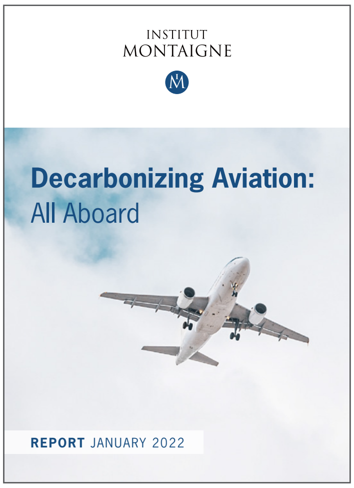



# Executive Summary

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 has been transposed into an actionable roadmap, combining a set of ambitious and proactive measures.

The aeronautics industry is strategic for both France and Europe: a successful transition is essential to avoid decline and 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.

As part of this framework, this report details all the levers that will make it possible to achieve the carbon neutrality target for global air transport by 2050, and measures the level of ambition that this target represents, in particular through an estimate of the investments this will require. Numerous discussions with a wide range of stakeholders (economic players, academics, public authorities, etc.) have contributed to the insights in this study. The report follows an industrial approach to the issue, examining the necessary conditions to decarbonize air transport, assuming that the growth dynamic expected by the industry is maintained.

## An essential sovereignty asset, the air transport sector is under pressure due to the health crisis

**Air transport has an essential strategic dimension, both in terms of travel and economics.** It is a major component of the mobility system of our modern societies, whether for personal reasons (visiting relatives or leisure) or professional reasons, making it possible to reach any part of the world in less than a day. Moreover, it is a crucial vector for opening up isolated areas. Finally, air transport facilitates long-distance exchanges, whether for passengers – 4.5 billion passengers in 2019, the tourism sector now constitutes nearly 10% of global GDP – or for goods – air freight accounts for 1% of volumes but 35% of the value of transported goods.

**The aeronautics sector is also one of the most important industrial sectors in Europe and in France:** it equates to nearly 350,000 direct industrial jobs in France, and constitutes the country's main export sector (13% in 2019). In addition, service operators (airlines, ground handling, airports) account for nearly 100,000 direct jobs in France. In Europe, air transport represented 13.5 million jobs (direct, indirect, tourism-related) in 2018, contributing $991 billion to GDP. The decarbonization trajectory of air transport must therefore also be examined in light of the industry's leading position in France and in Europe.

**The health crisis has particularly affected the air transport sector.** Airports and airlines were the first to suffer, with nearly two-thirds of the world's fleet grounded in April 2020. Manufacturers have not been spared and have had to reduce production rates, which has had repercussions on the entire sector's subcontracting chain. Strong government support has nonetheless made it possible to preserve these economic players, limit bankruptcies and maintain skills. While domestic traffic is gradually recovering, international transport remains the most affected at the time of publication.

**In this context of uncertainty, there is an emerging consensus in the industry that air traffic will return to its pre-crisis level probably around 2024.** Because of the pandemic and its impact on traffic long-term, the industry has revised its passenger traffic forecasts to +3.1% per year for the period 2019-2050.[1] Despite these uncertainties, the air transport industry has maintained its objective of making additional commitments to reduce its environmental footprint.

## Sector players have drawn up an ambitious decarbonization trajectory

**Air transport $CO_2$ emissions make up 2 to 3% of total world emissions,** and 10% of the transport sector's emissions. Air travel is a very efficient means of transport, currently achieving a fuel consumption of 3L/100km/passenger: air travel consumes less fuel per passenger-kilometer than a car, considering the average fuel consumption of both modes of transport. Moreover, air transport $CO_2$ emissions per passenger-kilometer have been halved since 1990 due to the combined effects of technological advances in aircraft and improvements in operations and infrastructure. Thus, despite a historically high growth in air traffic (+5.3% per year since 1990), the sector has managed to contain its carbon footprint (+2.5% per year).

**The airline industry is firmly committed to achieving carbon neutrality by 2050,** with the aim of designing a future for air transport that meets the objectives of the Paris Agreement and the societal expectations of consumers, public authorities, investors, etc.

1 Air Transport Action Group (ATAG), Waypoint 2050, 2nd edition (September 2021).

First and foremost, in practical terms this will require a reduction in, as well as offsetting of, the $CO_2$ emissions of air transport worldwide. While these are the main focus of this report, it should be noted that air transport is responsible for other emissions that can have a negative impact on the climate, in particular nitrogen oxides and contrails. Improving aircraft efficiency and optimizing flight profiles have been identified as ways of reducing these emissions.

## Decarbonization levers exist and must all be activated to enable the aviation industry to make its transition

**The baseline scenario used in this report is the most ambitious in terms of technological progress among the possible scenarios identified by the industry.[2] Four main levers are needed to achieve the carbon neutrality target of the aviation sector:**

**I.** Technological developments (~34% of the decarbonization effort by 2050);
**II.** Optimization of flight and ground operations (~7%);
**III.** Alternative fuels (~53%);
**IV.** Compensation measures (~6%).

### I. Create the proper conditions to stimulate technological innovation and encourage equipment renewal, to thus maximize the reduction of $CO_2$ emissions (~34% of the decarbonization effort by 2050)

**Incremental innovations** are based on concepts that can be rapidly adopted in future aircraft, and that will reduce aircraft's environmental footprint (improved aerodynamics, optimized engine efficiency, increased use of digitalization). This should account for one-third of expected benefits.

While **disruptive innovations** contribute more significantly to this objective – two-thirds of expected benefits – their low level of maturity requires continued investment in R&D. Several designs are being studied, the most emblematic of which are electric (hybrid) propulsion and hydrogen propulsion. However, because of the low energy density of batteries or fuel cells, electric designs will only service small aircraft (flying cabs, shuttles). Furthermore, the technological modifications for current aircraft designs are such that the first hydrogen-powered commercial aircraft will likely not be operational before 2035, with a maximum range of 2,000 km.

These innovations will thus mainly affect short- and medium-haul aircraft, and will have a more limited impact on long-haul aircraft – which make up nearly a third of air transport $CO_2$ emissions. A very large share of commercial aircraft (>80%) will continue to be powered by conventional engines in 2050, using conventional (kerosene) or alternative (biofuels, synthetic fuels) fuels.

**Aircraft renewal** makes it possible to take advantage of the beneficial effects of technological developments in favor of reducing fuel consumption and by extension $CO_2$ emissions. For example, the immediate theoretical replacement of 87% of older generation aircraft (in 2019) would result in reducing emissions by more than 10%. Regular fleet renewal, in addition to new technologies becoming available (every 15 to 20 years), can make a significant contribution to curbing emissions by 2050. However, this replacement must be compatible with the business models of airlines and of certain manufacturers (who are highly dependent on aircraft maintenance revenues to maintain their ability to invest in innovation).

**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.

### II. Activate the levers to optimize flight and ground operations (~7% of the decarbonization effort by 2050)

Several practices are being studied or deployed, driven by regulators, airports and airlines. They aim to **optimize traffic and airspace** (i.e., implementation of a "Single European Sky"), **flights and trajectories** (i.e., "perfect flight"), **ground operations** (i.e., reduced use of engines during taxiing, or reduced use of the APU when the aircraft is parked) and, finally, **operating practices** (i.e., limiting "tanking" practices, reducing the weight of cabin equipment). This lever can be more rapidly implemented than technological developments for aircraft, which are limited by the rate at which new aircraft enter airline fleets.

Furthermore, the development of **train-airplane intermodality** could be amplified, when warranted or relevant (e.g., France; Germany), by taking the train at the beginning and end of the journey.

2 ATAG, Waypoint 2050, 2nd edition (September 2021), scenario 3.

**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.

## III. Promote the use of biofuels to their maximum potential and develop synthetic fuels: a necessary lever to achieve carbon neutrality (~53% of the decarbonization effort by 2050)

The main lever for decarbonizing the aviation sector – even if the preferred scenario is the most ambitious in terms of technological progress – is to replace fossil fuels (kerosene) with sustainable aviation fuels (SAF).[3] Practically speaking, the latter are either **biofuels** produced from biomass feedstocks that are carbon "sinks" (agricultural crops, residues from human activity, algae, etc.), or **synthetic fuels** obtained by an industrial process combining $CO_2$ captured from the air with hydrogen. Either way, the combustion of SAF will release $CO_2$ which was formerly present in the atmosphere but offers a much better environmental balance than kerosene, which is derived from oil trapped in geological layers. On the other hand, the synthetic option is particularly energy-intensive and must be used only when relevant. While SAF should be used to supplement the aforementioned alternative technologies (electric aircraft, hydrogen aircraft) for regional (<500km), short (<1,500km) and medium-haul (<4,000km) flights, it accounts for the larger share of decarbonization for long-haul flights (>4,000km).

The development of SAF will require both foresight regarding future airline fuel demands, as provided for in European regulations (ReFuel EU Aviation) through the SAF blending mandate, as well as production support, in order to develop a competitive European industry. The introduction of mandatory SAF blending, initially limited to Europe, must not distort competition, at the risk of reducing the attractiveness of European hubs and weakening European airlines, or encouraging carbon leakage outside European borders.

3 Sustainable Aviation Fuel.

**RECOMMENDATION 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, depending on the activation rate and the efficiency of the various decarbonization levers.

**RECOMMENDATION 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, 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.

**RECOMMENDATION 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.

Although the potential of biomass necessary for biofuel production is very high (higher than the energy needs for all transport by 2050), actual availability, given the industrial, logistical and financial constraints, will be much lower than the actual needs of the different modes of transport wishing to decarbonize (road passengers, road freight, air, shipping). After accounting for substitution technologies (electric battery for road transport, ammonia for shipping, etc.), biofuels will make up about 20% of the residual fuel needs.

To overcome this limitation in feedstock availability and to produce sufficient quantities of SAF, the use of synthetic fuels is thus unavoidable. In addition, developing this pathway represents a short-term opportunity to stimulate the hydrogen industry (by creating outlets and encouraging investment, particularly in infrastructure) and to increase the maturity of $CO_2$ capture technology. These two aspects are significant not only for the decarbonization of the transport sector but of society more broadly.

**RECOMMENDATION 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.

**IV. Extend and expand compensation systems (~6% of the decarbonization effort by 2050)**

Two main carbon allowance systems co-exist in the world: **EU-ETS**[4] on a European scale and **CORSIA**[5] on a global scale. While they differ in their geographical coverage, approach, applicability and level of ambition, the objective of limiting the aviation sector's $CO_2$ emissions is comparable. It is essential, first, that the coexistence of these schemes not distort competition, second, that the schemes ultimately converge towards a carbon neutral objective, and third, that they cover all commercial flights.

**RECOMMENDATION 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.

**RECOMMENDATION 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.

## Decarbonizing air transport is part of a wider energy transition requiring a massive production of decarbonized electricity to replace fossil fuels

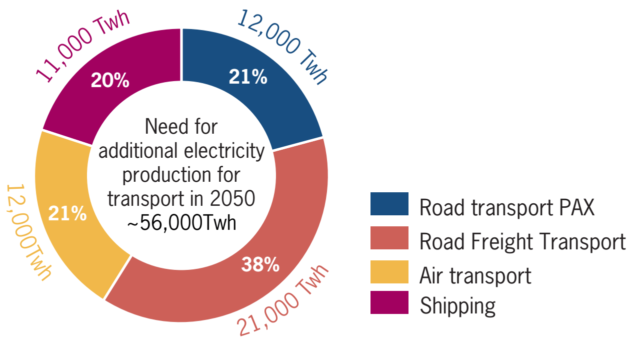
The production of synthetic fuels has many advantages: (almost) unlimited inputs (water, air) and a $CO_2$ impact close to zero when using decarbonized energy. However, this process requires a significant amount of electrical energy to produce the hydrogen and capture $CO_2$. The **decarbonated power needed** to produce synfuels are added to those needed to produce other alternative energy carriers (hydrogen, ammonia, powering electric batteries). In total, if the growth assumptions for the different modes of transport are confirmed, nearly 56,000 TWh would be needed by 2050 to produce fuel alternatives to fossil fuels for all means of transportation (for measure, the current world electricity production is 27,000 TWh). This would reduce $CO_2$ emissions by 90% compared to 2018.

Thus, our power generation system must now be re-examined in light of this energy challenge and investments must be made accordingly, with sufficient consideration of future needs. The

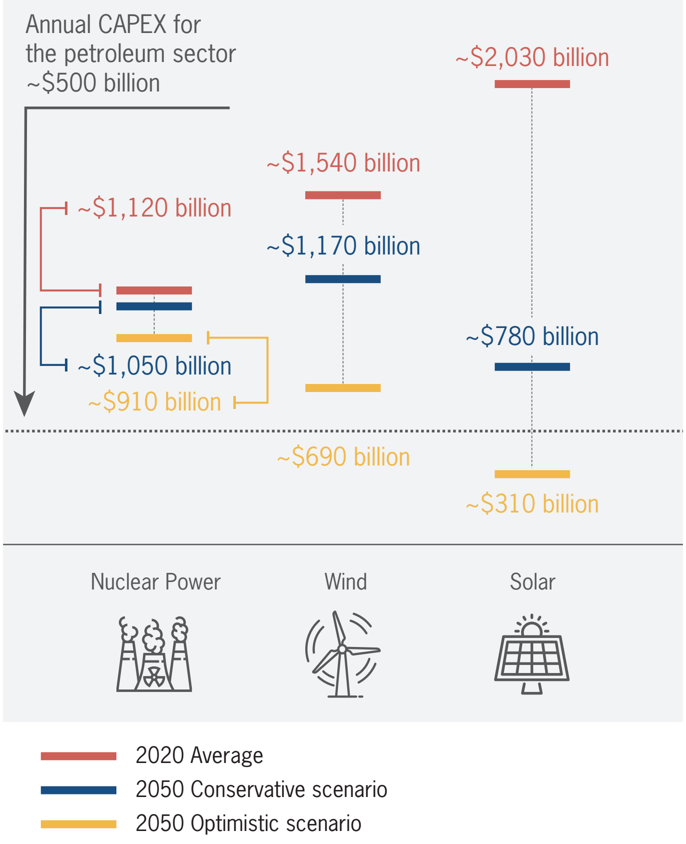
4 European Union Emission Trading Scheme.
5 Carbon Offsetting and Reduction Scheme for International Aviation.

investments required are substantial, approximately $1 trillion per year. Compared to the historical level of investment in the oil sector (nearly $500 billion per year), this amount seems attainable if very proactive policies are implemented.

**Investments required for additional power generation for transportation decarbonization by 2050, relative to the oil sector**




**Annual and average CAPEX investments over 2020-2050**




*Source: Archery Strategy Consulting analysis*

**RECOMMENDATION 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.

## High ambitions requires the rapid and strong mobilization of industrial players and governments

The implementation of all levers presented in this report should enable us to achieve the carbon neutrality target for air transport by 2050. The presented pathway is ambitious and represents a major challenge for the transport sector, notably the aviation sector, as well as the energy sector (producers of electricity and alternative fuels). It is crucial to carry out coordinated action between these sectors. States have a central role to play in order to enable and support the rapid implementation of the necessary investments, especially for the production of decarbonized electricity.

Not to engage in the dynamics presented in this study would present a triple risk for the air transport industry 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.