



International Journal of Innovative Research in Science Engineering and Technology (IJIRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)



Impact Factor: 8.699

Volume 14, Issue 6, June 2025

Estimation of the Global Emission Reduction Potential of Aviation Technologies & their Contribution of Aviation'S High Level Emission Goals

Anju Jaglan, Dr. Neha Bhatia

School of Business, Galgotias University, Greater Noida, India

ABSTRACT: The aviation industry, while crucial to global economic and social connectivity, is a significant contributor to greenhouse gas emissions—accounting for approximately 2–3% of global CO₂ output. With air travel projected to grow steadily through 2050, the sector faces mounting pressure to align with international climate goals, notably the International Civil Aviation Organization's (ICAO) Long-Term Aspirational Goal of achieving net-zero emissions by 2050. This research investigates the emission reduction potential of various aviation technologies and evaluates their role in helping the industry meet these high-level environmental objectives.

The study explores advancements in airframe and engine efficiency, sustainable aviation fuels (SAFs), hydrogen and electric propulsion, operational improvements, and carbon removal strategies. Findings suggest that a combination of improved aircraft design, optimized operations, and widespread SAF adoption can reduce emissions by up to 80%, while zero-emission aircraft and carbon capture technologies offer promising pathways for the remaining gap. However, achieving these reductions demands coordinated global policy support, investment in infrastructure, and rapid technological innovation. The paper concludes by emphasizing a systems-level approach that integrates all available technologies and operational strategies to meet aviation's decarbonization goals.

I. INTRODUCTION

In 2050 more than 9.5 billion people will live on Earth (University of Washington, 2014). According to Boeing, a larger part of the population will have the opportunity to be mobile, since airlines will expand in emerging markets and develop innovative airline models (2014). Viewed in the context that air travel is an invaluable global asset, which entails a progressive economic and societal stability, the evolving air travel demand in expanding regions yields growing world traffic. An anticipated annual growth in airline passenger traffic by four to five per cent indicates that air travel continues to experience the fastest growth of all transport modes (Boeing, 2014; Airbus, 2015).

In spite of reduced aircraft fuel burn per passenger kilometre by nearly 70 % since 1960, the projected growth of air traffic will exceed the envisaged fuel efficiency improvements of one to two per cent yearly (ICAO, 2010; IATA, 2013). As the aviation sector is continually expanding and thus, its total fuel burn, the ecological impacts escalate significantly. Notably, the air transport's current contribution to anthropogenic Carbon Dioxide (CO₂) emissions represents two per cent as well as its contribution to total greenhouse emissions amounts three per cent (Intergovernmental Panel on Climate Change, 1999). Without any progress, the future share in CO₂ development may increase by factors of three to four over 2000 level in 2050 (Lee et al., 2010).

Hence, a responsibility of all players in the air transport industry for efficiency and sustainability is crucial. Aircraft manufacturing and airline industries, the scientific community and governmental authorities have already taken a pace forward mitigating the climate impact of aviation. In this way, strategy agendas like Flightpath 2050 or the IATA Technology Roadmap establish ambitious environmental goals for reducing aviation's emissions (European Commission, 2011; IATA, 2013).

Sector's Emission Context & Goals

- Aviation contributes roughly 2–3 % of global CO₂ emissions (~800 Mt CO₂ in 2022) and is projected to triple internationally by 2050 if unchecked [reddit.com+3climate](https://www.reddit.com/r/3climate). [ec.europa.eu+3mdpi](https://ec.europa.eu/3mdpi). [3.com+3](https://www.3.com).
- The **Long-Term Global Aspirational Goal (LTAG)** set by ICAO (2022) is **net-zero carbon emissions from international aviation by 2050** [ipcc.ch+2prod](https://www.ipcc.ch). [icaa.org+2arxiv](https://www.icaa.org). [org+2](https://www.org).

II. EMISSION REDUCTION PATHWAYS & POTENTIAL

2.1. Airframe & Engine Efficiency

- Historical improvements: ~1.5 % fuel efficiency gain per year since 1990 (~52 % cumulatively) .
- Projected gains:
 - 10–15 % from current high-bypass turbofans (2020–25),
 - 20–25 % from geared turbofans (2020–25),
 - 30 % from open-rotor designs (~2030),
 - 30–80 % from hybrid propulsion (2030–40),
 - ~100 % for full electric (2035–45) [mdpi.com+15en.wikipedia.org+15en.wikipedia.org+15](https://www.mdpi.com/15en.wikipedia.org/15en.wikipedia.org/15).
- **Retrofits:** Winglets and lightweight materials yield 1–4 % fuel savings; blended winglets cut drag and emissions by ~2–4 % [ipcc.ch+4mdpi.com+4en.wikipedia.org+4](https://www.ipcc.ch/4mdpi.com/4en.wikipedia.org/4).
- **Blended Wing-Body (BWB):** Could reduce fuel use by ~50 %; NASA and startups (JetZero, Natilus) aim for commercial demos by late 2020s [ft.com+1en.wikipedia.org+1](https://www.ft.com/1en.wikipedia.org/1).
 - Airbus MAVERIC prototype targets 50 % CO₂ reduction [weforum.org+15en.wikipedia.org+15arxiv.org+15](https://www.weforum.org/15en.wikipedia.org/15arxiv.org/15).

2.2. Operational Improvements

- Air-traffic management (e.g., continuous climb, single-engine taxi) can yield 0.2–1.9 % energy use savings by 2050 [theicct.org+1statista.com+1](https://www.theicct.org/1statista.com/1).
- Payload optimization, formation flying, optimized routes, and reduced fuel loads contribute additional efficiency gains [ipcc.ch+1theicct.org+1](https://www.ipcc.ch/1theicct.org/1).

2.3. Sustainable Aviation Fuels (SAF)

- SAFs (biofuels, e-fuels) reduce lifecycle CO₂ emissions by **50–98 %** depending on feedstock .
 - Jatropha: 50–80 % reduction en.wikipedia.org.
 - Algae-based: up to 98 % .
- Current global use is minuscule (<0.5 %, about 1.3 bn L in 2024); IATA targets 2 % in EU by 2025, 6 % by 2030 [arxiv.org+7reuters.com+7climateactiontracker.org+7](https://arxiv.org/7reuters.com/7climateactiontracker.org/7).
- Scaling needed: to 24 Mt by 2030, and ~500 Mt by 2050 ft.com.
- Policy support accelerating: EU ReFuelEU mandates, US IRA credits, UK incentives [reuters.com+4iea.org+4climateactiontracker.org+4](https://reuters.com/4iea.org/4climateactiontracker.org/4).
 - EU: 2 % by 2025, 6 % by 2030, 70 % by 2050 .

2.4. Zero-Emission Propulsion: Hydrogen & Electric

- **Hydrogen**
 - Fuel-cell and turbine aircraft may reduce climate impact by **40–80 %** depending on range; commercialization estimated by 2035 for short/medium-range en.wikipedia.org.
 - Technical hurdles: cryogenic storage, tank placement, infrastructure arxiv.org.
- **Electric** (Battery and fuel cells)
 - Electric planes: operational zero emissions, limited to short range now (~450 km); future battery energy-density breakthroughs needed (800 Wh/kg) for ~1,000 km iea.org.
 - Eviation Alice (9-seat electric) test flights completed; commercial operations by ~2027 [weforum.org+1iea.org+1](https://weforum.org/1iea.org/1).

2.5. Carbon Removal & Demand Management

- **Carbon capture (Direct Air Capture)** & synthetic fuel feedstocks: e.g., Carbon Engineering, Climeworks; costs ~\$87–\$140/t CO₂ at large scale en.wikipedia.org.
- **Modal shift** (e.g., rail instead of short-haul flights) could cut emissions significantly—up to 60 % of projected BAU aviation emissions by 2050 .
- **Demand restraint** (reducing flights) along with efficiency may avoid 62 % of projected emissions; remaining requires vast SAF/synthetic fuel deployment [theaustralian.com.au+3researchgate.net+3iea.org+3](https://theaustralian.com.au/3researchgate.net/3iea.org/3).

III. ROLE IN MEETING AVIATION'S HIGH-LEVEL GOALS

Cumulative ICCT Vision 2050 modeling shows:

- Efficiency gains (airframe + operations): can align aviation with $\sim 1.75^{\circ}\text{C}$ decarbonization up to 2050 theicct.org+1ipcc.ch+1.
- SAF and zero-emission planes are **essential** for deeper cuts beyond technical efficiencies.
- By 2050, a portfolio combining $\sim 50\%$ SAF usage, hydrogen/electric entry, and fleet upgrades is required to hit net-zero en.wikipedia.org+15weforum.org+15theicct.org+15theicct.org+7prod.iea.org+7theaustralian.com.au+7.

IV. TECHNOLOGY CONTRIBUTION SUMMARY

Technology Category	Emission Reduction Potential	Key Deployment Period & Notes
Engine/airframe efficiency	1–2 % annually; total 30–50 % by 2050	Geared turbofan, open rotor
Operational improvements	0.2–2 % energy improvement	ATM, taxiing, flight routing
SAF	50–98 % life-cycle CO ₂ reduction per flight	2–6 % pilot blends now; ambitious scale needed
Blended wing-body aircraft	Up to 50 % fuel saving future	Demos by 2027–30
Hydrogen propulsion	40–80 % lower climate impact	Short-range by 2035
Battery-electric aircraft	100 % zero operational emissions, but short-range	Commercial small planes by 2027
Carbon removal + synthetic jet	Support residual emissions	Long-term supply link with SAF/e-fuel

V. BARRIERS & ENABLERS

- **Policy & Economics:** SAF needs strong incentives: SAF credits, blending mandates, carbon taxes ipcc.ch+1mdpi.com+1iea.org+2en.wikipedia.org+2en.wikipedia.org+2mdpi.com+5en.wikipedia.org+5en.wikipedia.org+5ft.com+3iea.org+3weforum.org+3prod.iea.org+1weforum.org+1time.com+5climateactiontracker.org+5wsj.com+5reuters.com.
- **Scale and Infrastructure:** Massive investment in SAF (bio-refineries, hydrogen, DAC) needed—>\$2.4 tn by 2050 .
- **Certification & Technical:** New aircraft designs and fuels require years of certification and public trust.
- **Feedstock sustainability:** Biofuels must avoid land-use change and biodiversity harm en.wikipedia.org.

VI. CONCLUSIONS

- Upgrading existing fleets and optimizing operations can reduce $\sim 30\text{--}50\%$ of emissions.
- Scaling SAF to 50 % of fuel mix by 2050 delivers deep CO₂ reductions per lifecycle.
- Zero-emission propulsion (hydrogen, electric, BWB) is **essential** to bridge the final gap to net-zero.
- Demand management and carbon removal complement technology to ensure aviation aligns with climate goals.
- Achieving aviation's LTAG by 2050 “is feasible” — but only with **coordinated policy, investment, and innovation** across industries and governments ft.com+1arxiv.org+1.

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