FLYING WITHOUT FOSSIL FUELS:

ENERGY SUPPLY OPTIONS FOR THE AVIATION SECTOR

Summary — February 2026

CONTEXT

A sector highly exposed to the dual carbon constraint

Fueled by fossil resources long considered inexhaustible, civil aviation has, in just half a century, become one of the most powerful drivers of international trade and global connectivity. Today, it offers a remarkable promise: linking almost any major hub in the world within a matter of hours while creating unprecedented geographical and economic continuity.

Yet airline operations remain almost entirely dependent on fossil fuels, placing the sector under a dual carbon constraint:

- The worsening climate crisis requires rapid reductions in CO_2 emissions.
- Fuel supply is threatened by the expected decline in conventional oil production and by geopolitical tensions.

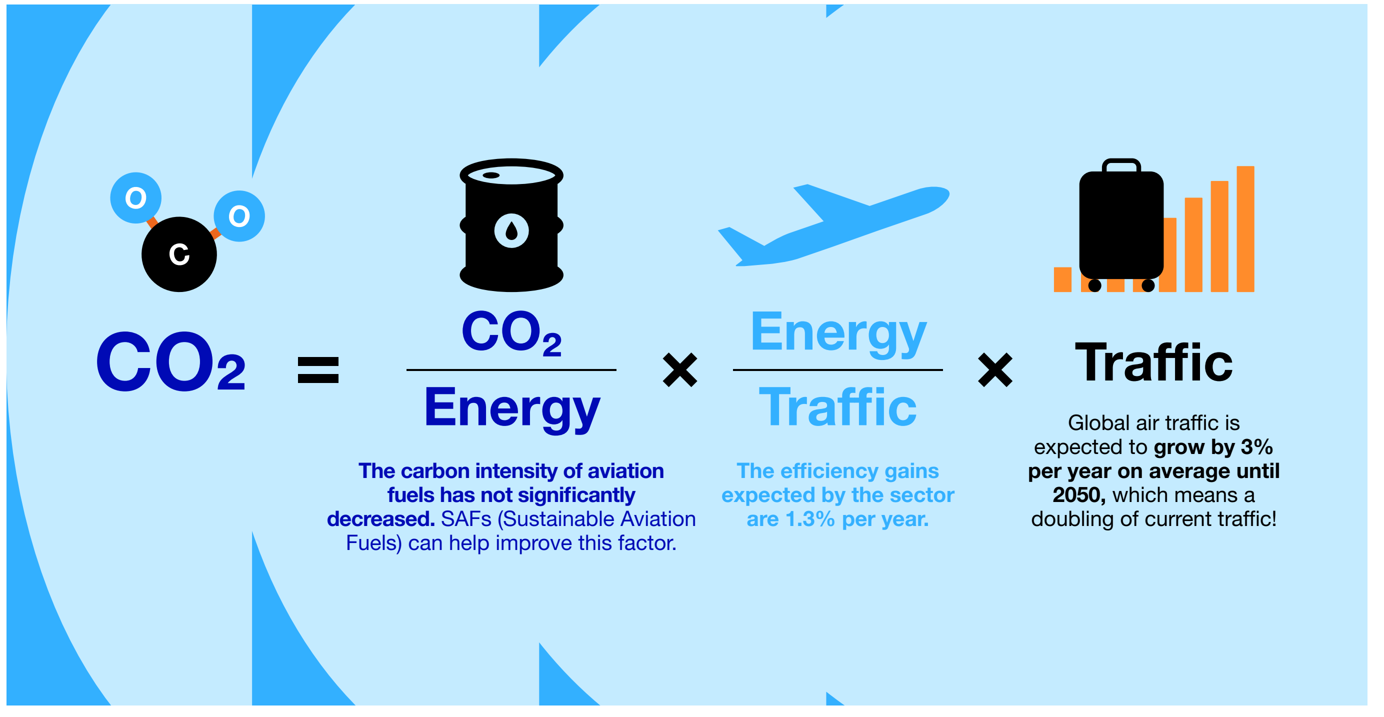
Commercial aviation is responsible for 2–3% of global CO_2 emissions, rising to nearly 5% in the European Union and 6.8% in France.

Its climate impact extends beyond CO_2 alone: when persistent contrails and high-altitude nitrogen oxides are included, commercial aviation contributes to nearly 5% of total anthropogenic radiative forcing.

Breaking down the sector's carbon footprint highlights three structural drivers of emissions: traffic volume, energy efficiency, and the carbon intensity of the energy used.

Since our previous report, **Flying in 2050,** the industry has explored technological breakthroughs based on alternative energy sources such as hydrogen and electricity. However, their large-scale deployment has been postponed well beyond 2035.

This report therefore focuses on **the feasibility of transitioning the sector to non-fossil liquid fuels, collectively referred to as Sustainable Aviation Fuels (SAFs).**



$$CO_2 = \frac{CO_2}{Energy} \times \frac{Energy}{Traffic} \times Traffic$$

The carbon intensity of aviation fuels has not significantly decreased. SAFs (Sustainable Aviation Fuels) can help improve this factor.

The efficiency gains expected by the sector are 1.3% per year.

Global air traffic is expected to **grow by 3% per year on average until 2050,** which means a doubling of current traffic!

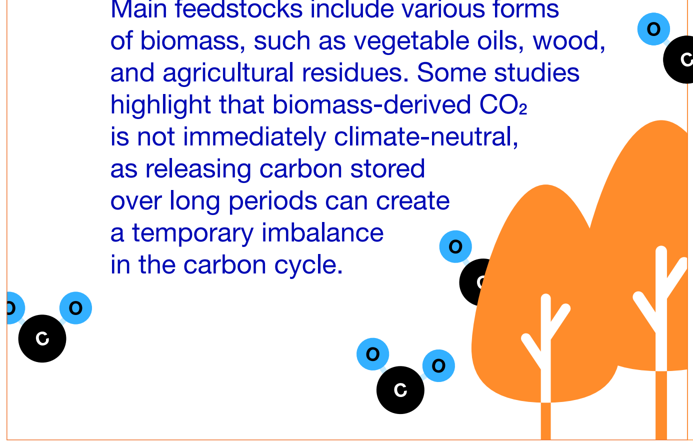
SAFs: non-fossil aviation fuels

Principles of the SAF Life Cycle

Sustainable Aviation Fuels (SAFs) are chemically similar to conventional fossil jet fuel. Their main advantage lies in the fact that the CO_2 released during their combustion was previously captured from the atmosphere. Under current accounting rules, SAFs are therefore considered climate-neutral from an accounting perspective. There are two main types of SAFs, distinguished by their carbon source:

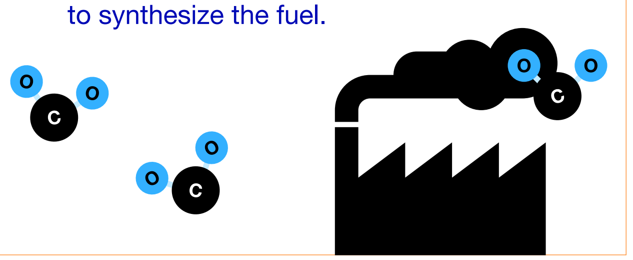
bioSAF

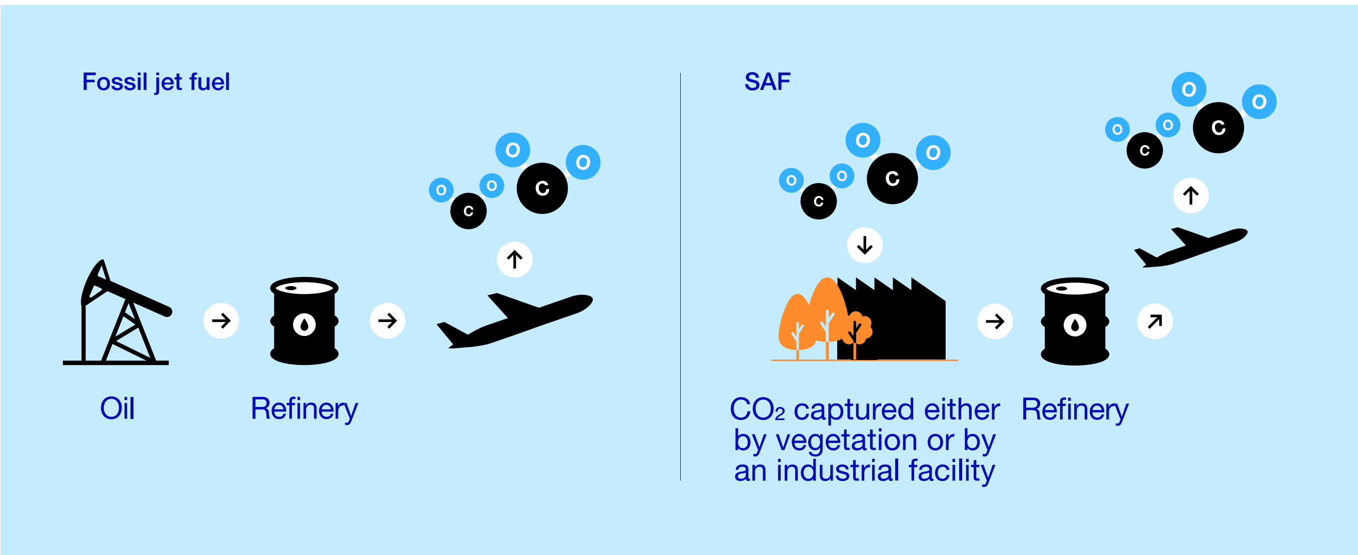
The carbon originates from CO_2 absorbed by plants through photosynthesis. Main feedstocks include various forms of biomass, such as vegetable oils, wood, and agricultural residues. Some studies highlight that biomass-derived CO_2 is not immediately climate-neutral, as releasing carbon stored over long periods can create a temporary imbalance in the carbon cycle.



e-SAF

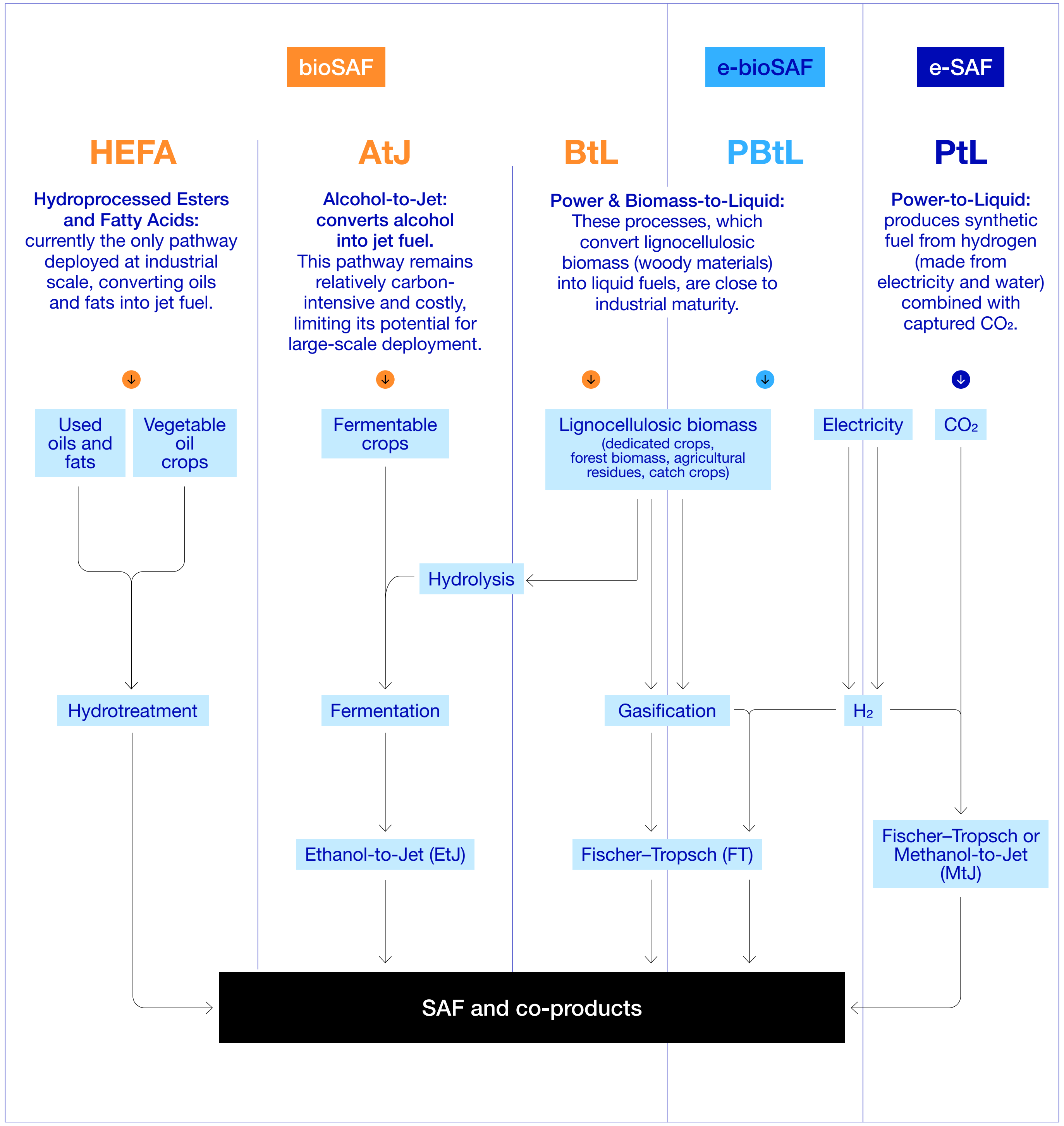
The carbon is captured through industrial processes, either from concentrated emission sources (fossil or biogenic) or directly from ambient air. Electricity plays a central role, as it is required both for CO_2 capture and for producing the low-carbon hydrogen needed to synthesize the fuel.





Diverse SAF production pathways

SAF can be produced through multiple technological pathways using various ressources, each relying on different feedstocks and processes.



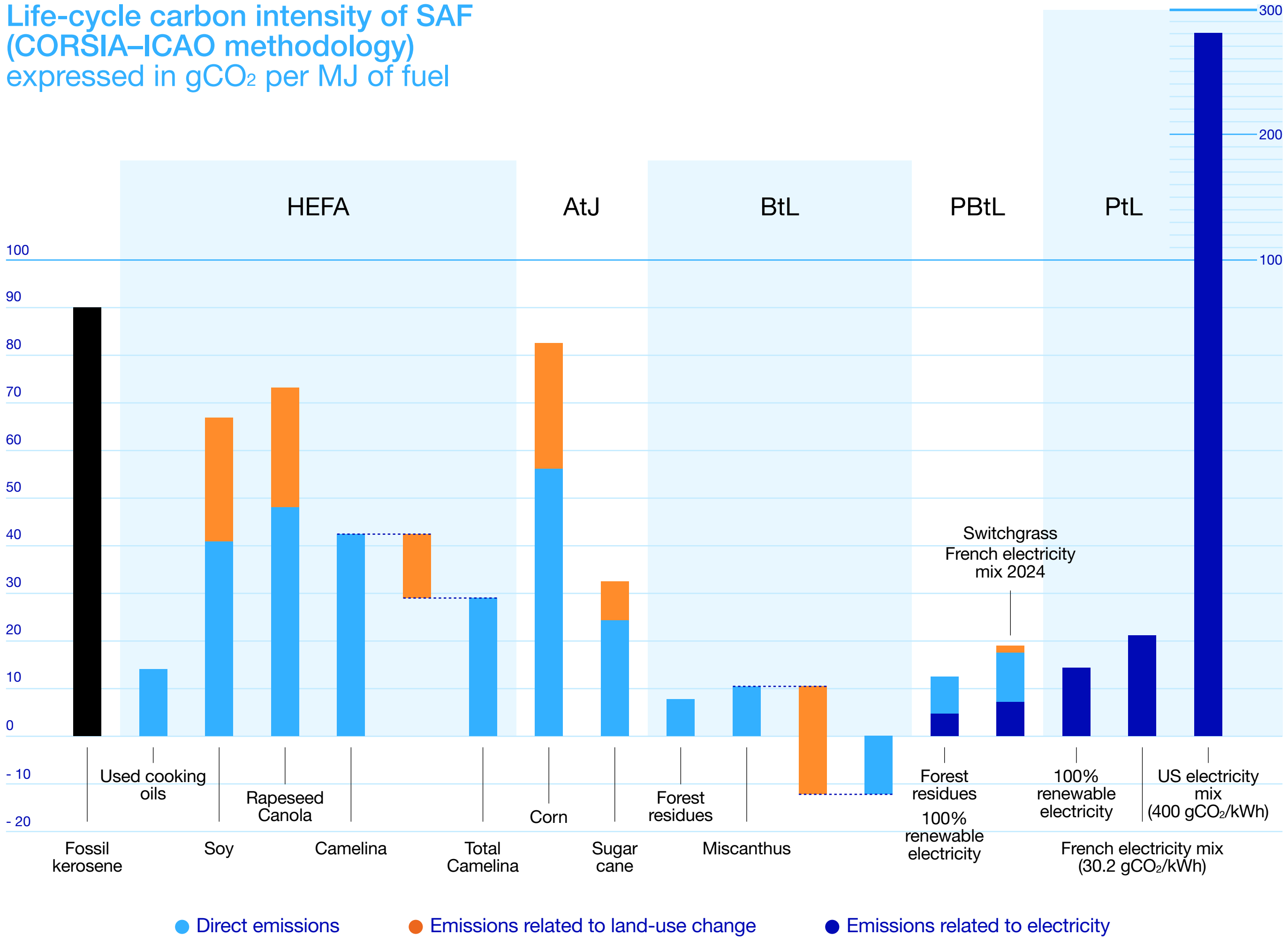
Not all pathways are equal

SAFs are not fully climate-neutral, as emissions arise from feedstock production, transport, and processing. Unlike fossil fuels, whose carbon footprint per unit of energy is well established, SAF emissions vary significantly depending on the production pathway, feedstock, and processing conditions:

- bioSAF: evaluation must include both direct production emissions and indirect emissions from land-use change, which are highly context-specific and vary from one field to another.
- e-SAF: emissions depend on the carbon intensity of the electricity used. EU regulations mandate at least a 70% reduction compared to fossil fuels, requiring electricity below 40 gCO_2/kWh currently achieved only by the electricity mix of three Member States out of 27: Finland, France, and Sweden.

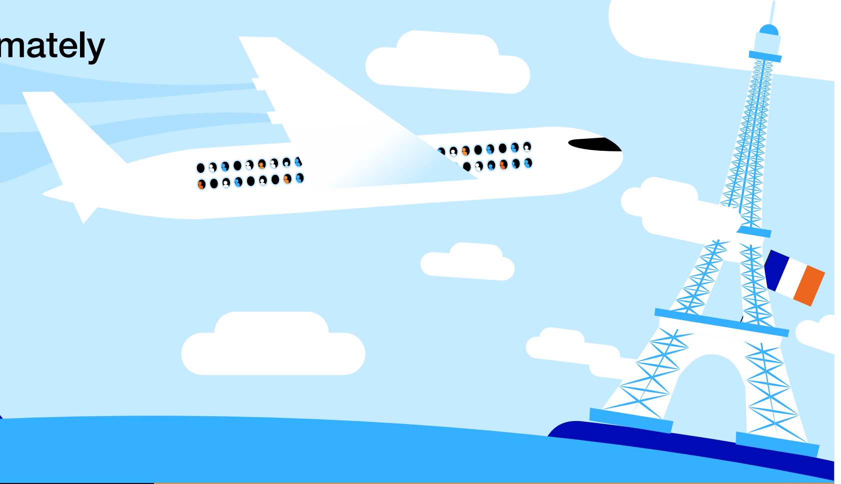
Life-cycle carbon intensity of SAF (CORSIA–ICAO methodology)

expressed in gCO_2 per MJ of fuel



SAF is a generic term in the aviation sector encompassing fuels with significantly different environmental performance levels. This acronym does not, in itself, guarantee strong sustainability.

Flying without fossil fuels: what it takes per passenger



For a round trip between Paris and Montreal (12,000 km) without fossil fuel, approximately

360 liters of fossil kerosene

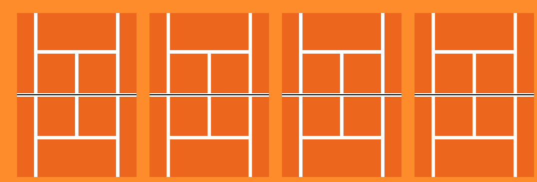
per passenger would need to be replaced by one of the following alternatives:

370 liters

of used cooking oil: about two months' collection from a fast-food restaurant

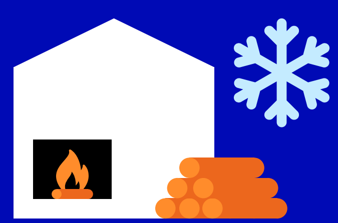
1,000 m²

of lignocellulosic crops: equivalent to 4 tennis courts of annual harvest



1,800 kg

of firewood or wood waste: enough wood to heat a well-insulated home for a winter



8,000 kWh

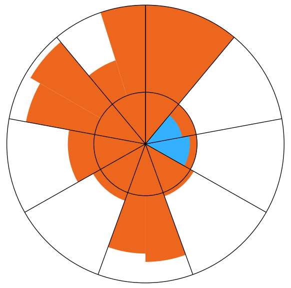
of electricity: twice the annual electricity use of a typical French household

These orders of magnitude are provided for illustrative purposes and calculated by Aero Decarbo.

bioSAF: strong limits on biofuel potential

Pressures on planetary boundaries

While fossil fuels primarily affect the climate, **the use of plant-based fuels also generates significant environmental impacts.** Agriculture and forestry, closely linked to biomass production, are major drivers of four critical planetary boundaries: biodiversity loss, land-use change, freshwater cycle disruption, and biogeochemical flows of nitrogen and phosphorus. Additionally, forest pressure and degradation can transform this natural carbon sink into a net source of emissions, thereby exacerbating climate change.



Rising competition for biomass across sectors

The use of biomass creates competition on three distinct and successive levels:

Land

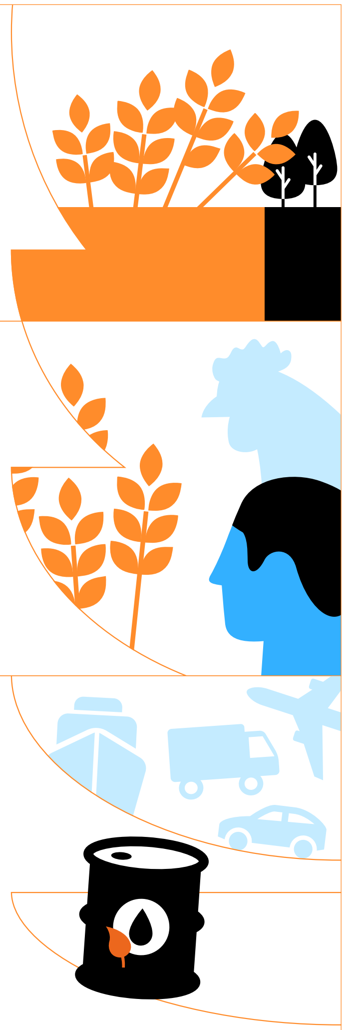
Expanding agricultural land comes at the expense of natural areas, driving biodiversity loss, land-use change, and reduced carbon sequestration.

Materials

Plant-based outputs should first support human and animal nutrition, then maintain soil fertility. Sectors that store carbon long term in solid form (construction, chemicals, and textiles) are expected to see rising demand as they align with decarbonization goals.

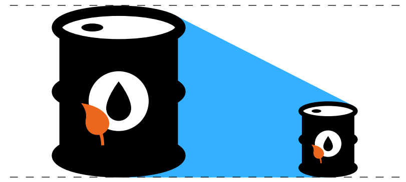
Bioenergy

Using biomass for energy (biomethane, biofuels, electricity) is the lowest priority because it releases carbon when burned. Moreover, multiple sectors (aviation, shipping, agriculture, and road transport) compete for the same limited biofuel volumes.

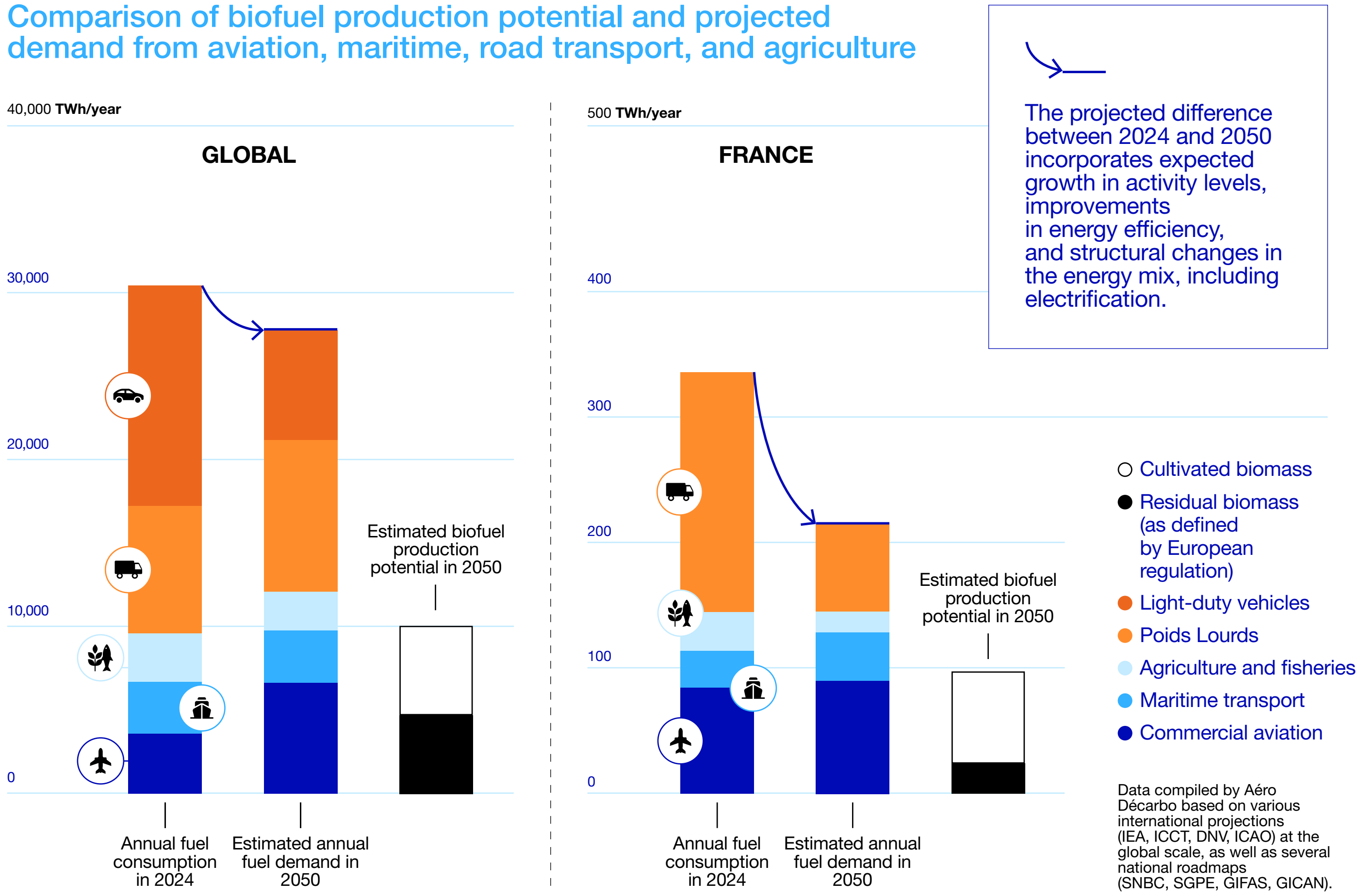


Supply-demand gap

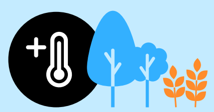
By 2050, liquid biofuel production is projected to be one-third to one-half of the needs of hard-to-electrify sectors (aviation, maritime, road transport, agriculture), even after accounting for growth, efficiency improvements, and energy substitution.



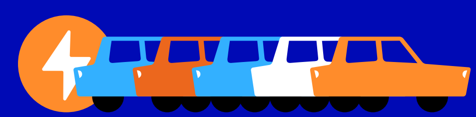
Comparison of biofuel production potential and projected demand from aviation, maritime, road transport, and agriculture



These projections exclude the potential impacts of climate change on biomass productivity and assume that biofuel production is prioritized in the allocation of available residual biomass resources for energy use.



Light-duty vehicles are excluded at the national level, as the French vehicle fleet aims to be fully electric by 2050 and would therefore no longer require liquid fuels.



AÉRO DÉCARBO THE SHIFT PROJECT

e-SAF: the electricity challenge

Non-fossil CO_2 and electricity

Today, most e-SAF projects capture CO_2 from the flue gases of large industrial facilities, where concentrations are roughly 100 times higher than in ambient air. For SAF production, **European regulations prefer, and will soon require, that this CO_2 be non-fossil.**

As industrial emissions decline with decarbonization, direct air capture will become necessary, **increasing electricity demand by about 20%.** Projected efficiency improvements are expected to offset this increase, maintaining electricity consumption at **approximately 30 MWh** per ton of fuel through 2050.

Significant electricity needs: an inefficient but essential use for aviation

e-SAF is one of the least efficient uses of low-carbon electricity, which makes it currently more expensive than other pathways. However, its development will be necessary for aviation decarbonization.

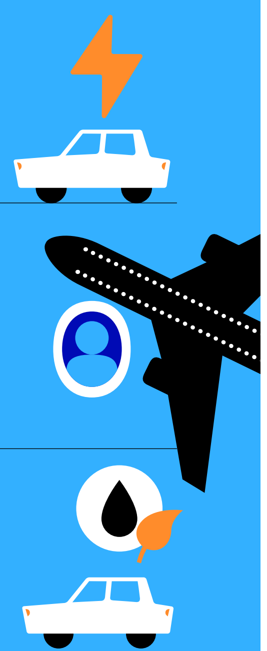
Unlike bioSAF, its deployment is less constrained by biological resource availability and therefore does not affect planetary boundaries as critically. Increasing production mainly requires expanding low-carbon electricity capacity, the main constraint being the industrial pace of deployment.

Distance per
1 MWh of electricity:

Electric car:
5,000 km

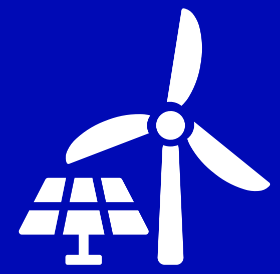
e-SAF aircraft
(per passenger):
1,250 km

Car running on e-fuels:
750 km



10,000 TWh

That is the amount of **low-carbon electricity** needed to replace current global fossil jet fuel consumption with e-SAF. This represents **the total renewable energy production or one third of the global energy production at present**[1].



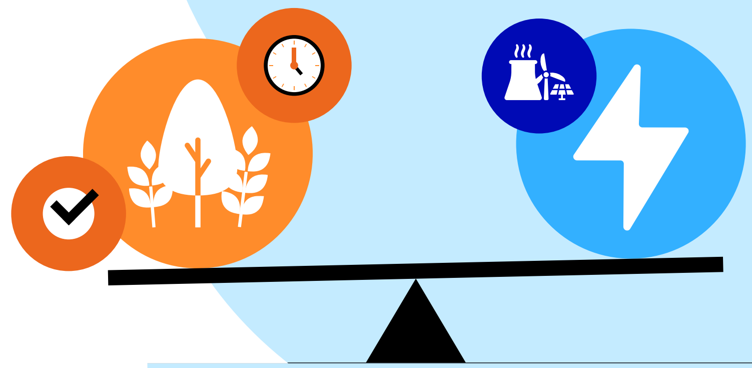
An Efficient Pathway: e-bioSAF

The e-bioSAF process enables the conversion of most of the carbon in biomass into SAF by co-processing biomass with hydrogen. As a result, the energy content of the produced fuel comes from both biomass and hydrogen feedstocks.

e-bioSAF requires
2-3 times
less biomass
than bioSAF.

e-bioSAF requires
2-3 times
less electricity
than eSAF.

For this pathway to be truly sustainable, it must meet criteria ensuring both **the sustainability of biomass sources** and the **use of low-carbon electricity.**



1. 2024 figures (315 Mt of kerosene for 9,800 TWh of renewable electricity)

AÉRO DÉCARBO
THE SHIFT PROJECT

Global Scenarios

To assess whether the deployment of **SAF production capacity** will be sufficient to enable aviation to meet its climate objectives, our first scenario adopts the assumptions of aviation and energy sector stakeholders:

Scenario assumptions

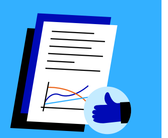
1. Future fuel consumption is based on traffic forecasts and projected aircraft performance improvements from the Air Transport Action Group (ATAG) S2 scenario, which is globally optimistic, for example assuming the arrival of new-generation open-rotor engines by 2030, whereas industrial schedules expect them after 2035.

2. SAF supply (bioSAF + e-SAF) corresponds to the volumes projected by the International Energy Agency (IEA) in its most ambitious decarbonization scenario (Net Zero by 2050).

3. Electricity: The IEA NZE scenario assumes a particularly ambitious 80,000 TWh of low-carbon electricity available globally by 2050—nearly three times the current total electricity production capacity (fossil and low-carbon combined).

4. Emission factors are drawn from the CORSIA regulatory framework, an international mechanism established by the International Civil Aviation Organization (ICAO).

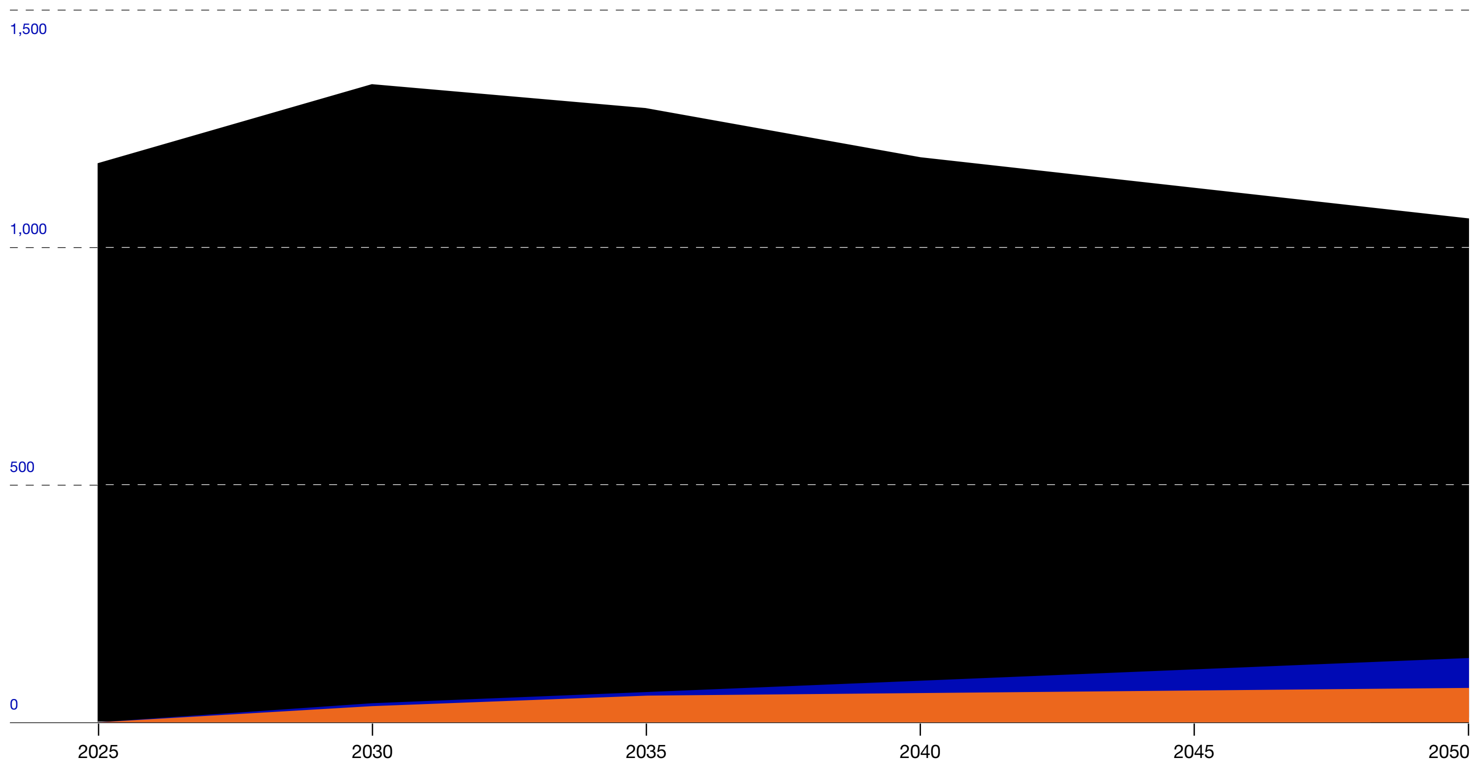
These deliberately optimistic assumptions ensure that the **conclusions drawn are robust:** any result obtained under such a favorable framework will a fortiori remain valid in a more constrained context.



Aviation emissions are not decreasing

Baseline scenario - sector announcements and resource availability according to the iea

Aviation emissions (Mt CO_2/year)



In the reference scenario, based on assumptions from aviation and energy sector stakeholders, **the average annual emissions over the period 2025–2050 are 3% higher than the 2025 level.**

22% (116 Mt) of bioSAF in 2050

26% (131 Mt) of e-SAF in 2050

8% Share of cumulative aviation emissions by 2050 in the carbon budget of a +1.7°C pathway[2]

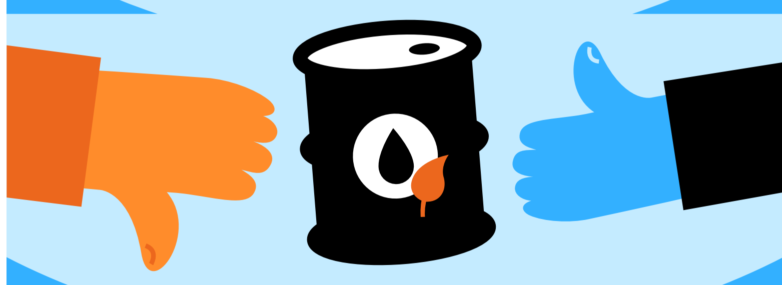
64% Share of aviation in residual emissions in 2050[3]

2. Global budget for 1.7°C: 390 Gt
Cumulative aviation emissions 2025–2050: 32.4 Gt
3. Total sequestration in 2050 (IEA 2023 – NZE Scenario): 1,710 Mt /Aviation emissions in 2050: 1,094 Mt

Weighing trade-offs to grow alternative fuel volumes

The aviation sector is exploring various ways to boost SAF production, though some approaches could actually harm the environment:

- **Relaxing SAF sustainability criteria** can put pressure on soil, water, and biodiversity, without significantly lowering the aviation sector's CO_2 emissions.
- **Giving aviation priority over other sectors** for access to low-carbon resources may increase overall emissions, due to differences in energy efficiency between aviation decarbonization solutions and alternatives such as road electrification.
- **Major investments in additional electricity capacity** could eventually produce enough e-SAF and e-bioSAF to meet the sector's fuel needs, as long as substantial resources are mobilized.



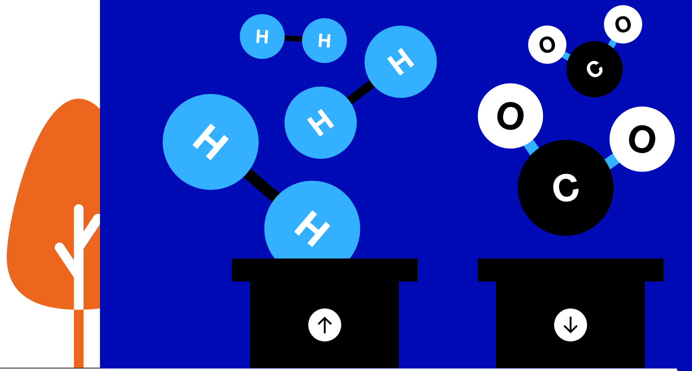
Flight plans in France

Managing competition for biomass and low-carbon electricity

The potential for SAF production in France depends on the quantities of sustainable biomass and low-carbon electricity that could be allocated to the aviation sector:

In terms of lignocellulosic biomass, compatible with European regulations: **10 million tonnes of dry** matter that can be valorized into liquid biofuels, to be shared among different uses (aviation, maritime transport, agricultural machinery, and road transport), with up to 60% allocated to aviation. SAF co-products account for at least 40% of the bioenergy in a production processes.

In terms of electricity: **Between 0 and 110 TWh** (aviation sector roadmap, GIFAS, 2023) to produce the required hydrogen by electrolysis and to capture the corresponding CO_2.

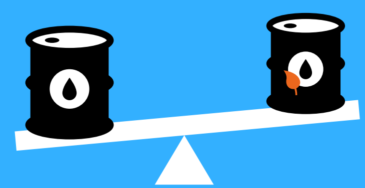


Electricity volumes dedicated to aviation

Share of residual biomass for aviation	10 TWh	30 TWh	50 TWh	70 TWh	90 TWh	110 TWh
0%	0.3 Mt	1.0 Mt	1.7 Mt	2.3 Mt	3.0 Mt	3.7 Mt
15%	0.8 Mt	1.5 Mt	2.1 Mt	2.8 Mt	3.5 Mt	4.1 Mt
30%	1.3 Mt	2.0 Mt	2.6 Mt	3.3 Mt	4.0 Mt	4.6 Mt
45%	1.8 Mt	2.4 Mt	3.1 Mt	3.8 Mt	4.4 Mt	5.1 Mt
60%	2.2 Mt	2.9 Mt	3.6 Mt	4.2 Mt	4.9 Mt	5.6 Mt

Note: each cell shows the total annual SAF production **in 2050** resulting from the combination of the two assumptions

The quantities of SAF produced in France would therefore range **between 0 and 5.6 million tonnes in 2050,** to be compared with the **7.3 million tonnes of fossil kerosene** consumed today.



Aviation's contribution to national emissions is likely to take off

If air traffic grows according to the sector's decarbonization roadmap (+1.1% per year[4]), **aviation emissions would represent between 17% and 46% of French emissions in 2050, depending on whether 5.6 Mt or 0 Mt of SAF is produced.**

For example, assuming **30 TWh of electricity and 30% of residual biomass available** for biofuel were allocated to aviation, this would result in:

37 %
Share of aviation in national residual emissions in 2050

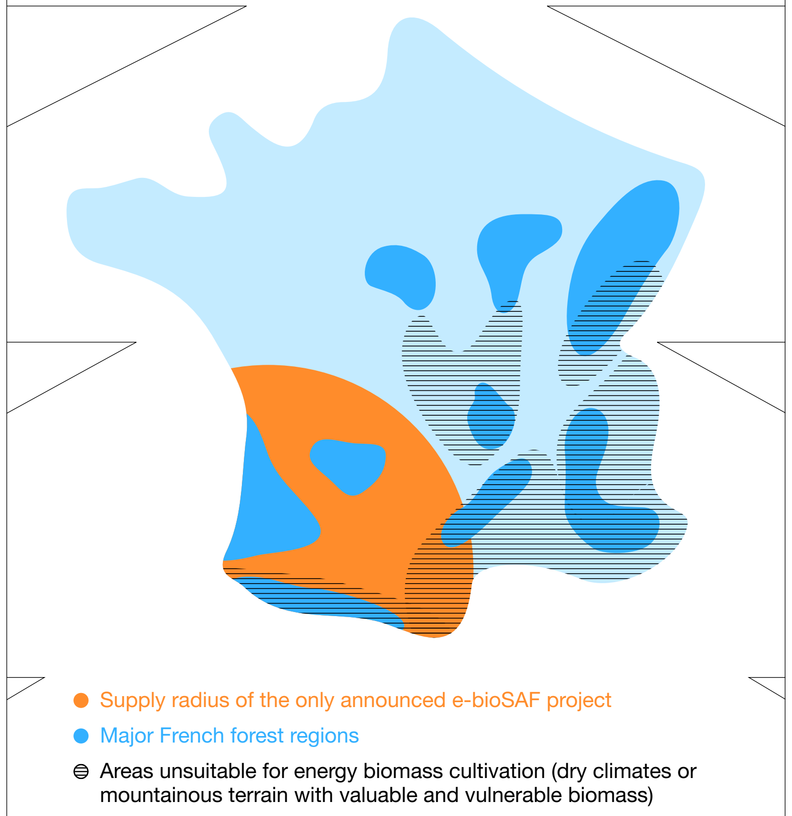
14 %
Share of aviation emissions in France's 2050 carbon budget (SNBC)

Biomass supply constrained by geography

Beyond theoretical estimates, the development of the e-bioSAF sector poses significant industrial and logistical challenges.

Valorizing 10 million tonnes of lignocellulosic biomass would require the deployment of around **30 industrial facilities,** whereas a single project already mobilizes a legally defined supply area covering the entire southwestern quarter of France (orange zone).

Map illustrating development constraints for e-bioSAF facilities



4. It should be noted that this decarbonization roadmap assumes a lower growth rate than observed trends (2.8% per year, according to the French government).

Traffic moderation:
ensuring sustainable access

French air traffic under triple constraints

In France, the objectives related to SAF are simultaneously:

- **Regulatory,** through compliance with the blending mandates set by the European ReFuelEU regulation. Given the national potential for SAF production, reaching the target rate of 70% SAF by 2050 would imply a reduction in air traffic, unless more than 70 TWh of electricity and at least 30% of liquid biofuels compatible with the RED III directive are mobilized.
- **Climatic,** aiming for carbon neutrality by 2050 while respecting a sustainable carbon budget: to keep the aviation sector's contribution at a level proportional to its current share (around 7% of national emissions), both in 2050 and over the entire period, French air traffic will have to be lower than its current level, unless the entirety of the biomass eligible for liquid biofuel production is consumed, along with 110 TWh of electricity (i.e., more than 20% of current electricity generation).
- **Sovereignty,** Involving to limit the oil dependance (currently 99% imported), thanks to the use of SAF.

Table showing the traffic evolution required to meet the SAF blending targets mandated by the European ReFuelEU regulation in 2050 (left) and to ensure that the aviation sector accounts for only 6.8% of national emissions in 2050 (right).

Residual Biomass	Electricity: 30 TWh	70 TWh	110 TWh
0%	-76%	-43%	-10%
30%	-52%	-19%	13%
60%	-29%	4%	37%

Residual Biomass	Electricity: 30 TWh	70 TWh	110 TWh
0%	-65%	-47%	-28%
30%	-48%	-29%	-11%
60%	-31%	-12%	7%

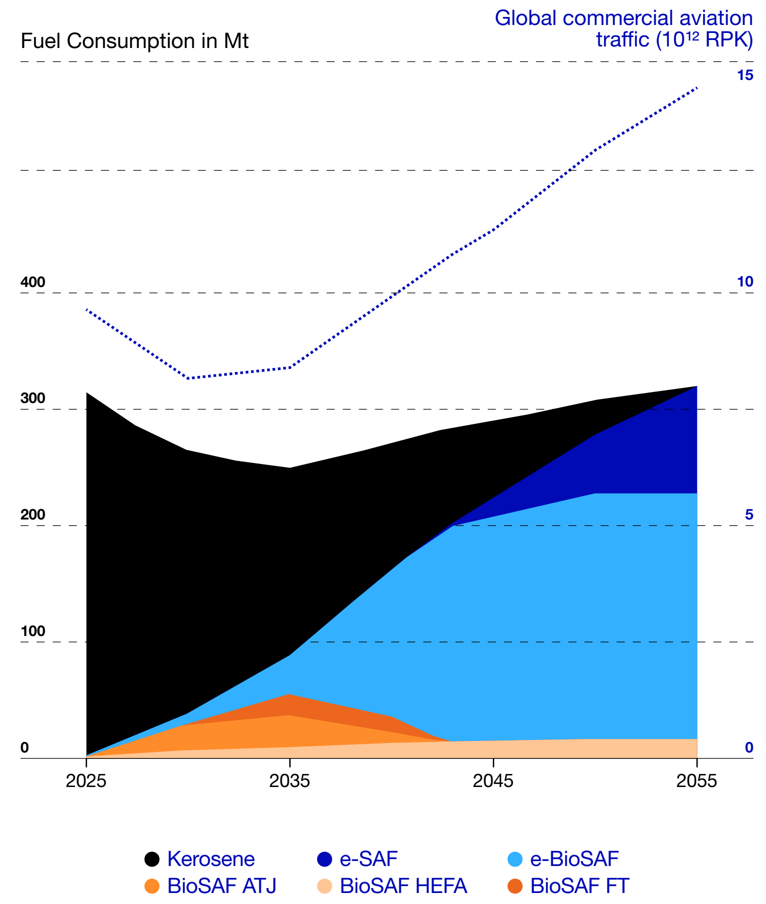
With an allocation of 30 TWh of electricity and 30% of liquid biofuels, **air traffic would need to be halved** in order to comply with ReFuelEU and achieve an emissions target compatible with carbon neutrality in 2050.

Globally, reducing traffic to increase it again later

Thanks to efficiency gains and the gradual incorporation of SAFs, **flights in 2040 or 2050 are expected to emit far less than they do today.** Consequently, it is precisely **now that traffic must be moderated,** in order to reduce emissions as much as possible while fossil kerosene remains the primary fuel for global aviation. Global traffic would thus need to decrease by at least 15% within the next five years to stay in line with a carbon budget limiting average temperature rise to 1.7°C, even with an aviation-favorable allocation. After this phase of sobriety, traffic can gradually resume, as SAFs are deployed and competing uses conflicts (biomass, electricity) are resolved.

Global growth is expected to be stronger than in France, reflecting the lower average per-capita traffic worldwide.

Traffic and fuel consumption trends (commercial aviation, global)



An achievable and desirable moderation

Given the limitations in low-carbon resources, emission control in the aviation sector requires, regulation of traffic both at the global level and within France. **Decarbonizing the aviation sector is ultimately as much a technological and industrial challenge as it is a matter of managing traffic.**

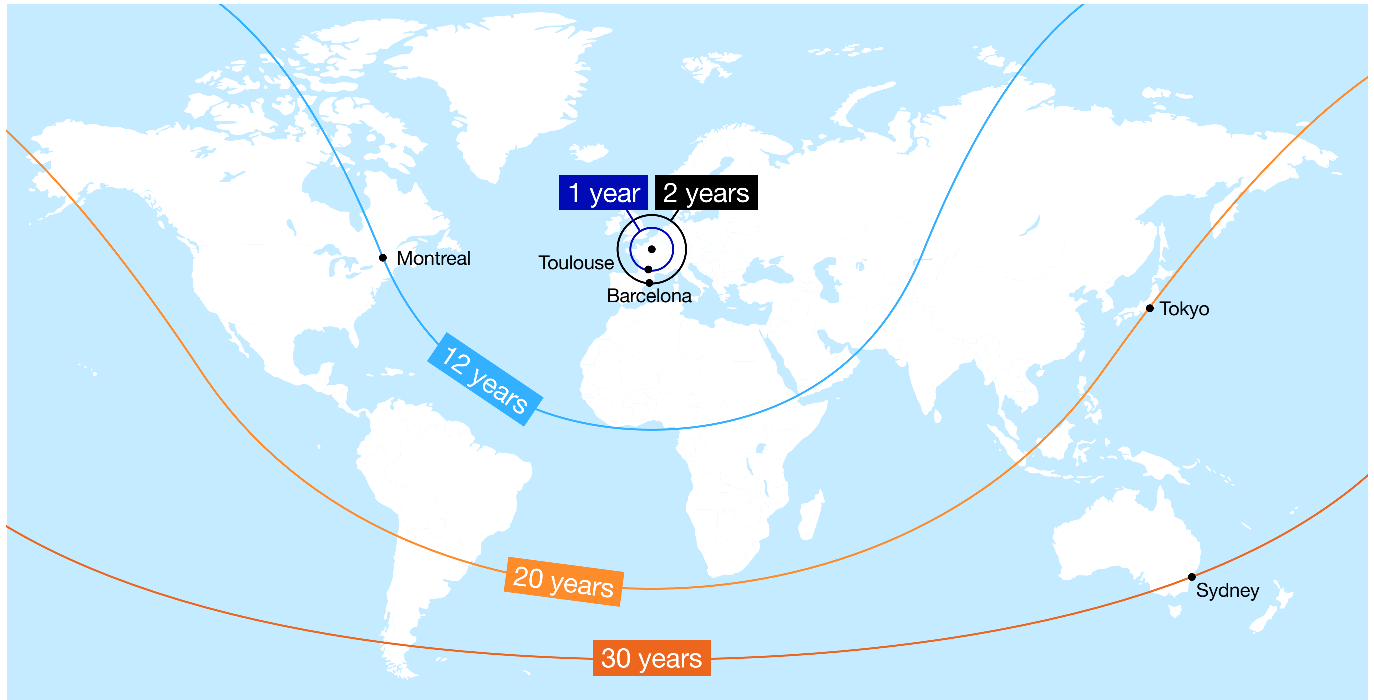
To make this sobriety acceptable for everyone, it is necessary to immediately initiate a democratic debate and to experiment with measures that act simultaneously on:

- **Reducing incentives to travel:** eliminating frequent flyer programs, regulating advertising, rebalancing the price signal of airline tickets.
- **Limiting demand:** CO_2 quotas or taxes, quotas or taxes, on kerosene or on kilometers traveled, at the individual and/or corporate level.
- **Regulating supply:** limiting airport capacity, eliminating routes that have effective alternatives.
- **Encouraging alternatives:** high-speed trains (TGV), night trains, buses, maritime links, and international rail connections.

Sustainable and fair access to air travel

Beyond climate and energy considerations, access to aviation raises important issues of justice and equity. Today, 1% of the global population is responsible for more than 50% of CO_2 emissions from the aviation sector.

If everyone in the world had equal access to air travel, the current level of traffic, which could be reached again around 2040 in the scenario above, would allow roughly 1,000 km of travel per person per year, equivalent, for example, to a round trip between Paris and Montreal every 12 years.

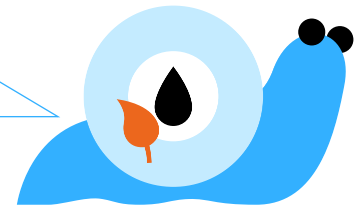


For many decades to come, aviation will remain a mode of transport requiring significant societal trade-offs, both in terms of energy, climate, and economics. However, combining collective management of air traffic with the deployment of decarbonized energy capacities will allow for a desirable outlook: an aviation sector compatible with the Paris Agreement, gradually freed from fossil fuels, and offering individuals the opportunity to travel, over the course of their lifetime, the equivalent of twice around the Earth[5].

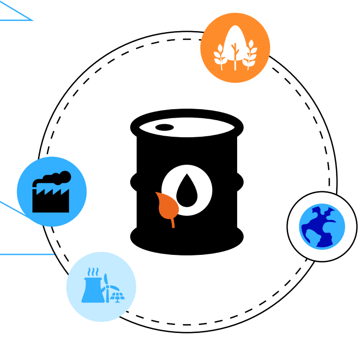
5. From the perspective of global air traffic returning to its current level after a period of restraint, the possibility for each individual to fly roughly 1,000 km per year would amount to a total of around 80,000 km over an entire lifetime, which is twice the circumference of the Earth.

Key Takeaways

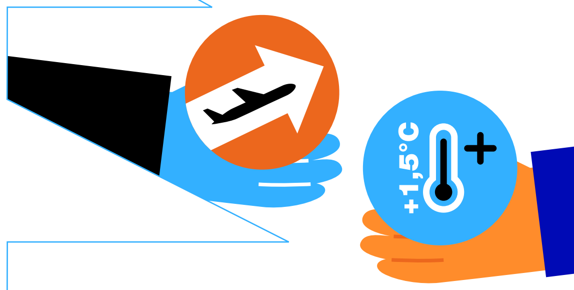
1. SAFs, and more specifically e-SAFs, are indispensable for aviation decarbonization, but they will not be deployed quickly enough to reduce CO_2 emissions in the short and medium term.



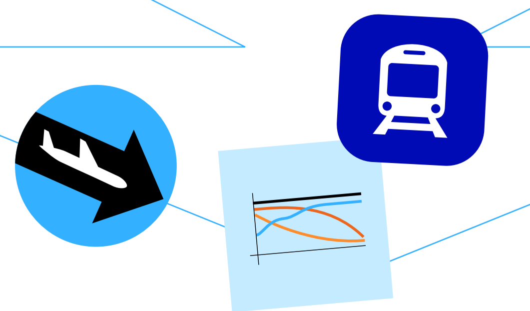
2. SAF production, both in France and globally, will be limited by physical and industrial constraints, as well as by competing uses for sustainable biomass and low-carbon electricity.



3. Maintaining projected traffic growth while simultaneously meeting climate objectives would require an extraordinary mobilization of resources. Under current constraints, moderating traffic growth becomes a necessary complement to technological progress.



4. Policy tools should therefore include experimentation with demand-management measures, incentive reform, supply-side regulation, and accelerated investment in sustainable transport alternatives.



THE SHIFT PROJECT

Aero Decarbo brings together employees, entrepreneurs, retirees, students, and aviation and aerospace enthusiasts around a shared mission: supporting these sectors in their transition toward a future that respects planetary boundaries. With scientific rigor and intellectual honesty, the organization analyzes and promotes the transformation of air transport to ensure the long term viability of the industries that depend on it.
www.decarbo.org

The Shift Project is a think tank dedicated to informing and influencing the debate on climate and energy challenges. We are a public-interest organization. Most of our funding members are companies. Guided by scientific and technical rigor, our perspective on the economy is primarily physical and systemic.
www.theshiftproject.org

Our partners
Aero Decarbo and The Shift Project would like to thank their partners for their technical and financial support.

Contacts

Timon Vicat-Blanc
President, Aero Decarbo
contact@decarbo.org

Ilana Toledano
Communication Officer, The Shift Project
ilana.toledano@theshiftproject.org

Design

Jérémy Garcia-Zubialde