Civil aeronautics technology: Sustainable aviation

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An excerpt from:

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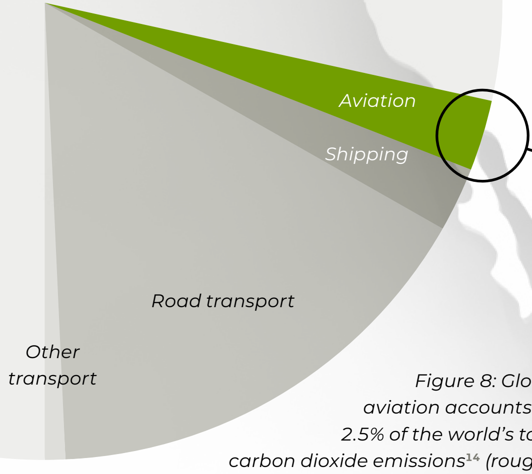


Figure 8: Global aviation accounts for 2.5% of the world's total carbon dioxide emissions[14] (roughly one-eighth of the total emissions of the transport sector[15]).

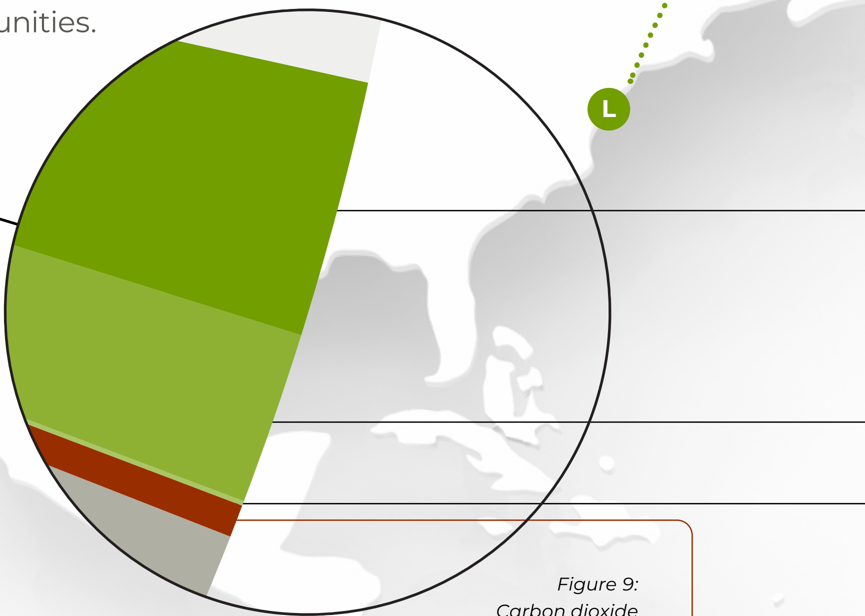


Figure 9: Carbon dioxide emissions from aviation by segment. (The total emissions also include the share from military aviation, which is approximately 7%, not discussed here.)

AVIATION'S IMPACT ON ENVIRONMENT AND CLIMATE

Aviation's impact on environment and climate is a central factor for the research that has long been prioritised by Innovair and within the NFFP programme. It is also a primary driving force for the aeronautics industry in its choices of national investments as well as for participation in major international programmes. The aeronautics technology sector is working hard to reduce both the absolute amount of emissions from aviation and aviation's share of total emissions, with the goal that all aviation is climate neutral by 2050.

The main environmental and climate problem for the foreseeable future is greenhouse gas emissions, primarily carbon dioxide. Aviation accounts for about 2.5% of global carbon dioxide emissions (see figure

L **LONG-HAUL FLIGHTS – 250 PASSENGERS OR MORE**

- **Share of global CO_2 emissions from aviation:** approx. 55%[16]
- **Share of total global CO_2 emissions:** approx. 1.4%[16]
- **Propulsion:** This segment focuses on the development of traditional propulsion technology aimed at significantly lower fuel consumption. The goal is a 30% reduction in CO_2 emissions from aircraft introduced by 2030. Total fossil-free status can be achieved with SAF (initially SAF-bio and later SAF-PTL).
- **Actors in Sweden:** GKN Aerospace, Saab Aeronautics + collaborating SMEs.

M **MEDIUM-HAUL FLIGHTS – APPROXIMATELY 150 PASSENGERS**

- **Share of global CO_2 emissions from aviation:** approx. 37%[16]
- **Share of total global CO_2 emissions:** approx. 0.9%[16]
- **Propulsion:** Focus here is on hydrogen propulsion through the combustion of hydrogen in turbofan or turboprop engines, as well as lower fuel consumption through ultra-efficient aircraft and engines. A challenge lies in fuel systems for cryogenic (extremely low temperature) fuels.
- **Actors in Sweden:** GKN Aerospace, Saab Aeronautics + collaborating SMEs.

R **REGIONAL FLIGHTS – TYPICALLY UP TO 500 KM, UP TO 40 PASSENGERS**

- **Share of global CO_2 emissions from aviation:** approx. 1%[16]
- **Share of total global CO_2 emissions:** approx. 0.03%[16]
- **Propulsion:** This size class offers opportunities for hybrid propulsion, with electricity from gas-turbine-driven generators or hydrogen fuel cells in combination with batteries. Several different hybrid concepts are being studied.
- **Actors in Sweden:** GKN Aerospace, Powercell, Heart Aerospace, FOI, Saab Aeronautics + collaborating SMEs.

Too small a share to be visible in figure 9.

S **SHORT-HAUL FLIGHTS – TYPICALLY UP TO 200 KM, UP TO 10 PASSENGERS**

- **Share of global CO_2 emissions from aviation:** very small[16]
- **Share of total global CO_2 emissions:** very small[16]
- **Propulsion:** This segment features the market for battery-powered flight, which may be the most appealing solution due to its high efficiency and simple systems. Battery development drives the ability to achieve longer ranges.

14 ourworldindata.org/global-aviation-emissions

15 ourworldindata.org/co2-emissions-from-transport

16 The shares of CO_2 emissions refer to flying and are assessed based on each segment's share of total aviation fuel consumption.

Figure 10: In this summary, where the examples of distances and different propulsion methods represent a hypothetical scenario for 2050, it is clear that medium- and long-haul flights account for the overwhelming majority (over 80%) of fuel consumption, which can be considered a reasonable measure of carbon dioxide emissions. Smaller regional aircraft and small short-haul aircraft only account for a small percentage of consumption/emissions. For this reason, Innovair focuses the civil part of its core activities on medium and long-haul aviation.

Figure 11: A look at any of the services providing real-time data on flights (here FlightRadar24.com) shows that at any given time, the large flight movements occur in other parts of the world than internally in Sweden – in market segments that do not exist regionally in Sweden, and in which we do not have any own OEMs.

8), which corresponds to roughly one-eighth of the total emissions of the transport sector, on par with shipping and about one-sixth of road transport.

The emissions from Swedish domestic aviation are lower, accounting for about 1% of our country's greenhouse gas emissions.

PROPULSION ALTERNATIVES FOR FOSSIL-FREE AVIATION

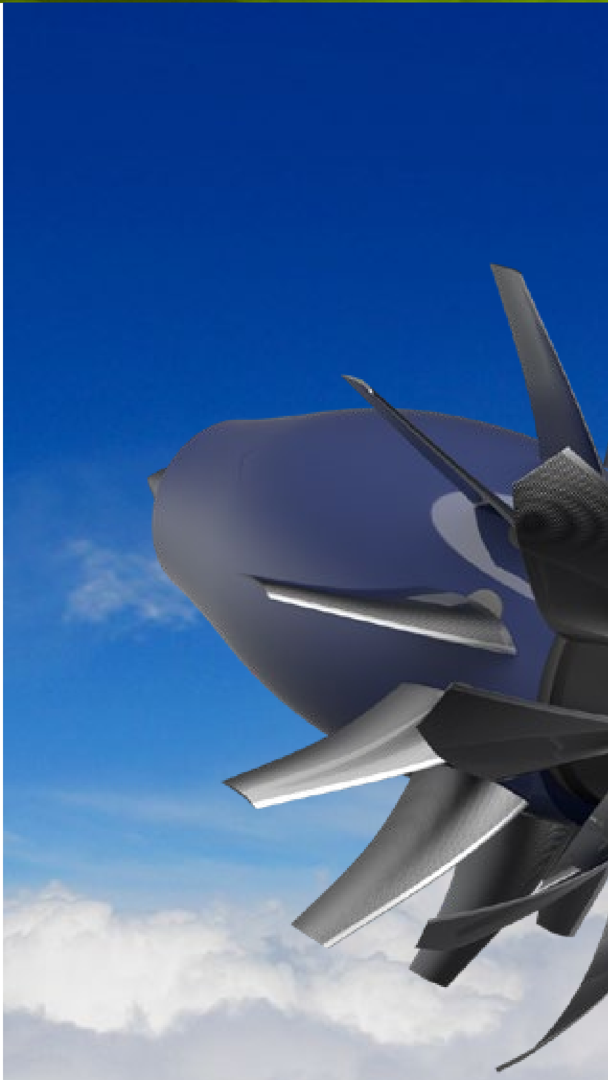
Since Innovair's last strategic innovation agenda, NRIA Flyg 2020, investments in fossil-free aviation have accelerated. A clear sign of this is the major EU programme Clean Aviation, which started in 2022 and, unlike its predecessors Clean Sky 1 and 2, includes significant investments in completely fossil-free aviation.

Part of the development needs relates to fossil-free fuels, with the main candidates being sustainable hydrocarbon-based aviation fuel (often referred to as SAF – Sustainable Aviation Fuel) and hydrogen burned in jet engines. Another path is using hydrogen in fuel cells to generate electricity for electric motor propulsion. Additional options involve using electric motors powered by batteries. Hybrid solutions between electric and combustion propulsion present further variations.

Even more development paths emerge when looking beyond the engine and fuel area, where significant advancements are occurring in everything from lightweight materials to entirely new aircraft concepts. Furthermore, electricity can be used to a greater extent than today to manage functions onboard. Therefore, the range of possibilities is very broad and includes disruptive development steps, as well as gradual improvements of existing technology. Many different technological pathways for fossil-free aviation are currently being developed in parallel (see **supplements A, B** – link on page 3).

A relevant Swedish report[17] in this context comes from the Swedish Energy Agency's assignment to Saab, Chalmers, GKN Aerospace and Linköping University, analysing the opportunities offered by various tech-

17 Svenskt hållbart flyg-Teknologi och förmåga bedömning mot 2045, final report, Energimyndigheten 2021-015938 (in Swedish).



FOSSIL-FREE CARBON-BASED FUELS AND CARBON DIOXIDE

Fossil-free carbon-based fuels also produce carbon dioxide emissions. The environmental and climate gain is that this carbon dioxide is not added to the cycle from the earth's interior but is sourced from the cycle in one way or another.

nological solutions to achieve fossil-free aviation by 2045.

The variety of technological pathways mentioned above pose different technical challenges and have various pros and cons, making some tracks better suited for different aviation segments (aircraft sizes, cruising speeds and ranges, see figures 9 and 10). In this context, it is important to know which segments account for the highest emissions in the global air transport system so that efforts are primarily directed toward those segments where they will have the greatest impact (see chapter 3 and **supplements A, B** – link on page 3). This perspective should serve as the basis for prioritising Swedish funding for research initiatives concerning fossil-free aviation (see further recommendation 2).

For maximum effect (in terms of climate benefit) of EU funding, the European Commission and the aeronautics industry have jointly decided that the large demonstrator project Clean Aviation will focus primarily on the segments where the EU's aeronautics industry can contribute and make a difference in the segments that currently have the highest emissions from aviation. In its SRIA[18], Clean Aviation clearly identifies three main areas:

- **ultra-efficient** aircraft/engines in the medium-haul segment (e.g. A320 and B737), with the goal of a 30% reduction in fuel consumption and the possibility of propulsion with 100% SAF;
- **hydrogen propulsion** – for combustion in jet engines (turbofan engines) and turboprop engines as well as using fuel cells;
- **hybrid-electric** regional aviation.

Clean Aviation has deliberately chosen to exclude other segments as they contribute too little to global CO_2 emissions (such as drones/UAS and helicopters).

CHALLENGE: There is a need for continued and expanded Swedish investment in technology development for fossil-free aviation, focusing on the segments that have the greatest climate impact, namely medium-haul (approximately 150 passengers) and long-haul (250 passengers).

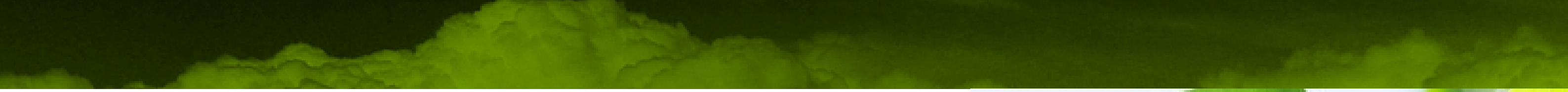
CHALLENGE: To achieve the climate goals, collaboration is required with both established and new actors, as well as an accelerated process to develop new solutions. This means a faster and more parallel design process than before, as well as simultaneous development within production and infrastructure for new energy sources.

18 clean-aviation.eu/strategic-research-and-innovation-agenda-sria

OTHER EMISSIONS BESIDES CARBON DIOXIDE

In addition to CO_2, other greenhouse gases, particles and water vapor are emitted during flight. These can result in both warming and cooling of the atmosphere but warming predominates. One parameter in the calculations is referred to as the high-altitude effect, which refers to emissions occurring at altitudes of more than approximately 8 000 meters. Often, short-lived contrails form at high altitudes; under certain meteorological conditions, these develop into extensive cirrus clouds, contributing to the greenhouse effect. The system is complex, and much research remains to be done in collaboration with meteorological R&D actors (read more on **innovair.org/hoghojdseffekt**).

Overall, the effects of all aviation have been estimated to account for nearly five percent of global warming.



FUEL PRODUCTION

Aviation will not electrify to the same extent – or as quickly – as the ground transport sector. There are several reasons for this, which are described in detail in **supplement C** – link on page 3.

Therefore, aviation will continue to depend on various types of fuels for the foreseeable future. The issue of access to such fuels will thus continue to increase in importance. Security policy and climate policy perspectives on the matter are also increasingly aligning. However, as long as there are no clear regulations and documented demand, industry players have been cautious about making investments to build production facilities. Currently, the market and willingness to invest are entirely driven by political decisions. Furthermore, as long as large quantities of these fuels are not produced, they are so costly that airlines' and passengers' willingness to pay the price is very limited.

Aspects of fuel production and the different alternatives are described in more detail in **supplement C** – link on page 3.

> **CHALLENGE:** A nationally coordinated effort is needed to secure access to SAF and hydrogen – and the green electricity required to produce these.

In **supplement F** – link on page 3 – there is a section discussing international collaborations that are important for ensuring resilience and interoperability concerning fuel for military jets. At the same time, there must be a clear connection to the general challenge of sustainable aviation and the fuels required to meet climate goals. Already in 2017, it was demonstrated that a Gripen aircraft could fly on 100% biofuel. Military aviation may have specific requirements regarding access to aviation fuel during conflict times, long-term storage and field storage, but the primary development goal should be fossil-free fuel for all types of aviation traffic.

The concept of resilience includes having access to the necessary fuels over time and creating conditions for domestic production. Sweden has the opportunity, provided that necessary political decisions are made, to establish such production as part of achieving climate goals and simultaneously becoming self-sufficient in fossil-free fuel.

> **CHALLENGE:** Sweden needs to identify the conditions for critical self-sufficiency and create resilient value chains for aviation fuel.

CIRCULARITY

A special aspect of sustainability is to minimise the environmental impact resulting from the development, production, use and disposal of aviation products, primarily the aircraft themselves. Buyers within the aviation sector and Swedish aerospace industry should incorporate this into their processes. Both manufacturing methods and lifecycle thinking are challenges that can be turned into competitive advantages, with the environment and sustainability as primary arguments. Therefore, measures for increased circularity should be emphasised in the aviation sector's development plans and included in new R&D initiatives. Read more in **supplement D** – link on page 3, where we also provide some examples of circular thinking from an environmental perspective.

FIRST "HALF-GREEN" AIRPORT
In 2023, Trollhättan-Vänersborg Airport decided to be the first airport in the world to offer refuelling exclusively with (the maximum allowed) 50% renewable fuel. Västflyg thus operates all its routes from there on this fuel, with support from GKN Aerospace and others.

> **CHALLENGE:** The entire lifecycle's environmental impact needs to be included in the planning of new products, based on a circularity mindset and thinking.

AIRSPACE

In the ambition to reduce emissions and climate impact from aviation, measures related to airspace, route planning etc. play an important role – issues that are high on the agenda of LFV, Eurocontrol, ICAO, IATA and

several other central aviation organizations[19].

The work to increase sustainability and reduce negative climate and environmental effects involves not only the introduction of aviation using non-fossil fuels but also improving support tools and information exchange between ATC and airspace users for increased predictability and more efficient sequencing (arrival and departure flows), more efficient approach procedures with higher navigational precision and laterally/vertically adjusted procedures, as well as dynamic allocation of cruising altitudes to counteract negative high-altitude effects.

The European aviation support organization Eurocontrol points out that the uncertainty surrounding the effects of contrails (see fact box on “Other emissions besides carbon dioxide” at the beginning of this chapter) is still significant enough not to motivate the establishment of new regulations. However, they emphasise the need to ”move from the concept of a green trajectory to a climate trajectory,” meaning that focus should go beyond reducing CO_2 to seriously tackling non-CO_2 emissions. These two ambitions should not counteract each other (emphasises Eurocontrol); route planning choices, among others, must be based on optimisation including conflicting goals. This needs to be based on data and research (as well as cooperation with weather services regarding contrails).

Read more about airspace in **supplement E** – link on page 3.

19 ICAO, International Civil Aviation Organization; IATA, International Air Transport Association; Eurocontrol, supports EU member states in their efforts for simplified procedures in a “Single European Sky”.

THE NEED FOR SYSTEM UNDERSTANDING

Successfully transitioning to a fossil-free society requires system understanding to weigh different investments against each other. Should we invest heavily in new nuclear power, expand our last free-flowing rivers, accelerate investments in wind and solar power – or should we do all of these? System understanding provides information on whether a proposed investment plan will yield good environmental benefits, robustness, resilience – and societal acceptance.

Taking an aircraft as an example, system understanding provides information about which subsystems have the greatest potential to improve the aircraft’s overall performance. We can identify bottlenecks, and we can also see which areas are ”overperforming” and significantly stronger than other links in the chain – thus likely too expensive.

This system understanding is an extraordinarily important component in both civil and military aviation innovation for the aforementioned two reasons: weak points can be identified, as well as unnecessarily expensive solutions. This contributes to the innovation efficiency that we depend on as a nation to compete against other aviation nations in the race for development contracts.

Sweden has long been prominent in the development of systems of systems, which has helped us maintain our strong position in aeronautics technology development. The question of system understanding also applies at the societal level. The development of civil aviation is primarily guided by transportation policy goals, where accessibility dominates, while sustainability development prioritises climate impact over other undesired environmental effects. The environmental and climate issues related to aviation do not have a single, all-encompassing sustainable solution. The complexity of the aviation system affects the ability to control development and function, which can lead to unintended consequences.

Sustainability issues are complex and increase the demands for balancing conflicting goals, managing these, and having sufficient understanding of overall system impact and requirements, with a sufficient number of system perspectives from various stakeholders. System developers and decision-makers need to motivate their choices and prove their awareness of the trade-offs being made both locally and globally.

CHALLENGE: Sweden needs to ensure that we retain – and strengthen – our capability for system understanding in the future. This applies at all levels and across all pillars of the triple helix, from academia and institutes through industry to the public sector.

In **supplements A, B, C, D** – link on page 3 – an expanded account of factors related to the environment and sustainable aviation is provided.

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