

This practice, better known as A-CDM,[45] aims to optimize airport operations and ensure fluid and efficient traffic. It relies on the sharing of reliable and accurate data (aircraft departure and arrival times, runways in use and associated capacities, weather, etc.) to enable partners to make the most appropriate decisions (airline, air traffic control, ground services, etc.).

Information sharing provides several benefits: the optimization of air traffic control capacities, the improvement of flight forecasts under normal and deteriorated weather conditions, the improvement of punctuality, the improvement of traffic flow on the ground, the improvement of ground assistance, etc. This reduces aircraft waiting time at the threshold of the runway thus reducing fuel consumption and, ultimately, CO_2 emissions.

Introduced and supported by Eurocontrol,[46] the A-CDM concept has been gradually implemented and is now fully integrated and used in the operations of nearly 30 major European airports (Paris CDG, Amsterdam, Frankfurt, Madrid, Rome, etc.).

Eurocontrol reports several benefits from this practice:[47] average taxiing time saved between 0.25 and 3 minutes per departure; average improvement in schedule adherence of between 0.5 and 2 minutes per flight; increased time slot adherence despite increased traffic demand; better use of ground handling resources; decrease in the number of late stand and gate changes.

The concept also exists in various forms in other parts of the world, notably in the United States, known as Surface-CDM.

45 Airport Collaborative Decision-Making.
46 OEuropean Organization for the Safety of Air Navigation.
47 Eurocontrol, *A-CDM Impact Assessment* (2016).

Deployment of continuous approach practices

Traditionally, in a typical descent, the pilot proceeds in steps, at low altitude. These steps require significant thrust from the engines and the use of high lift devices (leading-edge slats, trailing-edge flaps) to improve the aircraft life at low speeds.

The continuous descent (or climb) approach is a technique which allows the aircraft to land (or take off) while avoiding tiered flight phases as much as possible, thus reducing the engine load, which in turn limits noise pollution and saves fuel.

This technique, which meets flight safety requirements, necessitates a suitable airspace configuration, the definition of a specific operational procedure and appropriate control actions in real time.

Studies suggest that the benefits of improving continuous climbs and descents can be significant:

- The Safety Line startup has developed an optimization tool (OptiClimb), which only applies to the take-off phase: an experiment with Transavia has shown that it saves nearly 80 kg of kerosene each climb;[48]
- The OpenAirlines startup developed a software (SkyBreathe) which promotes eco-driving for aircraft pilots. The solution provides targeted recommendations for airlines to implement the most fuel-efficient procedures and reduce their consumption by up to 5%;[49]
- In September 2021, Air France tested a "perfect flight" between Paris and Toulouse (a collaboration including Airbus and the DSNA, the French Air Navigation Services). The challenge was to reduce fuel consumption by combining several technical and operational innovations. During the flight, the A320 optimized its landing trajectory by choosing a continuous descent, as a result, Air France stated that by achieving 100% continuous descent at Paris CDG airport, the airline could potentially save 10,000 tons of fuel.[50]

48 Transavia (avril 2021).
49 Air France (juillet 2020).
50 Laurent Lafontan (Director of Development for Air Operations).

However, the application of this technique remains limited at busy airports and during peak periods because of the need for tactical intervention by air traffic controllers to safely manage arrival and departure flows.[51]

Making military airspace available

Airspace has traditionally had two main users: civil aviation and military aviation. However, these two aviation branches generally cannot operate simultaneously in the same airspace block, requiring the establishment of boundaries or segregations.

While the existence of military airspace forces civilian aircraft to fly around, some States have been able to implement a flexible use of this airspace, turning it over to civilian air traffic management when it is not being used for military purposes. This allows for much more direct routing of civilian aircraft and thus saves fuel.

Limiting the take-off gap

Separation rules between aircraft are put in place to minimize the risk of wake turbulence. In practical terms, an aircraft wishing to take off after another aircraft must wait, even though waiting with the engines running consumes kerosene.

Additional information

Wake turbulence is aerodynamic turbulence that forms behind an aircraft. All aircraft in flight generate wake turbulence, which essentially forms two vortices. The risk increases according the size of both aircraft, the larger the leading aircraft (i.e., the higher the intensity of the turbulence) and the smaller the following aircraft, the more subject it is to wake turbulence.

…/…

51 Rate of completion of continuous descent procedures in 2020: Paris CDG ~27%, Nice Côte d'Azur ~33%, Paris Orly ~41%, Toulouse Blagnac ~51% (Source: Ministry of the Ecological Transition).

During takeoff and landing, wake turbulence extends to the rear of the aircraft, but also around the runway when the wind is light. When the wind is blowing, the wake turbulence moves to one side of the runway, or may even reach an adjacent or parallel runway. Inadequate assessment of wake turbulence has led to several accidents in the past (American Airlines flight 587).

The optimization of distances between runways can increase runway capacity, limit the waiting time of aircraft about to take off and waiting on the tarmac with their engines running, thus reducing fuel consumption.

Flight and trajectory optimization

Flight and trajectory optimization tackles the way aircraft are used in-flight by airlines.

This category of practices could have a medium impact on reducing CO_2. While several practices can be implemented to contribute to this objective, only one is currently available: the deployment of new planning software.

Overview of flight and trajectory optimization practices

Practice	Description	Accessibility	Carriers
Optimization of aircraft trajectories	**Optimizing aircraft trajectories to improve fuel consumption:** reduces the distance flown, adapts to (un) favorable weather conditions or adopts a more natural flight profile		**Airlines / ANSP / Airports**
Flight planning	**Deploying new versions of flight and trajectory planning software** to optimize fuel consumption		***Airline companies***

…/…

Practice	Description	Accessibility	Carriers
Expansion of “perfect flight” partnerships	**Carrying out flight demonstrations to optimize all the interventions and phases during a flight** involving air traffic control, the company, ground handling services, and manufacturer recommendations: identifies/constructs good practices leading to less fuel consumption		**Airlines / Manufacturers / ANSP / Airports**
Formation flight	**Developing software to coordinate closer flights between aircraft so that a following aircraft may benefit from the wake energy of a leading aircraft:** leads to energy recovery and therefore reduces unnecessary fuel consumption		**Airlines / Manufacturers / ANSP / Airports**
Space-based navigation	**Using the aircraft’s onboard equipment to transmit data to satellites or ground stations** that pass it on to air traffic control, allowing for precise positions in isolated areas / oceans, **reducing safety margins and optimizing the routes taken:** reduces fuel consumption		**Airlines / Airports / ANSP**

 Long-term development and/or deployment

 Medium-term deployment and / or retrofit

 Can currently be deployed

ANSP: Air Navigation Service Providers

Source: Waypoint 2050; Destination 2050; Archery Strategy Consulting analysis.

Direct or optimized trajectories

Traditionally, aircraft travel in air corridors – which are similar to highways with a predefined route – to optimize the management of aircraft flows. However, these air corridors limit the optimization of aircraft trajectories because they do not allow for:

• the reduction of the distance between the departure and arrival points;

- the aircraft to benefit from favorable winds;
- the natural trajectory of the aircraft, which, by consuming fuel, should naturally gain altitude – in actual fact, the pilot maintains the planned trajectory in the air corridor, which tends to increase fuel consumption.

These trajectories, which contribute to "perfect flights," allow significant emission reductions: the one carried out by Air France in September 2021, where the aircraft flew from Paris to Toulouse in a straight line, reduced CO_2 emissions by 7 to 8%.[52]

There are several ways to optimize aircraft trajectories:
- In the short term, technological solutions are emerging to allow pilots to request changes to their flight plan during their journey to benefit from a more direct trajectory based on requests already granted by air traffic controllers in the past. Transavia used Safety Line's OptiClim and OptiDirect tools in 2019 which saved nearly 5000 tons of CO_2;[53]
- In the medium term, the digitization of air traffic management will be essential to implement optimized trajectory profiles while maintaining the necessary safety measures.

Planning

The purpose of planning is to select the best flight path taking all relevant factors into account. A planning software program performs the calculations by integrating imposed routes, winds at altitude, the possibility of turbulence or thunderstorms en route, temperatures, restricted airspace, fuel efficiency, aircraft weight and altitude, etc. The flight plan is then transmitted to the pilots and downloaded into the navigation computer a few hours before departure. It may be updated again with the latest data (wind and exact weight of the aircraft).

52 L'Usine Nouvelle, *Interview with Yannick Assouad – Thales avionics* (December 2021).
53 Communication on the Safety Line website: https://www.safety-line.fr/optiflight/

Airlines adapt optimization algorithms and priorities to their own needs, and routes may change daily and hourly (e.g., a flight from Toronto to Vancouver may fly through Canadian airspace, or over the northern United States).

While other criteria may be taken into account (e.g., punctuality), airlines will generally seek to offer the cheapest flight options.

Other notable practices

In addition to the practices described above, others, which are more or less accessible, have interesting decarbonization potential. These include developing the possibility for aircraft to fly in formation to take advantage of wake energy. Another practice consists of using the aircraft's data to transmit more precise information regarding its position, thus reducing safety margins in isolated areas and optimizing trajectories.

Ground operations optimization

Ground operations optimization covers emissions related to aircraft operations, and in particular emissions related to gate parking and related movements between the gate and the runway. Furthermore, this category takes into account emissions generated, by ground support equipment (e.g., tractors) for example. It should be noted that in addition to reducing CO_2 emissions, the measures listed often also reduce noise and other emissions, thus contributing to improved local air quality.

This category of practices may have a more moderate impact on reducing CO_2 emissions.

Overview of ground operation optimization practices

Practice	Description	Accessibility	Carriers
Reduced use of engines when driving	**Not using all the engines for taxiing but only some of them** when the aircraft is not towed by a vehicle on the ground: reduces fuel consumption on the ground		**Airline companies**
Installing electrical terminals for airplanes when boarding	**Promoting the use of electrical and air conditioning connections on the ground to limit the use of the APU:** reduces associated fuel consumption		**Airports**
Converting the ground fleet to electric and/or hydrogen	**Converting the ground fleet to replace thermal tractors for towing** on runways at slow speeds (for long periods for very large airports): eliminates fuel consumption associated with the taxiing phase		**Airports**

Long-term development and/or deployment

Medium-term deployment and / or retrofit

Can currently be deployed

Source: Waypoint 2050; Destination 2050; Archery Strategy Consulting analysis.

Limit reactor use when driving

At the beginning and end of each flight, the aircraft must move from the tarmac to the runway via the taxiways and vice versa. This is called taxiing when the aircraft is moving using its own power and towing when another vehicle is used. Although the amount of fuel consumed during taxiing is limited compared with that consumed during flight, there are several ways to reduce this fuel consumption.

A common option today is reduced engine taxiing, in which one or more of the aircraft's engines are shut down for part of the taxiing, with the pilot starting up all engines when approachig the runway. On twin-engine aircraft, the possibility of using a single engine depends not only on the existence of a procedure issued by the airline,[54] but also on the specificities of the airport terrain (slope, turn, etc.):

- Single-engine taxiing is now standard procedure on the British Airways A320 fleet, saving an average of 70 kg of fuel per taxi at Heathrow (or 4,100 tonnes of fuel in 2014).[55]
- Other airlines, such as Corsair International, use low-engine taxiing, thanks to the use of software (such as OpenAirlines' SkyBreathe, mentioned above) which improves knowledge of the airport's physiognomy.[56]

Driving with only one engine has a positive impact not only on fuel consumption and thus on CO_2 emissions, but also on the noise footprint and engine life.

Limit APU usage when the aircraft is connected to the terminal

A lot of airplane equipment consumes electricity and this need is constantly increasing: navigation instruments, computers, flight controls, lighting, air conditioning, commercial loads (e.g., ovens to heat up meal trays). The electrical circuits of an aircraft operate at 400 Hz,[57] in order to limit the weight of the transformers required.

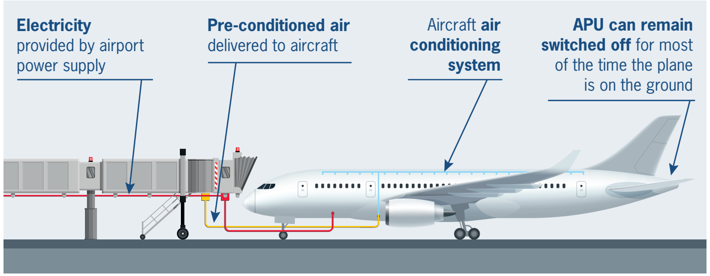
The operation of the engines in flight powers a generator to produce electricity. However, when parked, the aircraft can use another piece of equipment: the APU. It is a small engine, generally located at the back of the fuselage, designed to generate electricity (voltage of 115 V with 400 Hz) and to compress the air in order to supply the various on-board systems on the ground, in particular the air-conditioning, when the main engines are off (the APU can also be used in flight). While the use of this small engine saves fuel, it does consume kerosene.[58]

54 Single Engine Taxi Out (take-off procedure), Single Engine Taxi In (arrival procedure).
55 Aviation Benefits Beyond Borders.
56 Corsair International, OpenAirlines.
57 The frequency is 50 Hz in Europe and 60 Hz in the USA.
58 80 kg of kerosene for a short-haul flight with a 45-minute stopover and 300 kg for a long-haul flight with a 75-minute stopover (DGAC, 2007).

The APU is needed to help start the main engines, but it can be turned on just before the aircraft leaves, remaining off for most of the ground-time:

- To supply the aircraft with electrical power without using an APU, a ground power supply system can be used, either mobile (GPU)[59] or fixed (FEGP).[60] While the GPU is usually a diesel fueled generator (although it emits less CO_2 than the APU because it has a better output), it can sometimes be used as a simple converter. In the latter case, as with the FEPG, the system is directly connected to the local airport's electrical network, and can emit no CO_2 if a decarbonated electrical supply is used.
- To compress the air, a ground-based pre-conditioned air system (PCA)[61] also offers an interesting alternative to the APU: powered by the electrical grid, the PCA unit drastically reduces CO_2 emissions (and noise pollution).

Alternative systems to the APU



Source: Aviation Benefits Beyond Borders: https://aviationbenefits.org/case-studies/fixed-electrical-ground-power/

Converting the airport fleet to electric or hydrogen

Converting the airport fleet from internal combustion engines to electric and/or hydrogen has great potential to decarbonize ground operations. Electric

59 Ground Power Unit.
60 Fixed Electrical Ground Power.
61 Pre-Conditioned Air unit.

and hybrid-electric solutions are now being marketed for baggage carts, fuel trucks and aircraft towing tractors.

This transition is underway at many airports with the initial objective of reducing local pollution. For large airports with large distances between the terminal and the runway, emissions reduction will be even greater. In 2020, Schiphol Airport has committed to equipping itself with TaxiBots,[62] reducing ground emissions by 50 to 65% depending on the airport. Five years earlier, the technology was adopted by Lufthansa at Frankfurt Airport, after a period of testing and certification by EASA.

For fuel trucks, Gaussin has developed the ART Full Elec, in partnership with SAFT, which is capable of towing two 30 t tanks thanks to its 100 kWh batteries.

Improved operations and operating practices

In addition to how a flight is planned and executed, airlines have some control over operational parameters that affect aircraft weight in particular. Because each kilogram requires additional fuel to be carried, reducing weight can result in significant savings in fuel consumption and CO_2 emissions. This is what the lever for improving operations and operating practices aims to do.

This category of practices could have a more moderate impact on reducing CO_2. It includes, for example, the following improvements: limiting tanking practices by adjusting fuel and water supply to exact needs, more frequent cleaning of the aircraft and engines to eliminate all particles likely to degrade aircraft performance, and reducing the weight of cabin equipment (e.g., flight crew carts, passenger seats).

62 TaxiBots are semi-robotic vehicles with a hybrid engine (diesel and electric) controlled by the aircraft pilot and into which the aircraft's nose wheel is inserted in order to pull it along the taxiways with the engine switched off. Taxiways refer to the paths from the terminal to the runway and from the runway to the terminal.

Overview of operational improvement practices

Practice	Description	Accessibility	Carriers
Adjust fuel and water supply usage	**Supplying fuel and water according to the actual weight of passengers, luggage and the predicted flight conditions (especially winds) and stop tanking practices**: reduces the weight on board		Airlines
Maintain exterior paint in optimal condition	**Limiting exterior paint deterioration which can lead to losses in critical areas through more regular checks/maintenance:** maintains the aircraft's efficiency and thus optmize fuel consumption levels		Airlines
Exterior cleaning	**Limiting the accumulation of particles on the external walls through more regular cleaning:** maintains the aircraft's efficiency and thus ensuring optimal fuel consumption level		Airlines
Engine cleaning	**Generalize the use of modern systems to refine the cleaning of engines (remove more pollutants):** limits the increase of engine operating temperatures thus reducing fuel consumption		Airlines
Cabin / passenger / cargo areas cleaning	**Limiting the accumulation of particles inside the aircraft** (also limits the damage and costs associated with objects left behind): maintains the weight of the aircraft and the associated fuel consumption level		Airlines
Replace manuals with tablets	**Replace heavy paper magazines, manuals… with tablets:** weight reduction		Airlines
Lighten equipment used by the flight crew	**Replace the equipment used by the crew such as carts, cabinets,… with lighter equipment:** weight reduction		Airlines
Lighter seats	**Replace seats with lighter equivalents:** weight reduction		Airlines
Lighter container	**Replace the current containers used by airlines with lighter equivalents:** weight reduction		Airlines

…/…

 Long-term development and/or deployment

 Medium-term deployment and / or retrofit

 Can currently be deployed

Source: Waypoint 2050; Destination 2050; Archery Strategy Consulting analysis.

3.2. Train-airplane intermodality

RECOMMANDATION 4 (France/EU/World)

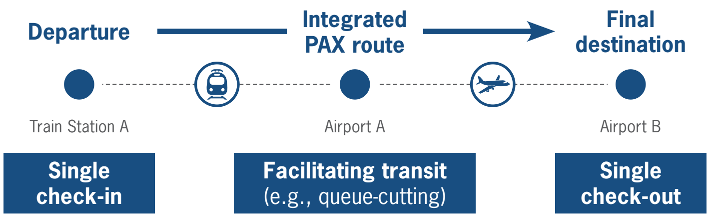
Promote intermodality for the start/end of trips, notably by ensuring connections between the main rail stations and the terminals to facilitate transitions, and by implementing integrated passenger transport pathways.

Train-airplane intermodality refers to the possibility for a passenger traveling by plane to make the beginning and/or end of their journey by train (e.g., Bordeaux-Paris trip by TGV to reach the Roissy hub for an international flight):[63] since the plane emits much more CO_2 than the train (especially if the latter is powered by a low-carbon electrical network), train-airplane intermodality minimizes the environmental impact compared to the same trip using a double airplane itinerary.

Train-airplane intermodality makes sense, especially in countries where the rail network covers the entire country, as is already the case in some European countries (e.g., France, Germany) and in Asia (e.g., South Korea, Japan). In fact, this intermodality is already happening in France thanks to the existence of a "Train + Air" offer, provided by a partnership between the SNCF and a dozen airlines (e.g., Air Caraïbes, Air France, Emirates, etc.): in practical terms, this service allows passengers to have a combined ticket to leave from ~20 provincial cities by train (e.g., Avignon, Bordeaux, Lille) and take a long-haul flight from the Paris airports (Roissy and Orly). While satisfaction surveys show that intermodal travelers are satisfied with the train-airplane combination, there are still relatively few of them in France, although their numbers are increasing. Intermodality at Paris CDG has gone from nearly 2% in 1999 to about 5% in 2014 (3.3M passengers out of a total of 61.4M).[64] Projects are underway to improve intermodality in France (e.g., CDG express, postponed to 2027), but some major metropolitan airports do not yet have a direct rail link (e.g., Toulouse-Blagnac airport, Bordeaux-Mérignac, Marseille-Provence-Marignane).

The main criteria for travelers opting for a combined train-airplane ticket, rather than a double airplane ticket, are mainly the trip's cost and duration (total travel time, connection time). To become more attractive beyond these criteria, the train-airplane journey must be better integrated both in terms of the journey (single check-in/check-out, end-to-end baggage tracking, synchronized and consistent integrated Traveler Information, etc.) and customer service (e.g., multimodal travel insurance), on the same model as the double airplane journey.

Train-aircraft intermodality



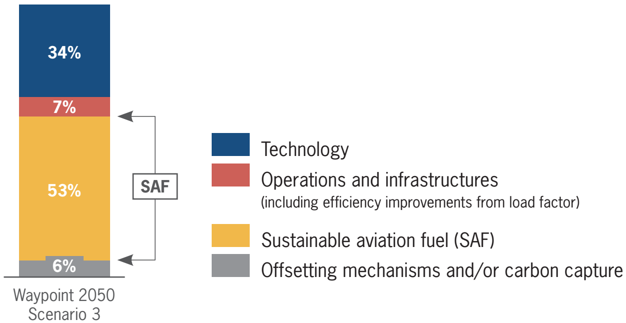
Source: Archery Strategy Consulting analysis.

63 Intermodality refers to the ability of a transport system to allow the successive use of at least two modes of transport (e.g., air, rail, car), combined in one travel chain.

64 DGAC, *Enquête complémentarité modale avion train* (2014).

4. Using large amounts of sustainable aviation fuels is necessary for decarbonization, as it contributes more than 50% to achieving the target

SAF contribution to the CO_2 emissions reduction target



Source: Waypoint 2050.

The previous sections highlight that the first two improvement levers (technology, flight and ground operations) alone are not sufficient to achieve the aviation sector's decarbonization goal.

Sustainable aviation fuels (SAF)[65] are the main lever for the considered trajectory (53%).

65 Sustainable Aviation Fuel.

4.1. Interest in, and manufacture of, Sustainable Aviation Fuels

Introduction

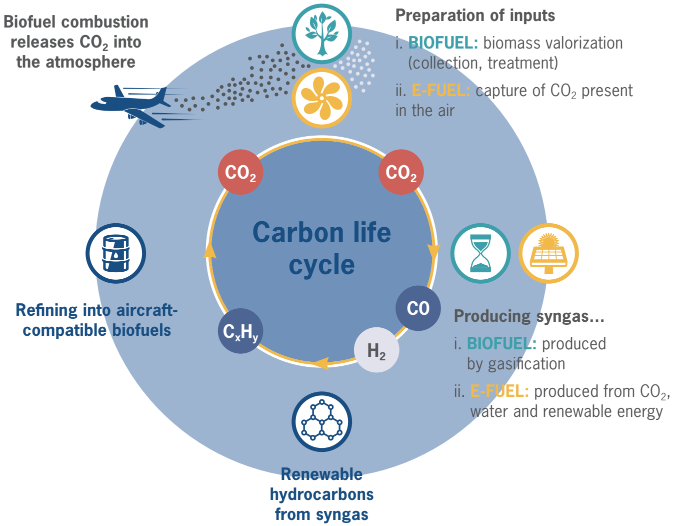
The term SAF refers to fuels with three essential characteristics:

- They meet the technical and certification requirements for use as fuel in commercial aircraft;[66]
- They are derived from alternative feedstocks rather than crude oil; this includes any renewable material or substance that can be used as fuel (cooking oil, vegetable oils, agricultural residues, etc.) or CO_2 capture.
- Their use is compatible with economic, social and environmental objectives, while preserving an ecological balance that avoids the depletion of natural resources (sustainability).

When using SAF, the carbon footprint reduction does not come from a change in fuel use – since SAF also come from a carbon chain combustion, producing as much CO_2 as when using kerosene – but from the fuel extraction process. Indeed, since kerosene is a petroleum product whose formation dates back some 20 to 350 million years, extraction is tantamount to releasing carbon trapped deep down. Conversely, the raw materials necessary for the production of SAF (e.g., algae, plants, etc.) are carbon sinks, in the sense that they absorb CO_2 present in the atmosphere during their lifespan (through photosynthesis). The combustion of SAF will therefore release CO_2 initially present in the atmosphere: as a result, the entire life cycle of SAF has a considerably reduced carbon footprint.

66 Certification of aviation fuels is issued by a global standards body, the American Society for Testing Material (ASTM). This certification of fuel safety and performance is required for use on scheduled passenger flights.

Carbon life cycle, from air capture to aircraft re-emission



Source: Public data; Archery Strategy Consulting analysis.

As a reminder, the SAF strategy will be considered according to the ability to substitute fossil fuels with an electric or hydrogen alternative:

- For regional, short and medium haul flights: these fuels are complementary to hydrogen or electric technologies;
- For long-haul flights, these fuels represent the bulk of decarbonization.

The interchangeability of SAF with existing kerosene (known as “drop-in” fuel)[67] reduces the need for modifications to aircraft, engines and other airport infrastructure, accelerating the possibility of a rapid and wide-spread solution. This is a key feature for aviation: any SAF that does not meet this requirement could present safety issues related to the risk of mishandling and would require the development of parallel infrastructure.

While the use of SAF in engines is currently limited to 50%, engine manufacturers are aiming for 100% use for engines entering service from 2030-35. At the close of 2021, US engine manufacturer Pratt & Whitney presented an evolution of its GTF engine, the *GTF Advantage*,[68] which will become the standard offering for the Airbus A320neo family starting in 2024, and will be compatible with 100% SAF blending. Other engine manufacturers (Safran, Rolls-Royce) have also begun trials to achieve this goal.

SAF types

Two main categories of SAF are usually distinguished: biofuels and synthetic fuels (often called synfuels, e-fuels or PtL – Power to Liquid).

Biofuels

Biofuels are produced from biomass, and are generally classified according to 3 generations:

- First generation biofuels are produced from crop inputs traditionally used for food: wheat or beetroot for ethanol, rapeseed or sunflower for biodiesel, etc. While first generation biofuels are the most widespread today, particularly because of larger input deposits and contained costs, their usefulness is controversial insofar as they can contribute to deforestation, compete with arable land (notably with food crops) and participate in the rise in food prices on the world market.
- Second generation biofuels are produced from human activity residues: wood and forest residues, agricultural residues (rapeseed stalks, straw, etc.), organic waste, cooking oil, etc. This generation uses only plant materials that are not recovered for food or for the wood industry (paper,

67 A drop-in fuel is fully compatible/substitutable with conventional jet fuel.

68 Pratt & Whitney *(pwgtf.com/advantage)*.

furniture, construction). If this generation is better accepted, the reserves are still currently insufficient, mainly due to a lack of residue collection in most countries.

- Third generation includes fuels produced from micro-organisms, such as microalgae, or through photosynthesis or fermentation. This generation, like the second, does not compete with food uses and is the focus of major research worldwide to demonstrate its feasibility on an industrial scale. Indeed, if this marine biomass benefits from unlimited deposits in the oceans, it is difficult to harvest and laboratory culture is generally favored, which is however more complicated (fragility of microalgae, high water and phosphorus requirements, etc.). Consequently, the path to third generation biofuel use is still long: not only will large-scale industrialization have to be improved (productivity of strains, production technologies, etc.) but so to the bottom line.

Second and third generation biofuels are sometimes called “advanced bio-fuels” because they compete with first generation biofuels in terms of food resource use.

Synthetic fuels

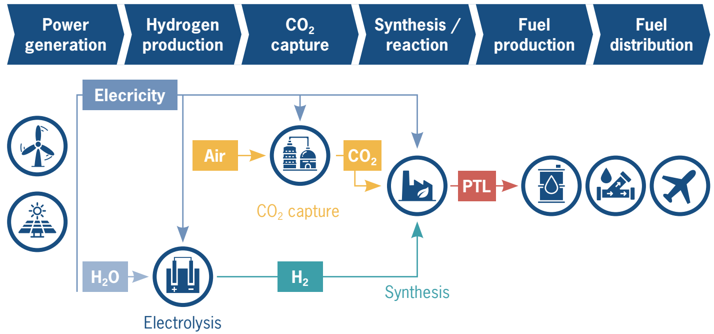
Synthetic fuel is produced from carbon dioxide (CO_2) and hydrogen (H_2). To its advantage, the only limit to production are the amount of electricity and water available.

To produce Synthetic Fuel, 3 main steps are necessary:

- To produce hydrogen, through water electrolysis;[69]
- Capturing CO_2 from factory outputs (iron and steel, cement, refinery, chemical and petrochemical), or directly in the air (DAC).[70] For DAC, membranes are used to capture the CO_2 which is subsequently extracted. DAC is more energy intensive because the concentration levels are much lower than those of factory outputs. However, this method of extraction will be essential in the long run because it will allow real carbon neutrality (the CO_2 used is already present in the air) and because factory output sources will remain limited in volume and will decrease as the industry decarbonizes;
- Synthesize fuel from hydrogen and CO_2, the most widely used process being the Fischer-Tropsch process.

69 Decomposition of water (HO_2) into dioxygen (O_2) and hydrogen (H_2) thanks to an electric current ($2H_2O \rightarrow 2H_2 + O_2$).
70 Direct Air Capture: direct capture of CO_2.

Synthetic fuel production graph



Source: Public data; Archery Strategy Consulting analysis.

Additional information

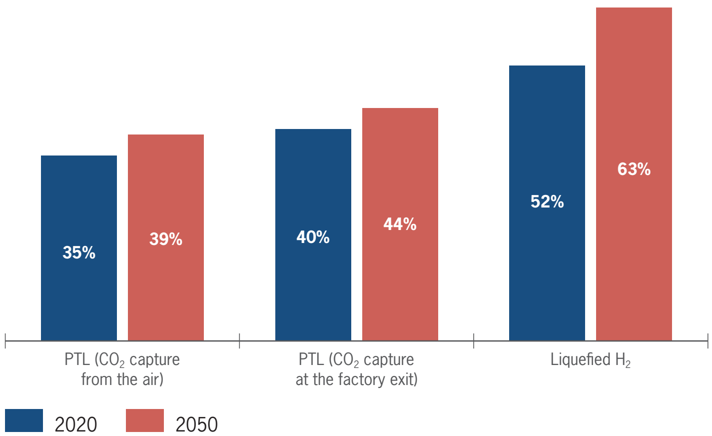
- As an example, Iceland started up a plant (Orca) at the end of 2021 capable of **extracting CO_2 from the air** and petrifying it in the rock: using 12 fans with filters, and powered by a nearby renewable power plant, it can remove nearly 4,000 tons of CO_2 per year (the consumption of nearly 870 cars, according to the US Environmental Protection Agency).

.../...

- Dihydrogen can be produced not only by a water electrolysis process, but also by a **steam reforming** process: a fossil fuel (e.g., CH_4 natural gas) is exposed to very hot steam and releases H_2 as well as CO_2, which can be re-injected/trapped in depleted oil wells. This process is most widely used today (~95% of H_2 produced).

The efficiency of the whole process is relatively low, estimated at around 40% (energy contained in SAF compared to the electrical energy input). Therefore, the amount of decarbonized energy needed to produce this type of fuel is extremely significant. Since biofuel production requires little electricity and hydrogen is nearly 40% more efficient to produce, these two methods could be favored.

Comparing production yields by process



Source: Public data; modeled by Archery Strategy Consulting.

Production chain

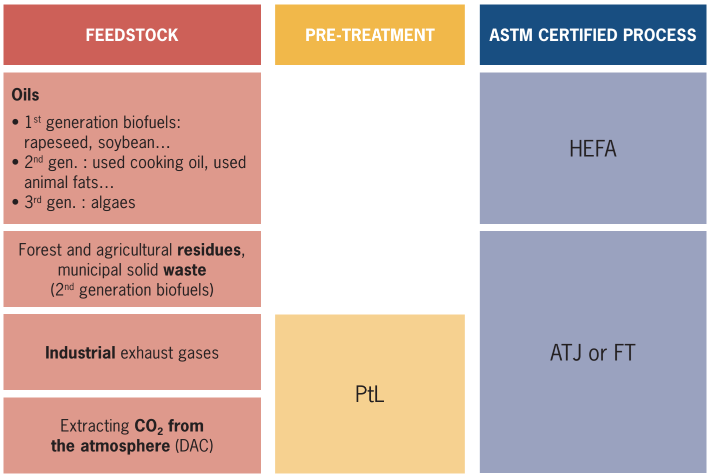
Production processes

While several SAF production processes are already certified by ASTM, or are currently being tested for certification, three main processes are now more or less mature:

- HEFA (TRL8 -9):[71] production of biofuel through the valorization of oils (vegetable oils, used cooking oils, used animal fats or tallow…); this process is largely dominant in the current production.
- Fischer-Tropsch (TRL7 – 8 – “FT”):[72] this process uses raw materials to produce synthetic gas, which is then converted into fuel; this fuel can be either :
  - Biofuel by direct valorization/fermentation of biomass (forest and agricultural residues, municipal solid waste…);
  - Synthetic fuel by applying additional treatments to the liquid synthetic fuel from the PtL process.
- AtJ (TRL 6-7):[73] this process is based on the transformation of certain raw materials into alcohol (isobutanol or ethanol), which is then processed and upgraded into biofuel; as with the FT process, the fuel obtained can be either biofuel (by fermentation of sugars, starch, etc.) or synthetic fuel (processing of the fuel from the PtL process).

71 Hydroprocessed Esters and Fatty Acids.
72 Named after 2 German researchers (Franz Fischer and Hans Tropsch), whose 1st patent (1923) aimed to valorize coal.
73 Alcohol-to-Jet.

SAF production processes[74]



Source: Public data; Archery Strategy Consulting analysis.

Production cost

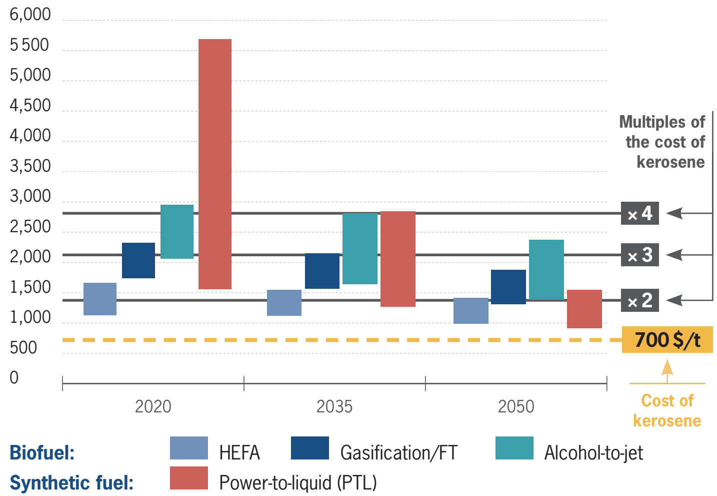
Regardless of the chosen process, scaling up to industrial levels poses a series of challenges, as some raw materials may be difficult to collect in sufficient quantities (availability, logistics), and some processes may require additional maturation before becoming fully operational (R&D efforts).

The various estimates of production costs, regardless of the production method, show a higher cost than that fossil kerosene at current prices (excluding the application of a carbon cost for the latter).

74 AtJ = Alcohol to Jet; FT = Fischer-Tropsch; PtL = Power to Liquid.

Comparing production costs by process

(Unit: dollars per ton of biofuel)



Kerosene cost ~$700 per ton (cost calculated at ~$60/barrel)

Source: WEF; Clean Skies for Tomorrow; Destination 2050; Archery Strategy Consulting analysis.

Moreover, some airlines have reported higher fares than those advertised: this is the case for Air France, which reports a cost 4 to 8 times higher than the cost of jet fuel, due to the high cost of producing SAF, in particular via the HEFA process.[75]

The production of SAF using the HEFA process, for example, requires lower initial costs for infrastructure (CAPEX) but higher recurrent costs for raw

75 Air France communication to AFP (January 2022).

materials (OPEX): it is therefore not very conducive to economies of scale. Conversely, the FT process requires considerable initial infrastructure costs (CAPEX) but very low recurrent costs for raw materials (OPEX).

Transport and distribution

The SAF production chain brings together a wide range of players: farmers / food industry for first generation inputs (e.g., the French sugar cooperative group Tereos); waste managers for the second generation inputs (e.g., Veolia and Suez); oil companies (e.g., TotalEnergies or Neste), etc.[76]

For example, TotalEnergies produces SAF at the La Mède biorefinery (Bouches-du-Rhône) and at the Oudalle site (Seine-Maritime), which specializes in lubricants.[77] Investments should enable the French oil company to also produce SAF at its Grandpuits site (Seine-et-Marne). The Group has also announced that all SAF will be produced from waste and residues from the circular economy (animal fats, used cooking oils, etc.).

The distribution of aviation fuels includes an upstream portion to service the airports and then logistics within the airports. Airlines negotiate supply contracts with distributors, such as Shell Aviation or Air BP, who then provide transportation from production refineries to fuel depots at the airports. Airports supplied with SAF must set up distinct management of the 2 fuel flows (conventional kerosene and SAF), and ensure traceability. Furthermore, blending facilities must be provided to inject SAF into kerosene.

In 2019, five airports were continuously supplied with SAF (Bergen, Brisbane, Los Angeles, Oslo and Stockholm) while others offer occasional supply.[78] With the top 100 airports accounting for more than 50% of global traffic (in terms of passenger numbers),[79] the availability of SAF at a limited number of airports could already meet a large portion of the demand.

76 Finnish company specialized in refining, 50.1% owned by the Finnish State.
77 TotalEnergies (press release dated April 8, 2021).
78 International Energy Agency.
79 Airports Council International (2017).

4.2. Clarify the definition of SAF

Establish shared criteria for SAF

RECOMMANDATION 5A (World)

Establish SAF sustainability criteria shared by all countries and defined by ICAO, both in terms of the reduction of their life cycle emission levels, and the type of feedstock used.

While the definition of SAF is clear from a technical point of view, it has yet to be defined from an environmental or ethical point of view. For example, in the United States, a fuel is considered SAF when it achieves a 50% reduction in lifecycle emissions, whereas in Europe, the threshold is set at 65%.

Moreover, some inputs/processes are less effective than others in reducing CO_2 emissions compared to kerosene: while agricultural or forestry residues can reduce CO_2 emissions by up to 90%, palm oil can only do so up to 33% under certain conditions (especially when open ponds are used as is sometimes the case in Indonesia or Malaysia)[80] and its exploitation contributes to deforestation in some cases.

It is therefore essential to build a common framework, at ICAO level, in order to limit harmful side effects when deploying SAF and to ensure fair competition between the players in the SAF sector.

Finally, in France, the predominance of nuclear power in the energy mix means that synthetic fuels and hydrogen produced in the country must be considered low-carbon.

80 Destination 2050.

Including hydrogen in the definition of SAF

RECOMMANDATION 5B (France/EU)

Include hydrogen in the definition of SAF to allow the development of all sectors contributing to the decarbonization of air transport.

While SAF are likely to play a major part in decarbonizing air transport, the energy carriers mentioned above, such as hydrogen, also have a role to play when produced in a clean and sustainable manner.

In this respect, it would be useful to grant hydrogen a mass equivalent in SAF, proportional to the efficiency of the associated propulsion chain. This would ensure its development – encouraged by the measures mentioned in this report.

4.3. Securing demand

RECOMMANDATION 5C (EU/World)

Expand the SAF blending mandate to all geographical regions, based on the European Refuel EU model; in Europe, be more ambitious than the 63% target for 2050 provided by Refuel EU Aviation, depending on the activation rate and the efficiency of the various decarbonization levers.

To accelerate the development of SAF, it is necessary to increase demand visibility for project developers. To this end, incentives and regulations are defined (or are being defined) at national and international levels:

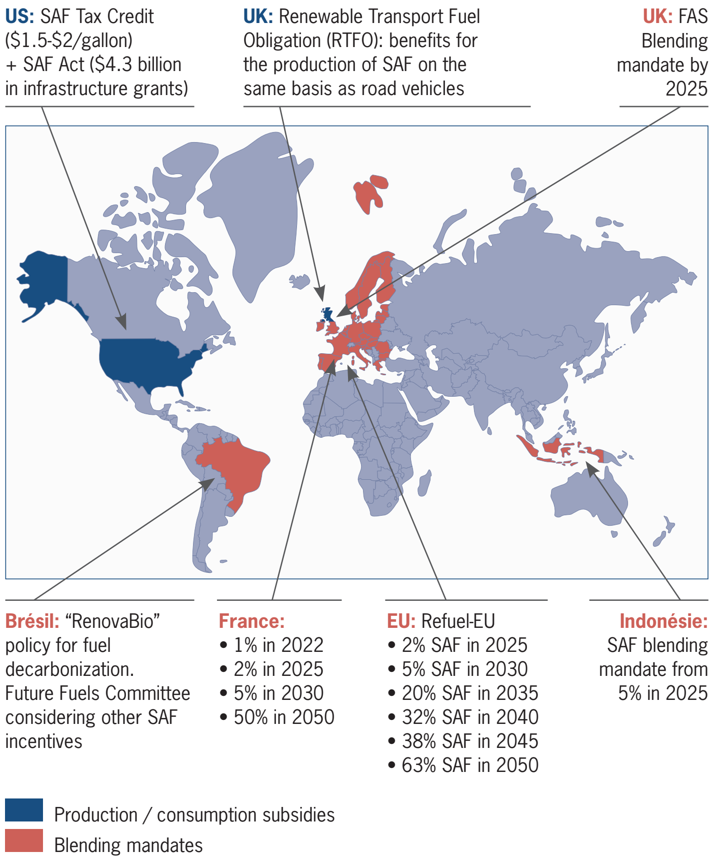
- Only three countries in the world have made SAF blending mandatory by January 1er, 2022: Norway (since 2020), Sweden (since 2021) and France (since 2022). In the first two countries, regulations require a 1% blend of SAF with conventional kerosene for all aircraft refueling on their territory, with a target of 30% SAF by 2030. France has also defined its strategy for biofuels, which calls for an SAF blending mandate from France according to an "ambitious but realistic" trajectory:[81] 1% in 2022, 2% in 2025, 5% in 2030 and 50% in 2050.
- At the European level, a proactive pathway to 2050 has been developed as part of the ReFuel EU Aviation initiative. This scheme, for which a proposal will soon be presented to the European Commission, will apply only to flights departing from European airports. While the mandatory percentage of SAF blending is relatively low in the short term (minimum 2% SAF by volume in 2025 and 5% in 2030), it will gradually increase by 2050 (minimum 63% SAF by volume, including a minimum 28% e-fuel).[82]
- Finally, the UK, Indonesia and Brazil are also considering SAF blending mandates.

What is more, other countries are currently focusing on subsidies for the production/use of SAF:

- United States[83]: the US Congress introduced the Sustainable Skies Act in May 2021, aimed at strengthening incentives for SAF use ($1.50 to $2/gallon credit for blenders, based on greenhouse gas reduction performance, with a minimum of 50%), requiring eligible SAF to use the full set of ICAO sustainability criteria, and providing a $1B grant over 5 years to increase the number of SAF production facilities. In September 2021, the United States announced a new goal to increase SAF production to at least 3 billion gallons per year by 2030, as well as an increase in financial support of $4,3billion to support SAF projects/producers.[84]
- United Kingdom:[85] the British government published its Net Zero strategy in October 2021, announcing a commitment of £180 million to support the development of SAF production. It also considering an SAF blending mandate from 2025 (1%, then 3% in 2030 and 6% in 2035).

81 Ministries, *French Roadmap for the Deployment of Sustainable Aviation Biofuels* (2020).
82 European Commission, *ReFuel EU Aviation Project* (July 2021).
83 IATA, *Fact Sheet: EU and US policy approaches to advance SAF production* (October2021).
84 The White House, *Fact Sheet: Biden Administration Advances the Future of Sustainable Fuels in American Aviation* (September 2021).
85 HM Government, *Net Zero Strategy: Build Back Greener* (October 2021).

Overview of incentives for SAF use around the world



Source: Public data; Archery Strategy Consulting analysis.

To encourage greater use of SAF in aviation, it would be beneficial if systems similar to the one proposed by Europe could be developed in regions that do not currently provide them.

In Europe, although the trajectory defined in the framework of Refuel EU is ambitious given current sector maturity, both in terms of supply and demand (SAF blending target of 63%), this alone does not make it possible to achieve the carbon neutrality target by 2050: this SAF blend rate will have to be progressively increased between now and 2050 at the global level.

4.4. Supporting supply to create a competitive SAF market in Europe

Help SAF production technologies reach industrial maturity

RECOMMANDATION 6A (France/EU)

Finance functional prototype projects for various technologies, including biofuels and synfuels, using EU ETS funds.

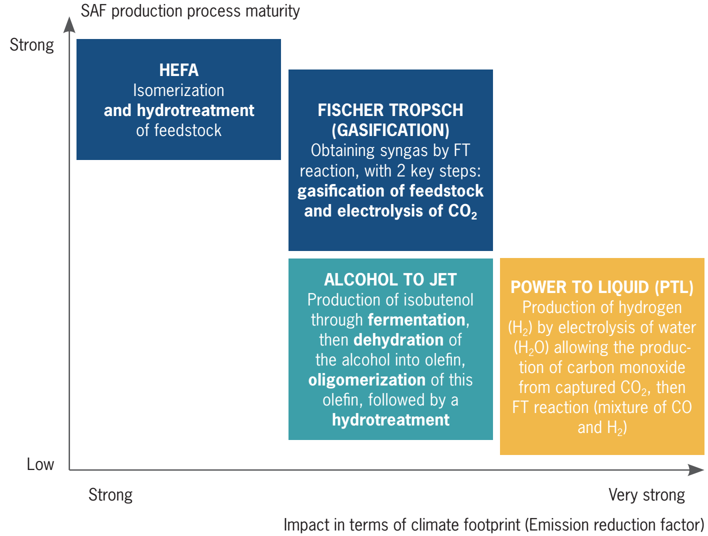
In the short term, the HEFA sector is based on a mature technology (TRL 8-9),[86] well mastered and already deployed on an industrial scale throughout the world. For this reason, the production of biofuels by this route is now predominant. For example, the transformation of its La Mède refinery into a biorefinery should enable Total to produce jet fuel from recovered waste products using the HEFA process. However, the development of this process is limited by the small quantities of raw materials available. In the long term, this technology should only provide a small proportion of SAF volumes.

In the longer term, the Gasification/Fischer-Tropsch process (TRL 7-8) or the Alcohol-to-Jet process (TRL 6-7) would make it possible to generate larger

86 Destination 2050.

volumes by mobilizing other types of resources. Funding prototype projects should help create the conditions for the industrial maturity of these different processes.

Comparing SAF production processes, by maturity and expected benefits



Source: Archery Strategy Consulting analysis.

In France, the BioTfueL pilot project was launched in 2010.[87] It brings together a consortium of players, centered around Total and financed in part by ADEME's research demonstration fund (up to €30 million), and should make it

87 Total, *BioTfueL: towards the development of 2nd generation biofuels.*

possible to adapt the FT process to industrial scale – with the aim of bringing it to market in early 2022. Another example is the Futurol project, financed by Bpifrance (€30 million), which has demonstrated the technical feasibility of a large-scale bioethanol production process: commercialized by Axens (an IFPEN subsidiary), a first license has been granted to the Croatian oil company INA and should enable the production of 55,000 tons of bioethanol.[88]

EU ETS funds could also be used to finance demonstration projects for biofuels and synthetic fuels. For example, the European NER 300 (New Entrants' Reserve) Demonstration Fund, created in 2009 and funded by the proceeds of 300 million EU ETS emission allowances (i.e., €2.1 billion),[89] has financed several innovative low-carbon energy demonstration projects in France and Europe. Its successor, the Innovation Fund, is endowed with 450 million emission allowances (+50%) and will also benefit from the funds not spent by NER 300.

Support the launch of the SAF sector in Europe

RECOMMANDATION 6B (France/EU)

Set up Calls for Proposals (guaranteed price) and ensure the competitiveness of SAF produced in Europe during the first years (subsidies), in order to boost sector development in Europe and secure the launch of the first production units.

88 Green formula, *Axens markets its Futurol process for the first time* (March 2020).
89 European Union Emission Trading Scheme: a European exchange allowing each company to buy or sell CO_2 emission allowances.
90 Ministère de la Transition écologique (2021).

RECOMMANDATION 6C (EU)

Dynamically adapt the SAF blending trajectory as defined in the framework of Refuel EU Aviation, in order to avoid plateau effects and to be consistent with the industrial environment; in this respect, an increase in the 2030 target could be considered.

RECOMMANDATION 6D (EU)

Maximize production volumes, provide incentives (e.g., tax credits) to offset the cost premium between SAF and kerosene for blends above base requirements.

Partnerships have been announced between energy companies, airlines and manufacturers. For example, TotalEnergies and Safran signed a strategic partnership in 2021 to improve compatibility between SAF and aircraft engines, facilitating a 100% blending rate.[91] The same year, Boeing began a partnership with SkyNRG Americas to improve SAF availability, and announced it was investing in its partner's first dedicated SAF production facility in the United States.

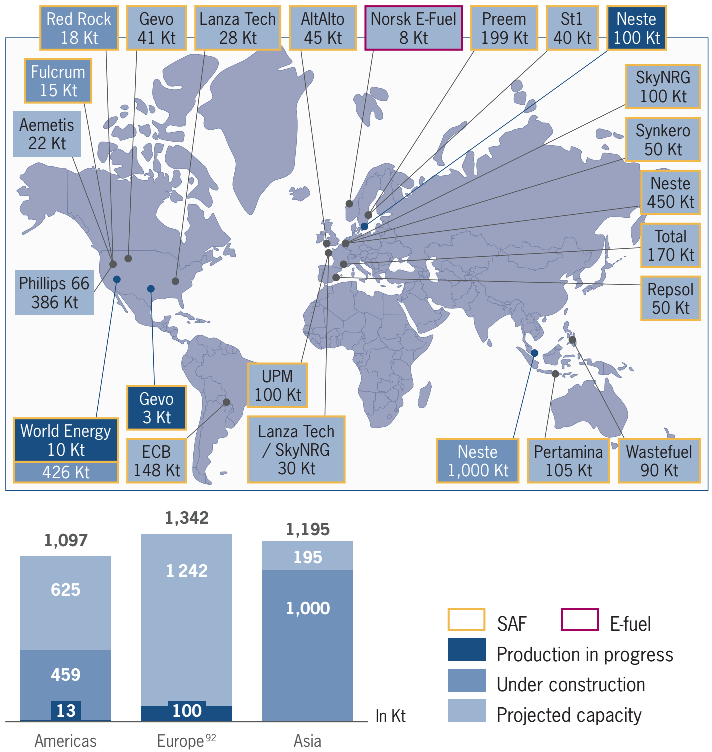
Nevertheless, the current SAF production chain is still largely underdeveloped at the international level. Aeronautical and energy players are on standby, with no clear vision of their respective positions in this new sector.

Global biofuel production in 2021 is around 100,000 tons; as mentioned earlier, HEFA is currently the only technology that has been used on a commercial scale (production of more than 100 kt per year). Including the units under construction, and the announced capacities, this production could reach 3.6 million tons per year, or about 1% of the sector's kerosene needs (about 350Mtoe in 2018). Half of this capacity will be provided by Neste (in Europe

91 L'Usine Nouvelle, *Safran and TotalEnergies join forces to get sustainable fuels off the ground* (September 2021).

and Malaysia) and World Energy (in the United States). While there are numerous projects to build new units, supply remains well below demand.

Overview of incentives for SAF use around the world



Source: SkyNRG – WDB Action Programme; Archery Strategy Consulting analysis.

92 Europe: 2.3 mt/year potential SAF output, currently used for other outputs.

It should also be mentioned that the majority of installed capacity, or those under construction, are located on the American and Asian continents.

In order to secure project leaders' business plans, and therefore the development of new production capacities, it is essential to give SAF producers visibility on long-term demand, so that they can confidently invest in production tools:

- For volume, the blending mandate guarantees and secures a significant and growing demand from airlines;
- For value, there is considerable uncertainty about the expected price cuts for various SAF, with a risk of losing competitiveness in the medium term.

In response to this constraint, Call for Proposals type schemes can provide greater visibility: manufacturers wishing to invest in SAF production units can see their income guaranteed over a long period (e.g., 10 years), which would allow them to strengthen their business plans. This method has notably been used for the development of renewable energies (solar photovoltaic, wind power, biomethane, etc.).

In the past, the case of road biofuels has shown the risks of imbalance between geographical regions, as the European Union has had to face very aggressive competition from outside Europe, whether it be due to bioethanol from the United States or biodiesel imported from Argentina.[93]

Since biodiesel produced from soybeans in Argentina is more competitive than European biodiesel produced from rapeseed, this has led to an influx of Argentine biodiesel in Europe, which has also heavily penalized European producers, with the French leader Avril being forced to temporarily reduce production and furloughing employees at five plants. European subsidies granted for biodiesel have served the interests of the Argentine industry more than the European industry. In 2019, this situation has led to the introduction of anti-subsidy countervailing duties on pure or blended biodiesel from Argentina.

93 National Assembly, *Information Report on Agrofuels* (January 22, 2020).

Moreover, the major producers of road biofuels, such as Brazil, Argentina and Indonesia, have developed their biofuel sectors while considering not only their domestic needs, but also the prospects of the North American and European markets, with the intention of exporting massively to these consumption centers.

In addition, Europe has limited agricultural area compared to other regions, which makes it necessary to use fuels that are more expensive to produce (use of waste or synthetic fuels).

Thus, if Europe does not act now to boost its SAF sector, it will be difficult to catch up later, and Europeans will have to import massively to meet the industry's demand for clean fuels – with the extra cost of incorporating SAF charged to the European passenger not contributing to the European economy but going instead to these other countries.

In order to ensure Europe's SAF supply independence, while waiting for prices to balance out as the various production methods mature and increase in output, the sector must be supported. This could be done, for instance, through subsidies to balance the cost of production or sale of SAF in Europe with the international market.

Funding an SAF subsidy scheme equivalent to the one considered in the USA

Principle: the subsidy allows a company to benefit from government support and can vary (feed-in tariff, additional remuneration, etc.). The proposition here is to mirror the American system, which on the one hand facilitates the creation of new production units (investment subsidy) and on the other hand supports the non-competitive production of SAF proportionally to the volumes produced (operating subsidy).

…/…

Scope: this provision is applicable at a supranational level (e.g., EU member states).

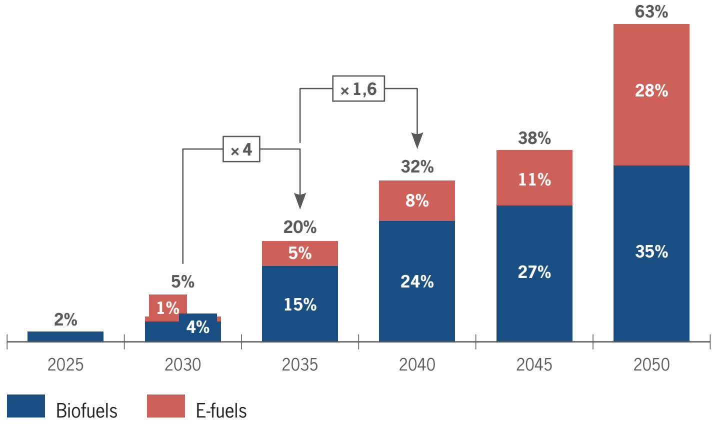
Annual cost: €1 billion per year in 2025 and then €2.2 billion per year in 2030, at the European level.

Assumptions:
- EU aviation fuel/kerosene consumption: Mt55,5 (2025) – 71,1 Mt (2035); linear extrapolation: 63.3 Mt (2030)
- SAF blending rate (ReFuel EU Aviation): 2% (2025) – 5 % (2030)
- US capital grant: $4.3 billion (2021-2030); operating grant: $1.5 to $2/gallon (1 gallon ~ 3.8L)
- Exchange rate (2021): €1 = $1.13

The trajectory of SAF blending considered by the ReFuel EU Aviation initiative seems very ambitious (with, for example, a fourfold increase in the SAF blending rate between 2030 and 2035). If the conditions are right to trigger a favorable investment dynamic for the emergence of a SAF sector, we must also accept the risk of generating local overcapacity. If this were to happen, which is of course hypothetical, it would be up to the States to set up a system that would allow these surpluses to be absorbed without producers suffering (e.g., subsidies).

Europe's planned SAF blending trajectory

(% blend in kerosene)



Source: ReFuelEU Aviation; Archery Strategy Consulting analysis.

In order to respect the ambitious blending trajectory set by Refuel EU, all available capacities must be mobilized and projects must not be delayed. Therefore, a tax credit type incentive should be set up for companies that blend more SAF than the target set by Refuel EU. This will ensure that any additional output has an outlet, and will smooth the blending trajectory by avoiding a plateau effect.

4.5 Limiting distortions of competition

RECOMMANDATION 7A (EU/World)

In the short term, set up a European compensation mechanism applicable to all journeys departing from the EU. It should be proportional to the distance traveled by each passenger to subsidize the SAF blending at no additional cost compared to kerosene, thus avoiding competitive distortions and limiting risks of carbon leakage for journeys outside the EU not subject to the same SAF blend requirements.

RECOMMANDATION 7B (EU/World)

In the medium term, allow for different speeds of implementation of SAF blend ratio requirements between countries/geographical regions without distorting competition between hubs/airlines; back SAF blending mandates at the point of departure for each passenger and throughout their journey.

RECOMMANDATION 7C (EU/World)

In the long term, implement homogeneous SAF blend ratios at ICAO level.

SAF costs will remain higher than current kerosene costs due to very heavy investments (R&D, raw material supply logistics, construction of new manufacturing facilities, etc.), but economies of scale and the maturation of the various technologies should eventually lead to a significant drop in prices.

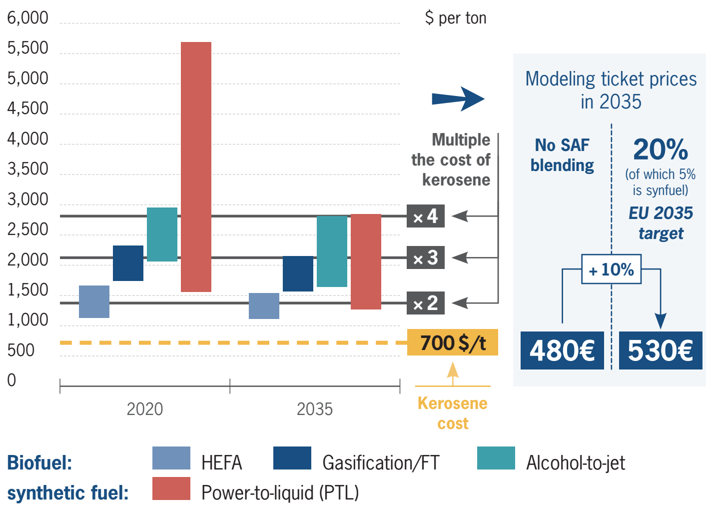
To illustrate this point: with oil at ~$700/ton, the production cost of SAF in 2035 will be 2 to 4 times higher than that of kerosene.

Let's consider the example of a flight from Paris to Singapore:

Modeling the impact of SAF blending on the price of a Paris – Singapore ticket in 2035

Case study:

Distance: **~12,000 km** / Average price: **~500€**
Assumptions:
- Fuel price = **~120 €** (24% of total cost, Source: IATA – 2019)
- Fossil kerosene stable over time
- Improved fleet efficiency (vs. 2020): 15% in 2035 and 30% in 2050
- Inflation neutralized



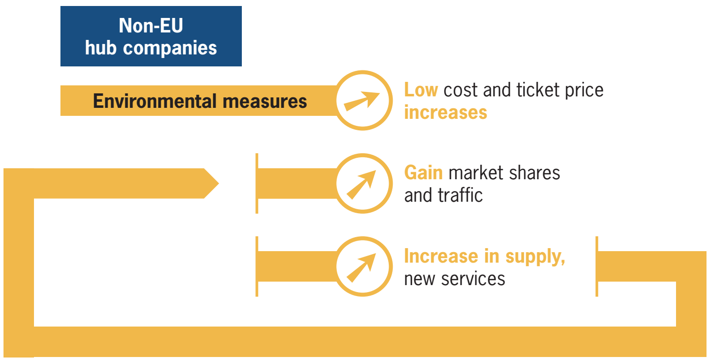
Kerosene cost ~$700 per ton (calculated at ~$60/barrel)

Source: Clean Skies for Tomorrow; Destination 2050; Archery Strategy Consulting analysis.

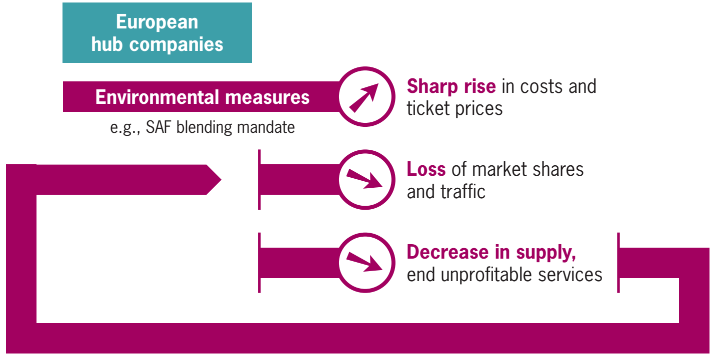
This example shows that, given the price difference between kerosene and SAF, the SAF blending mandate will lead to additional operating costs for airlines, which will mean higher marketed ticket prices (in this case, an increase in ticket prices of about 10% in 2035 compared to current prices, all other things being equal).

This increase in costs and prices, provided it is gradual, homogeneous across geographies, and if necessary accompanied by a transitional period, does not call into question the sector's viability. On the other hand, a heterogeneous application in relation to other regions of the world would be a source of major distortions of competition, particularly for certain destinations where price elasticity is significant.[95]

The distortion of competition phenomenon



95 Price elasticity measures the sensitivity of demand to a change in price: the higher the elasticity, the more sensitive the consumer is to price.



Source: Working Group.

These distortions of competition between airlines with different SAF blending mandates (or no mandate at all) creates a phenomenon that could also have an impact on the distribution of traffic between these airlines. According to an IATA study,[96] for a 1% increase in the unilateral price of one airline, it is estimated that there is a 1.5 to 2.5% traffic transfer to other airlines. On the previous example (Paris - Singapore flight), faced with a 10% increase in ticket prices in 2035, and according to the same study, European airlines could lose around 10% of traffic solely due to distortions of competition on routes subject to competition from international hubs.

96 IATA, *Estimating Air Travel Demand Elasticities* (December 2007).

More broadly, if we consider a passenger wishing to fly from Madrid to Beijing, there are several possible itineraries, all other things being equal (market situation allowing the choice between several itineraries / European or non-European airlines / stopovers, etc.):

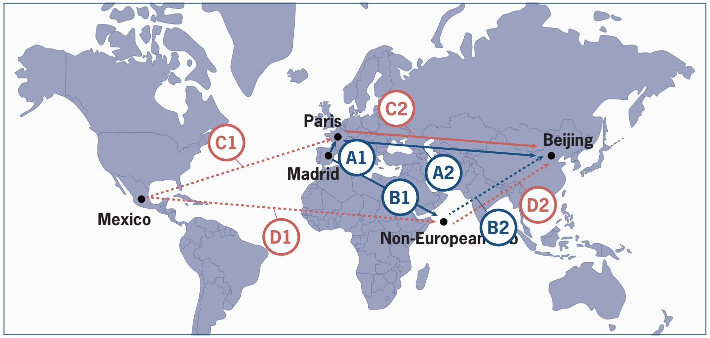
- Option (i): fly direct from Madrid to Beijing, in which case the entire flight is subject to the European SAF blending mandate (departure airport in Europe);
- Option (ii): stopover at a European hub, in which case, again, the entire flight is subject to the European SAF blending mandate (departure and stopover airports in Europe);
- Option (iii): stopover in a non-EU hub, which means that the first part of the flight is subject to the European SAF blending mandate (departure airport in Europe), while the second part is not (stopover airport outside Europe).

This first example leads us to conclude that flying via a non-European hub is more competitive than a direct flight or a flight with a stopover in a European hub (all other things being equal).

A similar demonstration, this time for a Mexico-Beijing trip, would lead us to conclude that international trips via a non-European hub are more competitive than trips via a European hub (all else being equal).

Distortions of competition resulting from the European SAF blending mandate

Model Under construction: All flights from the EU are subject to SAF blending mandates on the entire amount of fuel.



Distorsion n°1: Going through a non-EU hub is more competitive than a direct flight or going through an EU hub
A stopover outside the EU: reduces the part of the journey subject to regulation (B1 vs. A1 + A2) → **Route B1 + B2 more competitive than A1 + A2**

Distorsion n°2: Going through a non-EU hub is more competitive than going through an EU hub
A stopover in the EU: the entire journey is subject to the regulations → **Route D1 + D2 more competitive than C1 + C2**

Flight not subject to this mandate

Flight subject to the SAF blend mandate

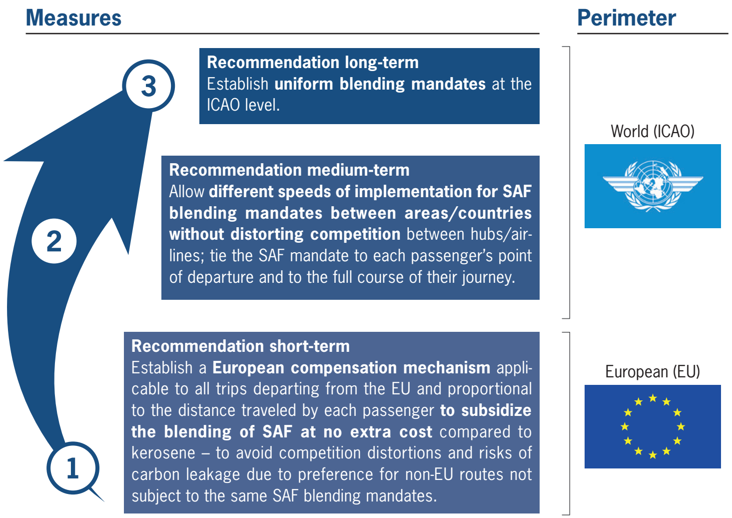
Source: Archery Strategy Consulting analysis.

Possible models

In order to ensure that the transition phase which will lead the air transport industry to carbon neutrality is not detrimental to the players to whom the strongest obligations will apply, in particular European airlines and airports, we propose three measures to avoid or mitigate distortions of competition.

These measures could be implemented in an iterative manner depending on the balance of SAF blending mandates at the global level and convergence dynamics for shared rules at ICAO level.

Complementarity and tiered measures which would allow the roll-out of SAF throughout the world while limiting distortions of competition



Source: Working Group; Archery Strategy Consulting analysis.

Short-term

In the short term, an international mechanism seems complicated to put in place. In this context, it is necessary to identify measures to mitigate the SAF blending mandate for passengers in transit via a European hub.

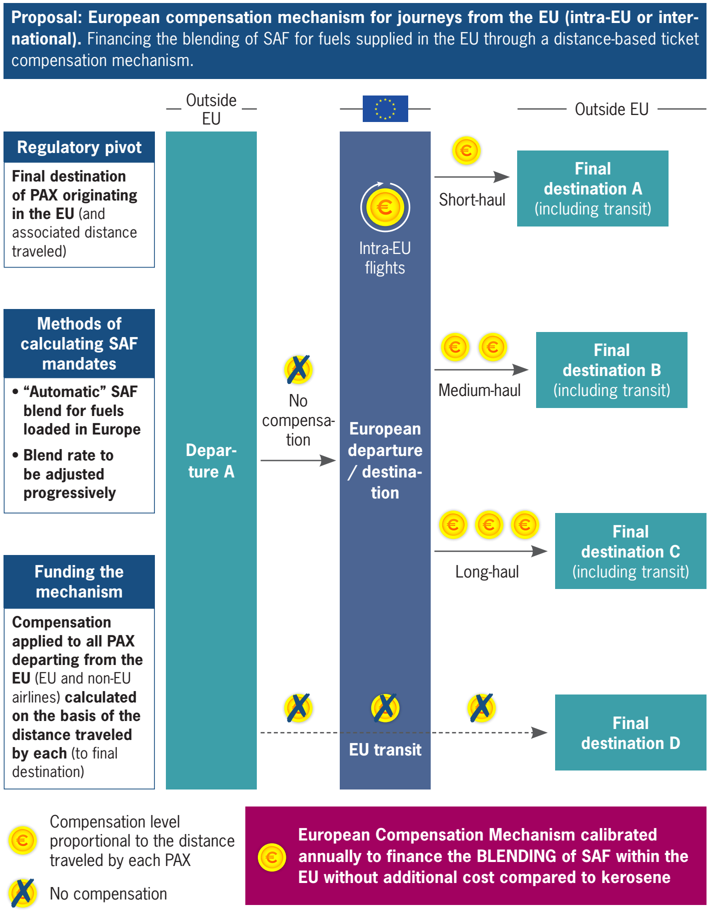
This mitigation mechanism would be paid for by the end customer – who would pay an additional fee included in the price of their ticket, proportional to the extra cost generated by SAF blending mandates. The amount would be proportional to the total distance traveled by the passenger, regardless of stopovers, including code-sharing journeys.[97] The amounts collected would go into a fund allowing airlines to finance the SAF needed. The proposed mechanism is self-financing and therefore requires no public financial support.

All passengers departing from the EU would be eligible for this mechanism, while passengers originating outside Europe and transiting through a European hub would be exempted, regardless of the airline.

Furthermore, in order to finance the blending of SAF in the EU with a limited additional cost compared to kerosene, the level of compensation would take into account the evolution of the price differential (SAF-kerosene), and would be adjusted on an annual basis. This re-assessment would not only account for changes in the price of kerosene, but also the expected decline in the price of SAF over time, as well as changes in blending levels.

97 Code sharing is the practice of allowing several airlines to put their code (unique identifier) on the same flight or, practically speaking, to have flight numbers corresponding to several airlines for the same flight. This practice allows the company to better fill its planes, to offer better flight frequencies and to serve inaccessible markets (for example, domestic flights in the United States by a European company). In addition, Code Share allows passenger to benefit from a "one-stop shop" by using a single airline.

A European compensation mechanism to limit distortions of competition



Source: Working Group; Archery Strategy Consulting analysis.

Medium-term

The implementation of SAF blending mandates will not occur at the same speed worldwide due to different decarbonization trajectories and available input volumes. This situation should not hinder SAF roll-out and a specific regulatory framework, negotiated at ICAO level, can be put in place to allow for different levels of blending between countries without generating distortions of competition.

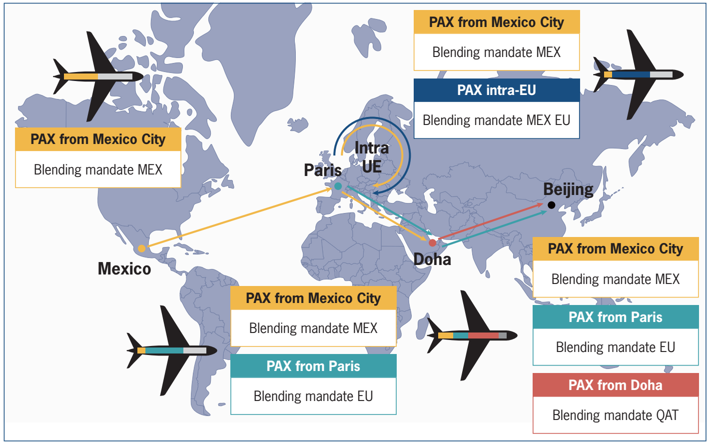
To this end, it would be necessary to base the level of SAF blending not on each aircraft but on the point of departure of each passenger, regardless of stopovers, including in the context of code-sharing routes. Each airline ensures that SAF blending is proportional to the mandates of its passengers' countries of origin. For example, a passenger departing from Mexico City and traveling to Beijing will be subject to Mexico's blending mandate for the entire trip, regardless of stopovers.

In practical terms, it would be necessary to set up a shared database at ICAO level so that airlines can report the fuel consumption of all their passengers by country of origin as well as the volumes of SAF blended. This would make it possible to balance the SAF actually blended and the SAF to be blended.

Additionally, it would even be possible to localize SAF blending mandates. Thus, all of the SAF blending that a company must include for passengers from Europe could be blended in Europe. This could avoid phenomena that would prevent countries with ambitious blending mandates from benefiting from the returns in economic and employment terms.

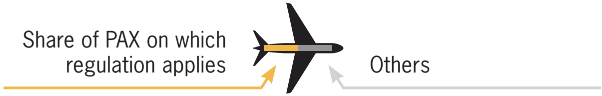
A model for implementing different SAF blending mandates by geography

Proposal: Globalized model allowing for different BLEND requirements by geography. Regardless of the route (with or without a stopover), the fuel consumed by PAX on all flights is subject to the blending mandates required by the country of departure



Regulatory pivot
Departure of each PAX journey regardless of stopovers and arrival point (international)

Calculation of SAF blending mandates
• **Each country's blending mandates** applied to all PAX trips **from departure country to the final destination** (including stopovers) • Also applies in the case of **code sharing**



Source: Working Group; Archery Strategy Consulting analysis.

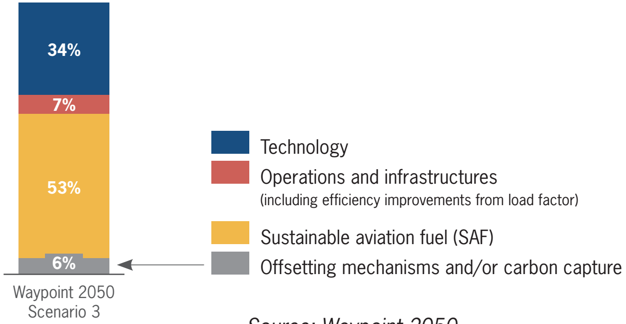
In order to ensure the operational implementation of the regulation, it will be essential that countries/regions set up the SAF supply conditions required by their regulations within their airport infrastructure.

Long-term

Eventually, convergence of SAF blending mandates would be preferable, if not inevitable. In practice, this implies defining, via ICAO,[98] a single SAF blending rate mandate across the world.

5. Existing mitigating systems must be expanded and amplified

Contribution of market measures to the CO_2 emissions reduction target



Source: Waypoint 2050.

98 International Civil Aviation Organization (ICAO): organization, part of the UN, gathering 193 signatory States, in charge of establishing the world regulatory framework for air transport, including environmental protection.

Two carbon quota systems currently co-exist in Europe: EU ETS (European Union Emission Trading Scheme) and CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation).

RECOMMANDATION 9 (EU)

In the short term, set up a mechanism to limit the distortion of competition related to connecting traffic between Europe and the rest of the world subject to the EU ETS, for example by maintaining a fraction of free allowances to ensure balanced competition with flights subject to the CORSIA system.

RECOMMANDATION 10A (World)

Encourage the implementation of ETS-type market mechanisms for domestic emissions in countries and regions outside Europe.

RECOMMANDATION 10B (World)

In the medium term, ensure the alignment of carbon allowance systems with each other and with the industry's "Net Zero" objective.

5.1. EU-ETS

The EU Emissions Trading Scheme (EU ETS) is a mechanism for trading CO_2 emissions that has been in place since 2005 to reduce global CO_2 emissions and meet the EU's targets under the Kyōto Protocol.[99] It establishes a limit on the gases allowed to be emitted and the creation of a carbon market. Emission allowances determined by the public authority are distributed, free of charge or by auction, to authorized organizations. They can also buy or sell additional allowances on the market.

Currently, the scheme covers the main emitting sectors: power and heat generation, energy-intensive industries (steel, paper, glass, cement, ceramics) and commercial aviation. Nearly 11,000 power plants and large industrial sites, including airlines, are covered by the European carbon market.

For aviation, this scheme covers all flights within the zone, which includes not only EU countries, but also those of the European Economic Area (EEA) – Norway, Liechtenstein and Iceland – as well as Switzerland, which joined the carbon market in 2020.

In order to meet the target of reducing emissions by 55% between 1990 and 2030, recently raised by the European Commission in its Climate Target Plan 2030 (compared with the previous 40% target), the emissions of the highest emitting organizations will have to be reduced. This will be achieved by gradually reducing the total number of emission allowances available on the market and, for airlines, by phasing out free allowances by 2027. By moving to a full auctioning of allowances from that date, the European Commission hopes to create a stronger price signal and increase emission reductions.

5.2. CORSIA

International flights, on the other hand, are covered by CORSIA, a program ratified in 2016 by the International Civil Aviation Organization (ICAO). CORSIA aims to offset the share of CO_2 emissions from international flights that exceeds 2019 emission levels. In other words, the scheme sets a goal of carbon-neutral growth from that date.

In practical terms, airlines exceeding 10,000 t CO_2/year on international flights must now report their emissions based on the actual consumption of their fleet.

99 The protocol, which was signed in 1997 and came into effect in 2005, contains binding and quantified targets for the limitation and reduction of six greenhouse gases (carbon dioxide CO_2, methane CH_4, nitrous$_2$ oxide NO and fluorine-based compounds HFCs / PFCs / SF_6).

Signed by 191 countries, this market-based mechanism requires airlines to purchase credits generated by eligible international low-carbon projects. The CORSIA scheme came into effect for a voluntary trial period in January 2021 and will then become mandatory for all airlines worldwide in 2027.

In 2021, 88 states (including the EU) representing 77% of international aviation activity have volunteered to participate in CORSIA.[100] Some high emitting markets are not participating in the voluntary phase, and will only participate in the mandatory phase from 2027.

5.3. Two different approaches share one similar goal

Both EU ETS and CORSIA are based on the reporting of CO_2 emissions by airlines to their state governments each year, after verification by an independent external auditor.

While the two carbon quota systems differ in their geographic coverage, approach, applicability and level of ambition, the objective of limiting the level of CO_2 emissions in the aviation sector is comparable.

The EU ETS is a cap-and-trade system: sectors covered by the European carbon market, such as aviation, cannot emit more than the cap allows. If there are no more allowances, no more greenhouse gases can be emitted. As the cap is reduced, the total amount of CO_2 emissions is also reduced.

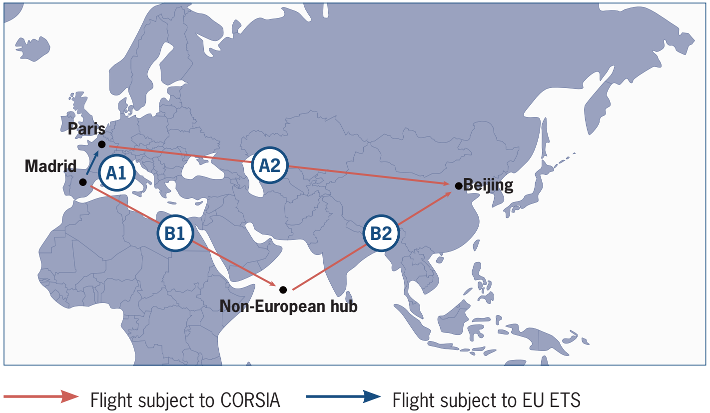
CORSIA, on the other hand, is an offset system. This means that there is no cap on the total amount of CO_2 emitted into the atmosphere. The system requires participants (airlines) to offset the amount of CO_2 they emit against a predetermined baseline (the 2019 level). Offsetting typically means planting trees (so that an equivalent amount of CO_2 is captured and stored in biomass) or funding CO_2 reductions in other industries.

100 Eurocontrol, *CORSIA and the EU's Emissions Trading System: how EUROCONTROL supports European aviation to foster sustainability* (May 2021).

5.4. Limitations and proposals

Avoiding distortions of competition

The coexistence of 2 carbon quota systems



Source: Archery Strategy Consulting analysis.

First of all, the CO_2 emission reduction target of the EU ETS system is more ambitious than the CORSIA system,[101] and will therefore entail higher costs. However, when considering the example of a passenger wishing to travel to Beijing from Madrid, there are several options:

- Option (a): stopover in a European hub (e.g., Paris), in which case the intra-European route (a1) is subject to the EU ETS system, while the second part of the route to Beijing (a2) is subject to the CORSIA system;
- Option (b): stopover in a non-European hub, in which case the entire flight (b1+b2) is subject to the CORSIA system.

101 Destination 2050.

The ticket price will be higher with option (a) than with option (b), all other things being equal. This example highlights a distortion of competition that will encourage travelers to prefer the route via the non-European hub, which will be much less affected by the carbon quota systems in place.

Extend the two carbon quota systems to domestic flights

Level of coverage of EU-ETS and CORSIA mechanisms by region and type of journey

	Intra-European	Europe-World	Rest of the world
International flights	8% **EU-ETS** Objectif 2030: 2030 target: 61% below 2005 emissions[102]	16% **CORSIA** Goal: carbon neutral growth from 2019	40% **CORSIA** Goal: carbon neutral growth from 2019
Domestic Flights	3% **EU-ETS** Objectif 2030: 2030 target: 61% below 2005 emissions[102]	N/A	33% **Not covered**

x% Share of global traffic

Source: Public data; Archery Strategy Consulting analysis.

Domestic flights in non-European countries (outside the EU), which today account for nearly one-third of global air traffic, are not covered: this is particularly true for China (second largest domestic market in terms of CO_2 emissions in 2019), India (third) and Brazil (sixth).[103] The level of traffic in these very dynamic regions, particularly in Asia, could increase in the future.

102 Overall objective for all sectors included in the EU-ETS mechanism.
103 ICCT, *CO_2 emissions from commercial aviation* (2020).

Extending these carbon quota systems to domestic flights, in countries and regions of the world other than Europe, will therefore be necessary to cover air traffic emissions as best possible.

Systems need to be aligned with the decarbonization objective

The EU ETS and CORSIA systems do not yet take the 2050 carbon neutrality objective for the aviation sector into account (“Net Zero” objective) and will therefore have to evolve in this direction.

IV

DECARBONIZING AIR TRANSPORT IS PART OF A WIDER ENERGY TRANSITION THAT INVOLVES A MASSIVE PRODUCTION OF DECARBONIZED ELECTRICITY TO REPLACE FOSSIL FUELS

1. Energy requirements must be considered for all modes of transportation

Petroleum is a source of fossil energy, widely used in transportation because it has the advantage of being very energy dense, easily transportable and easy to supply. It is also an irreplaceable material for the petrochemical industry (plastics, paints, dyes, cosmetics, etc.). It is also used as a fuel for domestic heating and as a heat source in industry. The analysis presented in this report focuses on transportation.

Fuel requirements by transport mode in 2018 and 2050

	Traffic and emissions 2018			Ballistic trajectory 2050	
	Traffic 2018 (Bn passenger.Km or Bn T.Km)	Fuel consumption 2018 (Mtoe)	Of which biofuel	Traffic 2050 (Bn passenger.Km or Bn T.Km)	30% reduction in consumption (Mtoe)
Road transport for passengers	30	**1,200**	2,4%	71	2,000
Road transport for goods	22	**800**	3%	58	1,600
Air transport	8	**350**	0,1%	22	600
Shipping	85	**250**	0,1%	269	600
		2,600 Mtoe			**4,800 Mtoe**

Source: ITF Transport Outlook 2019, Waypoint 2050, IEA, Archery Strategy Consulting Analysis.

Global consumption of petroleum-based fuels (gasoline, diesel, kerosene, heavy fuel oil, etc.) reached approximately 2,600 Mtoe in 2018,[104] largely driven by road transport (people and goods). With nearly 350 Mtoe, the aviation sector accounts for 13% of this total.

By 2050, transportation is expected to continue to increase in volume and, with it, fuel consumption will also increase. Including a reduction in consumption due to technological improvements (improved efficiency), total consumption could reach nearly 4,800 Mtoe.

Part of this consumption will be enabled by alternative technologies to petroleum products (battery, fuel cell/hydrogen, ammonia, etc.), the level of

104 Megatonne of oil equivalent: energy measurement unit, corresponds to the calorific value of one tonne of oil.

which will vary according to their accessibility for all the means of transport in circulation. For example, in a cautious scenario, the share of electric cars among all automobiles could represent nearly 30%, while it would be 75% in a more optimistic scenario. This range reflects the potential differences in the speeds of electric mobility development (replacing thermal vehicles with electric vehicles, deployment of recharging infrastructures, incentives in legislative and regulatory framework, etc.).

This study considers a single scenario of accelerated decarbonization (optimistic) that takes into account ambitious benefits from using alternative technologies. Considering varying levels of penetration depending on the technology, the residual fuel requirement could amount to nearly 2,200 Mtoe by 2050.

Single scenario for decarbonizing transport

	Alternative Fuels (excluding biofuels and PtL)		
	Main Substitute	Target traffic in 2050	Residual fuel requirement (Mtoe)
Road transport for passengers	Battery H_2/FC	**75%** **5%**	400
Road transport for goods	LH_2/FC Battery	**30%** **15%**	900
Air transport	LH_2	**15%**	500
Shipping	Ammonia	**40%**	400
	Accelerated decarbonization		**2,200 Mtoe**

Source: Public data;
Archery Strategy Consulting analysis.

Each means of transport (roadways, airways and waterways) is engaged in a more or less advanced decarbonization trajectory. Therefore, beyond the penetration level of substitution technologies specific to each (for example, ammonia for shipping), there is a common appetite for the use of biofuels to facilitate the environmental transition – without which the use of petroleum products will remain high.

As a result, biomass resources being finite, this will be subject to competition between sectors, so the contribution of biofuels to the supply of alternative fuels for aviation will remain limited.

2. Synthetic fuels have an essential role to play in achieving decarbonization

RECOMMANDATION 8 (France/EU)

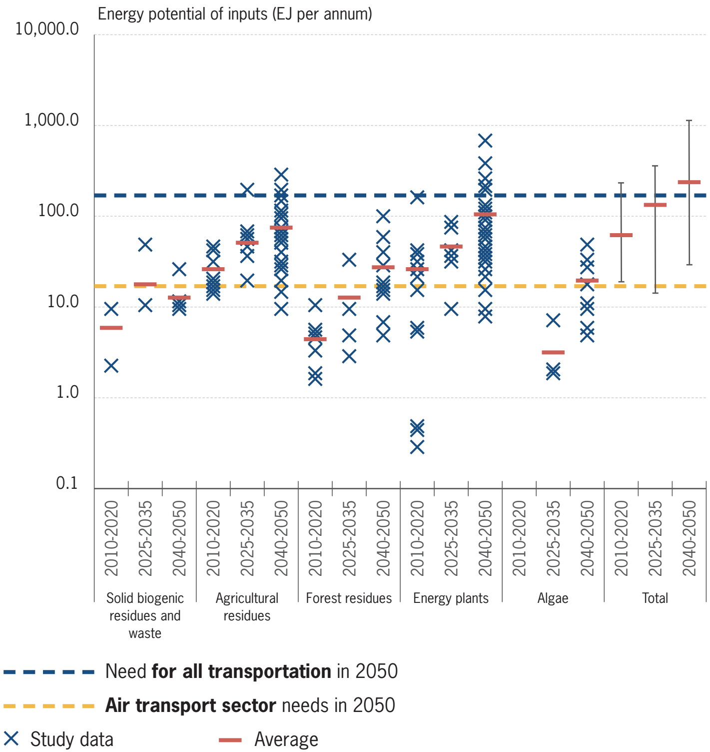
Promote synthetic fuel to stimulate the development of a large-scale hydrogen production chain:
- Synfuel opens up a large volume market for hydrogen production in the short term and allows for the implementation of large-scale production facilities, which are essential for lowering costs;
- Synfuels make it possible to bypass the problems of transporting and storing hydrogen when there are no dedicated infrastructures;
- The synthetic fuel manufacturing process circumvents the issue of feedstock availability because it uses only air, water and electricity;
- Investments could then be used for the distribution of hydrogen to airports when hydrogen-powered aircraft are entered into service;
- The production of synthetic fuel also allows for the development of CO_2 capture technology.

2.1. Biofuel availability

By 2050, biofuels will constitute a significant share of SAF. While estimates of the energy potential of inputs by 2050 are very heterogeneous, it appears that the biomass potential is considerable and exceeds the biofuel needs for all transportation in 2050 (road, air, maritime), and therefore even more so for aviation alone.

Feedstock availability for biofuel production

(Unit: Exajoule per year[105])



Source: IRENA, Innovation Outlook – Advanced Liquid biofuels p33; Archery Strategy Consulting analysis.

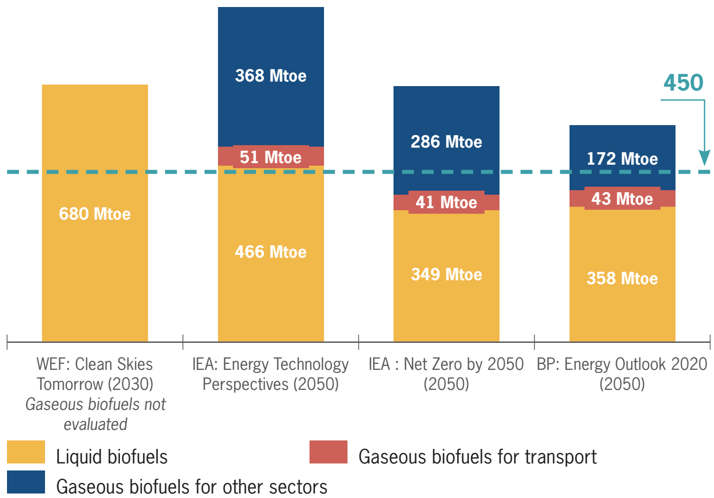
105 The exajoule (EJ) is equal to 10^{18} joules, a unit to quantify energy. Kilojoules (kJ) or calories are usually used in nutrition.

While the availability of inputs exceeds the need for biofuels to decarbonize all transportation, the reality is that not all of these inputs can be used for this purpose for several reasons:

- Liquid biofuels are more suitable for transport, especially air transport, than gaseous biofuels obtained, for example, by methanation (decomposition of organic matter by micro-organisms, producing biogas in particular), of which only a moderate fraction (about 12%) is retained for use in transport;
- The logistical challenges of capturing diffuse deposits (residues, waste, etc.) and concentrating biomass to limit the need for transportation are considerable;
- Resource availability varies seasonally and it is necessary to identify a variety of inputs that are compatible with each other and with the industrial facility in the same geographic area to ensure year-round operation.

It is therefore widely accepted that the sustainable bioenergy potential in 2050 would be limited. According to several key players in the energy sector, this potential could amount to nearly 450 Mtoe.

Estimated liquid biofuel production in 2030 / 2050 according to different players

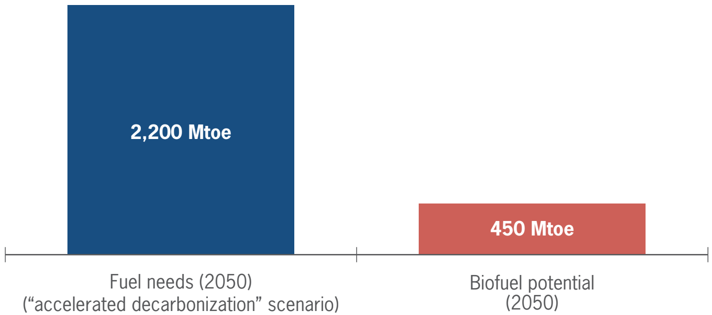


Source: IEA, Net Zero by 2050 & Energy Technology Perspectives; Clean Skies Tomorrow; BP, Energy Outlook 2020 Edition; Archery Strategy Consulting analysis.

2.2. Competition between transportation sectors and penetration of alternative fuels requiring e-fuels

Accounting for all the different modes of transport, these 450 Mtoe only make up 20% of the residual fuel requirement after taking into account alternative technologies.

Comparing the energy potential of biofuels with residual fuel needs in 2050



Source: Archery Strategy Consulting analysis.

To overcome the problem of feedstock availability, particularly in the face of competition from other transport sectors that are also keen to decarbonize, and to produce SAF in sufficient quantity, the use of synthetic fuels is thus essential.

The development of the PtL (Power-to-Liquid) sector is all the more relevant as it would constitute a short-term outlet for the H_2 sector, which is not expected to be used as a "direct" fuel before 2035:

- Hydrogen is an essential input for the PtL process, which opens up a vast volume market for hydrogen consumption in the short-term, allowing the implementation of large-scale installations and the increase in maturity of installations to optimize production costs.
- The PtL process makes it possible to free oneself from the operational constraints of hydrogen transport and storage.
- The production of synthetic fuel also makes it possible to develop technologies for capturing CO_2.

3. Energy needs associated with decarbonization are vast and require unprecedented investments

RECOMMENDATION 11 (World)

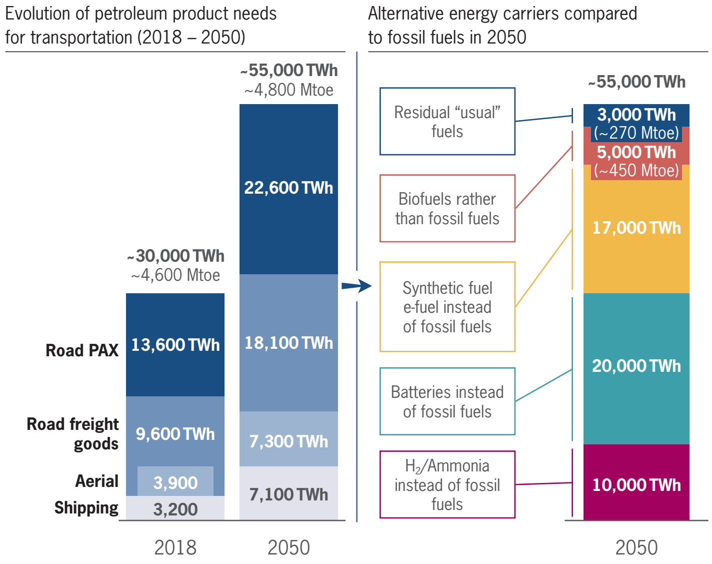
Implement a massive investment policy for decarbonized energies that goes beyond the replacement of production methods currently used, in order to meet the new needs of transport players by 2050.

3.1. Decarbonized electricity production needs

The production of synthetic fuels has many advantages: unlimited inputs (water, air) and a CO_2 impact close to zero. However, this process requires a significant amount of electrical energy to produce decarbonized hydrogen and capture CO_2 present in the air or emitted by industrial plants. To ensure a net reduction in emissions, this energy must be produced using low CO_2 emitting units, such as renewable energies (wind, solar, hydraulic) or nuclear.

By 2050, the energy needs of all the transport sectors could amount to nearly 550,00 TWh (i.e., ~4,800 Mtoe). In the selected scenario ("accelerated decarbonization"), the penetration of alternative technologies (electric batteries, hydrogen) is significant. With the availability of biofuels estimated at 450 Mtoe, the residual fuel needs can be met either by conventional kerosene or by synthetic fuels (PtL). We choose to take into account an incompressible rate of about 6% of the energy needs covered by fossil fuels (which can be compensated). The remaining energy needs are therefore covered by synthetic fuels (i.e.,17,000TWh).

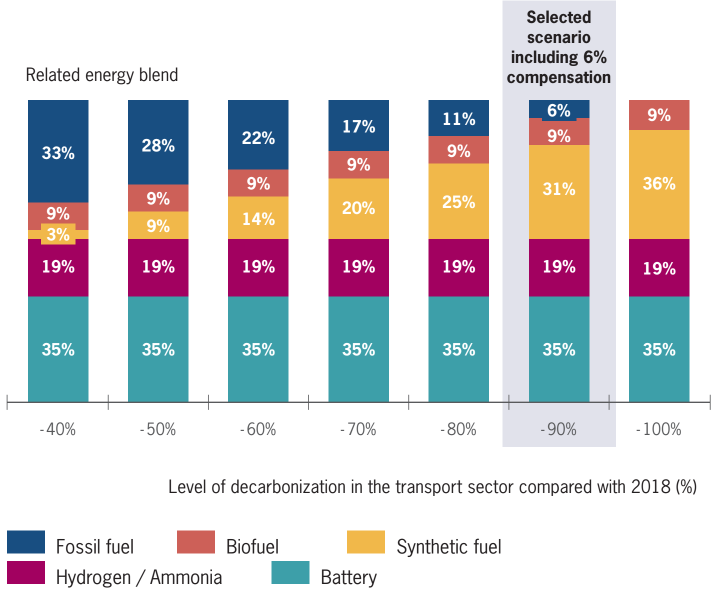
Breakdown of transport energy needs in 2050 by fuel type / solution



Source: Archery Strategy Consulting analysis.

The proposed energy blend allows for 90% decarbonization of all transportation, which is consistent with the ATAG proposal in the scenario considered here *(Waypoint – scenario 3)*, and which requires offsetting measures to achieve carbon neutrality.

Energy blends according to expected level of decarbonization in the transport sector compared to today



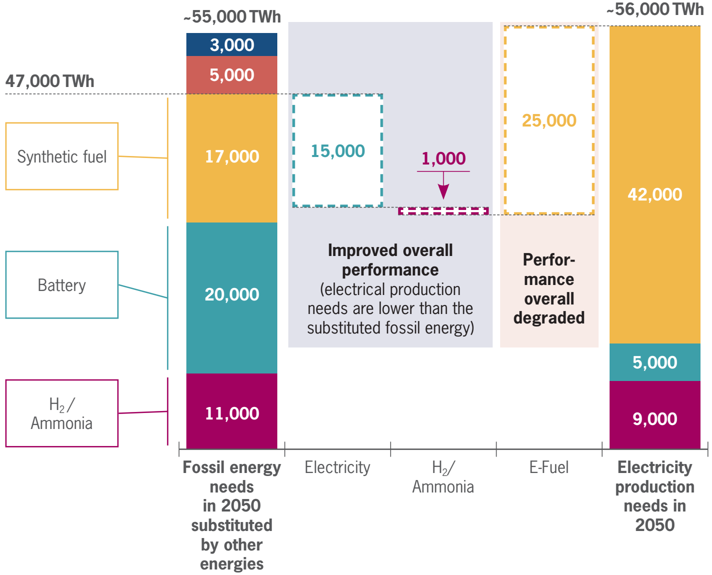
Source: Archery Strategy Consulting analysis.

The electricity requirements for the production of synthetic fuels are added to those for the implementation of other decarbonized alternative technologies (electricity to produce H_2 and to power batteries). In order to assess the required electricity production, it is also necessary to take into account the efficiency of the different means considered as substitutes for fossil fuels:

- The electric propulsion of a road vehicle is particularly efficient and requires nearly 50% less primary energy than the energy contained in gasoline;

- H_2/ammonia propulsion for maritime transport is overall equivalent in terms of energy (a little more if using direct H_2 combustion, as is the case for air transport, a little less if using a fuel cell) ;
- Synthetic fuels are used in the same engines as fossil fuels, so there is no advantage in terms of combustion, but production is very energy-intensive, with production efficiency around 40%.

Power generation required to obtain the energy associated with alternative technologies

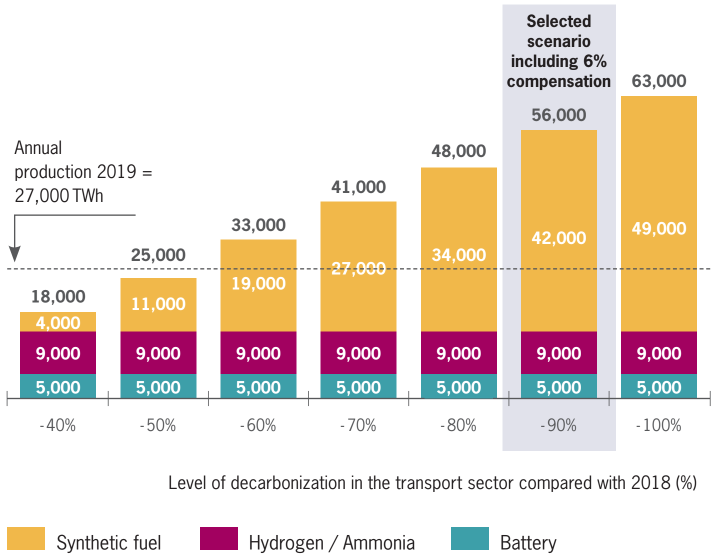


Source: Archery Strategy Consulting analysis.

Thus, nearly 56000 TWh will be needed in 2050 to provide alternative technologies to fossil fuels and supply the same energy. Considering that the world's electricity production currently amounts to nearly 27,000 TWh, mainly for the residential, tertiary and industrial sectors, this is equivalent to tripling the current annual world electricity production (all other things being equal).

Power generation required to activate alternative fossil fuel technologies, depending on the expected level of decarbonization in transport compared to today

(power generation (in TWh))



Source: Archery Strategy Consulting analysis.

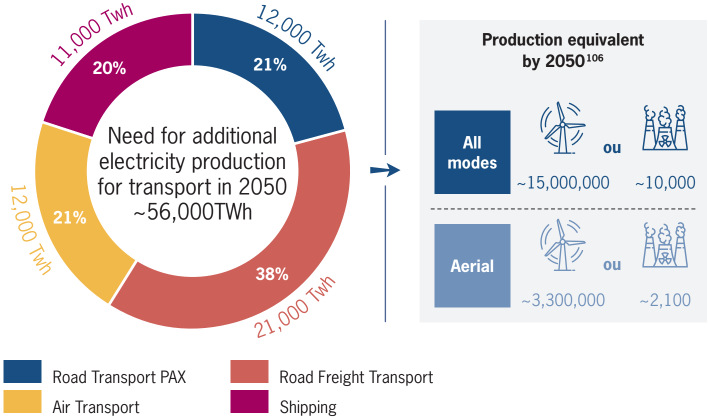
In summation, the use of synthetic fuels to accompany the supply of alternative technologies (battery, H_2) and biofuels is particularly energy intensive, accounting for nearly 75% of new electricity needs (~42,000 TWh out of ~56,000 TWh). Moreover, the decarbonization of air transport would be more energy intensive compared to other transport sectors (road in particular). Efforts to develop synthetic fuels (via the PtL process) as a solution to the decarbonization of aviation could therefore be considered either as an added reason to accelerate investments in additional electricity generation capacity (renewable or low-carbon), or as a less significant user of this resource compared with other transport modes and users.

3.2. Means of production

Producing about 56,000 TWh of additional electricity in 2050 to decarbonize all transportation in the world using SAF and alternative technologies (battery, H_2) is equivalent to the electricity production of nearly 15 million wind turbines, or 10,000 nuclear units of power commensurate with the average installed base in 2019.

For air transport alone, this would mean nearly 3.3 million wind turbines or 2,100 new nuclear units.

Additional power generation required for the decarbonization of transport

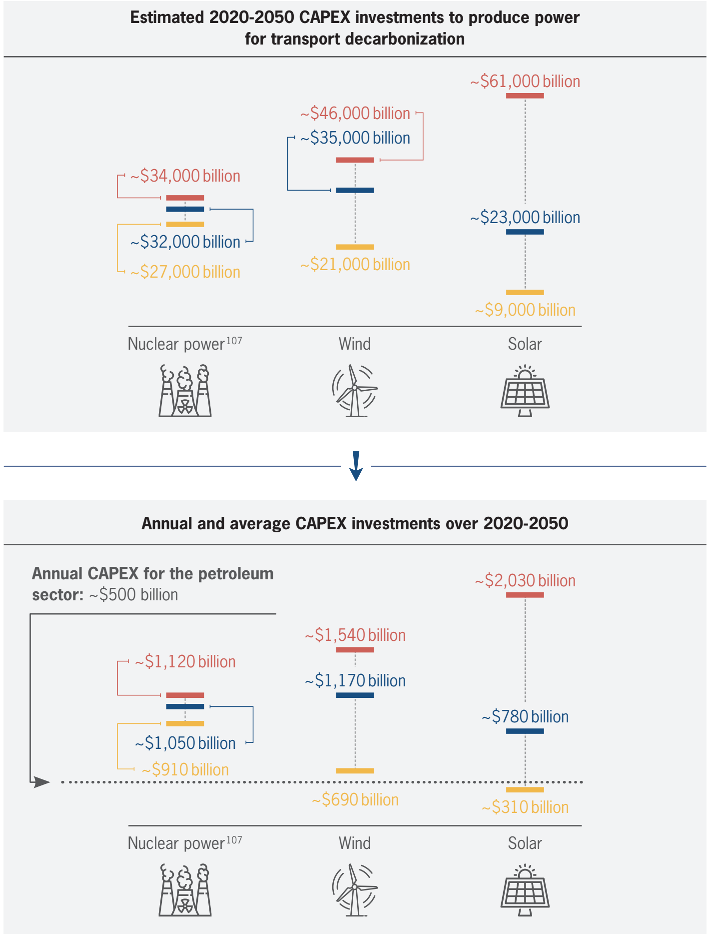


Source: Archery Strategy Consulting analysis.

Depending on the chosen technology and assuming a decrease in production costs, the cost of the electrical system required to produce 56,000 TWh varies immensely.

106 Estimates based on 2019 installed base production.

Comparing investment needs with the level of investment in the petroleum sector



Hypotheses:

Nuclear power[107]	Wind	Solar
• 4,000 $\$/kW_e$	• $1,800 $\$/kW_e$	• $1,300 $\$/kW_e$
• 3 750 $\$/kW_e$	• 1 360 $\$/kW_e$	• 500 $\$/kW_e$
• 3 250 $\$/kW_e$	• 800 $\$/kW_e$	• 200 $\$/kW_e$

Average 2020 — 2050 Conservative Scenario — 2050 Optimistic Scenario

Source: Usine Nouvelle[108], IRENA[109], Sustainable Energy Handbook[110], Archery Strategy Consulting analysis.

Our power generation system should be re-examined in light of this energy challenge and investments should be made accordingly, bearing in mind future needs. The required investments are huge, about $1 trillion per year. However, compared to the historical level of investment in the oil sector (close to $500 billion per year), this amount does seem achievable if very proactive policies are put in place.

Comparison with RTE forecasts

In its study on the future of the electricity system titled "Energy Futures 2050," published in 2021, the French electricity transmission system operator RTE assesses France's energy needs for 2050. This analysis is notably based on the forecasts of the National Low-Carbon Strategy (SNBC), France's roadmap for fighting climate change. .../...

107 Cost of capital not taken into account (higher in the case of nuclear vs. renewable energies).
108 L'Usine Nouvelle, Why the world's nuclear power capacity fell in 2019... 99 but not production (June 2020).
109 IRENA, Wind and solar PV – what we need by 2050 (January 2020).
110 Sustainable Energy Handbook, Module 6.1: *simplified financials models* (February 2016).

We aim to identify the differences between the analysis conducted for this report and the consumption trajectories presented by RTE. Thus, the assessment of energy needs in the RTE reference scenario differs on 4 key points:

1. The assumptions for air traffic growth (0.4% per year at the national level) are significantly lower than those used by the air transport industry, and are based on a different scope (approximately 3% per year on a global scale);

2. RTE, like SNBC (National Low-Carbon Strategy), estimates that air and sea transport will not be totally decarbonized by 2050, with 50% of energy needs still covered by fossil fuels, whose emissions will be compensated by natural carbon sinks (e.g., forests): for air transport, the remaining 50% is based solely on sustainable aviation fuels (biofuels and synfuels), with hydrogen aircraft not being considered (technological lever);

3. RTE, like SNBC, does not take into account international bunkers, the energy needs of air and maritime traffic whose final destination is outside France (metropolitan France and French overseas departments and territories);

4. Finally, the use of hydrogen and synfuels is low; moreover, they are not necessarily produced in France.

…/…

Fuel requirements by transport mode in 2019 and 2050, RTE reference scenario

		France consumption (2019) Mtoe	**Projected growth rate SNBC (National Low-Carbon Strategy)** AAGR 2015-2050	**Residual fuel requirement, biofuel or synfuel** (incl. consumption optimization and substitution) 2050	
Road transport for passengers		26 Mtoe	-0.1% p.a.	0.4 Mtoe	ADEME expects about **8 Mtoe of liquid biofuel** in France by 2050 and about **7 Mtoe of biogas,** mainly used for non-transport purposes (assuming 20% of biogas is used in bio CNG) This means **9.5 Mtoe could be used for transport**
Road transport for goods		16 Mtoe	+ 0.3% p.a.	8.1 Mtoe	
Air transport	**National**	1.7 Mtoe	+ 0.4% p.a.	1.3 Mtoe[111]	
	International	6.1 Mtoe	Not mentioned: ISO France hypothesis	4.8 Mtoe[111]	
Shipping	**National**	0.2 Mtoe	+ 1% p.a.	0.2 Mtoe[111]	
	International	1.7 Mtoe	Not mentioned: ISO France hypothesis	1.6 Mtoe[111]	
		52 Mtoe		**16.5 Mtoe**	

Source: RTE "Energy Futures 2050"; Archery Strategy Consulting analysis.

In the RTE reference scenario, considering consumption trends anticipated by SNBC and taken into account in its analysis, as well as the availability of biofuels (liquid and bioGNV) by 2050 predicted by ADEME, a residual fuel need of about 7 Mtoe in 2050 is clear. This will

…/…

111 Hypothesis of lower consumption not mentioned in the SNBC, value of 30% taken into consideration.

be covered by fossil fuels, leading to a decarbonization level of about 85% compared with 2019 (largely driven by road transport).

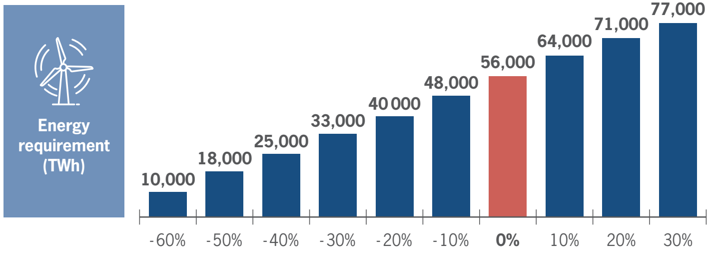
In an alternative scenario titled “Hydrogen +”, RTE expects a more advanced decarbonization of air and maritime transport, with electrical production dedicated to the production of synthetic fuels. This production increases from 9 TWh in the reference scenario to 72 TWh in the “Hydrogen +” scenario, which would allow the production of about 2.5 Mtoe of additional synfuel, and would reach a decarbonization level of about 90% compared with 2019. This scenario also implies an increase in electricity consumption in France (754 TWh instead of 645 TWh in the reference scenario).

3.3. Sensitivity to changes in traffic

Energy requirements are very strongly correlated to the evolution of traffic, so a decrease in traffic of about 30% compared to the levels expected in 2050 would reduce the need for decarbonized energy by around 40% and an increase in traffic of about 30% would require an increase of 35%.

Even if traffic remains very close to current levels, it will be essential to have an electricity production capacity of around 10,000 TWh to ensure the replacement of current fossil fuel use.

Sensitivity of energy needs to changes in traffic for a decarbonization of transport at -90% compared to 2018



Evolution of traffic in 2050 compared to reference value

Road transport for passengers	-0.2%	0.5%	1.1%	1.6%	2.0%	2.4%	2.7%	3.1%	3.3%	3.6%
Road transport for goods	0.2%	0.9%	1.5%	2.0%	2.4%	2.8%	3.1%	3.4%	3.7%	4.0%
Air transport	0.2%	0.9%	1.5%	2.0%	2.4%	2.8%	**3.1%**	3.4%	3.7%	3.9%
Shipping	0.7%	1.4%	2.0%	2.5%	2.9%	3.3%	3.7%	4.0%	4.3%	4.5%

CAGR 2018-2050

Waypoint 2050 Scenario

Source: Archery Strategy Consulting analysis.

CONCLUSION

This study has addressed all the levers that would enable air transport to reach its carbon neutrality objectives by 2050, as well as the various recommendations that we believe should rapidly be implement to step up the sector's decarbonization process. While the trajectory presented seems ambitious and constitutes a major challenge for both the aviation and energy sectors, it is nonetheless achievable under the following conditions:

- Incremental changes and operational improvements should be implemented as soon as possible;
- Disruptive innovations are essential to drastically reduce aircraft consumption;
- The renewal of aircraft fleets must be optimized in order to gain the expected benefits in terms of CO_2 emissions, whether they result from incremental or disruptive innovations;
- Biofuel production must be maximized to limit the need for electricity;
- The production of synthetic fuels – which will likely constitute the majority of fuels substituted for fossil fuels by 2050 – requires an unprecedented level of investment in power generation infrastructure, entailing a two-fold increase in the investments currently made in the petroleum sector.

Historically, while air transport has managed to contain its emissions in a context of increasing traffic, without relying on alternative energies, this situation is no longer compatible with the sector's decarbonization target. It is therefore becoming essential to implement coordinated action between the aviation sector, electricity producers and energy companies that produce alternative fuels (biofuels, hydrogen, synthetic fuels), while maintaining overall consistency between the measures implemented to decarbonize the various modes of transport.

States therefore play a central role in supporting this sector's transition, especially in order to support the implementation of new means of electricity production and sustainable fuels.

Moreover, it is certain that decarbonization will be achieved at different speeds depending on geographical regions (hinging on the situation and ambitions of each State). Institutions will have to remain vigilant to ensure that measures taken locally do not distort competition with the most proactive geographical areas – aviation being a globalized sector by nature.

Not to engage in the dynamics presented in this study would constitute a triple risk of seeing (i) the growth dynamics of air traffic being called into question, (ii) the aviation sector being downgraded (iii) the emergence of a new dependence on countries exporting sustainable aviation fuels.

Therefore, the recommendations made in this report should be pursued as they constitute the best chance to achieve a decarbonized air mobility model.

APPENDIX

OVERVIEW OF VARIOUS RELATED STUDIES

Numerous publications have attempted to outline scenarios for air transport decarbonization by 2050, assessing the implications for the power generation system. Some were taken into account in the writing of this report, others were not, though their insights were no less interesting.

The studies referred to in this report – *Clean Skies for Tomorrow; Waypoint 2050; Destination 2050* – emphasize the key role of SAF in their air transport decarbonization scenarios, in particular the role of synthetic fuels (Power to Liquids) to supplement the supply of biofuels given their limited bioenergy potential by 2050 (nearly 400 Mtoe in 2050).

While all agree that access to sustainable sources of CO_2, green hydrogen, and renewable electricity at competitive costs is the main barrier to achieving the desired goal, there are points of dissent nonetheless:

- The *Clean Skies for Tomorrow* report assumes that biofuels will be used primarily for air transport,[112] which is considered more difficult to decarbonize given the low technological maturity of electric or hydrogen propulsion for airplanes compared to cars for example (the same is true for electricity production or home heating). The report proposes to accelerate the deployment of petroleum alternatives for transportation.

112 Clean Skies for Tomorrow, *Guidelines for a Sustainable Aviation Fuel Blending Mandate in Europe* (July 2021).

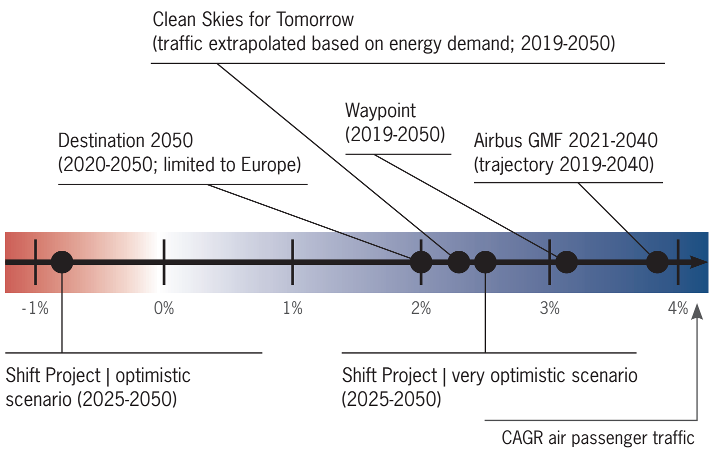
- The *Destination 2050 and Waypoint 2050* reports emphasize that decarbonized electricity generation must be stepped up in the EU.

Whereas the Shift Project suggests establishing a carbon budget to meet the target of containing global warming to 2°C by 2100 (Paris Agreements), taking into account the return of air traffic to its 2019 (pre-crisis) level in 2024, with a subsequent growth of 4%/year until 2050.[113] It concludes its analysis by emphasizing that only a re-examination of air traffic growth would make it possible to meet the initial objective. It notably distinguishes two more or less ambitious decarbonization scenarios to abide by the carbon budget:

- A “very optimistic” scenario: technological roadmap in line with the most optimistic forecasts in the sector (short/medium haul hydrogen and long haul engines running on 100% SAF in 2035…), fleet renewal every 15 years, 100% of SAF production going to aviation, etc.
- An “optimistic” scenario: technological roadmap happening 5 years later compared to the previous scenario, fleet renewal every 25 years, 50% of SAF production allocated to aviation (the rest to other transport sectors).

113 Think tank whose mission is to inform and influence the debate on the energy transition, financed in part by industrial sponsorship. From the briefing paper *Flying in 2050: what aviation in a constrained world?* (March 2021).

Air passenger traffic assumptions by source
(Unit: CAGR[114])



Source: Waypoint 2050, Destination 2050; Clean Skies for Tomorrow, Airbus Global Market Forecast 2021-2040, Shift Project, Archery Strategy Consulting analysis.

It should be mentioned that the hypothesis in this report is based on the Waypoint scenario, with air traffic growth of 3.1% per year between 2019 and 2050.

114 AAGR = average annual growth rate.

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The views expressed in this report are not binding for the individuals named above or for the institutions they represent.

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THERE IS NO DESIRE MORE NATURAL THAN THE DESIRE FOR KNOWLEDGE

Decarbonizing Aviation: All Aboard

In 2021, the airline industry made a formal commitment to take a further step in its decarbonization trajectory by announcing a carbon neutrality target for 2050 at the global level, in line with the Paris Agreement. This goal must be transposed into an actionable roadmap, combining a set of ambitious and proactive measures.

Air transport CO_2 emissions make up 2 to 3% of total world emissions, and 10% of the transport sector's emissions. It is a major component of the mobility system of our modern societies, with 4.5 billion passengers in 2019 and plays a key-role in the way our societies and economies work.

The aeronautics industry is strategic for both France and Europe: a successful transition is essential to reaffirm its status as a world-class player in terms of competitiveness and technology, while enabling French and European citizens to continue to benefit from the major contributions of aviation to our society.

In this report,Institut Montaigne takes up the issue of decarbonization of the aviation industry and offers a detailed account of all the levers required to achieve the carbon neutrality target at the global level in 2050 while measuring the level of investments this will require.

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