Decarbonising Aviation in the IEA's Net Zero Emissions by 2050 Scenario

By Praveen Bains, Hyeji Kim and Jacob Teter (International Energy Agency – IEA)

The roadmap for aviation in the Net Zero Emissions by 2050

The energy sector is the source of around three-quarters of greenhouse gas emissions today. In the International Energy Agency (IEA) Net Zero by 2050 Roadmap[1] (henceforth "NZE"), we have analysed a pathway where the global energy sector achieves net-zero CO_2 emissions by 2050 with no offsets from outside the energy sector, and with low reliance on negative emissions technologies. It is designed to maximise technical feasibility, cost-effectiveness and social acceptance while ensuring continued economic growth and secure energy supplies.

In the NZE, the aviation sector remains one of the net emitters by 2050, together with other sectors where emissions are hard to abate such as cement, iron and steel, chemical, road freight and shipping (Figure 1). Despite rapid adoption of sustainable aviation fuels (SAFs) and alternative technology options using electricity and hydrogen, residual emissions from aviation total about 210 Mt (direct emissions from fossil fuel combustion) by 2050, or just over 10% of unabated CO_2 emissions from fossil fuels and industrial processes.

The aviation sector today is characterised by the low technology readiness level of zero or near zero emissions technology options, with over 90% of the future abatement potential lying in different technologies that are in prototype or demonstration phase today[2]. These include both the most promising production pathways for expanding low-life cycle emissions SAFs, as well as new engine and aircraft designs (such as open rotor and blended-wing-body aircraft). Commercial aircraft taking advantage of

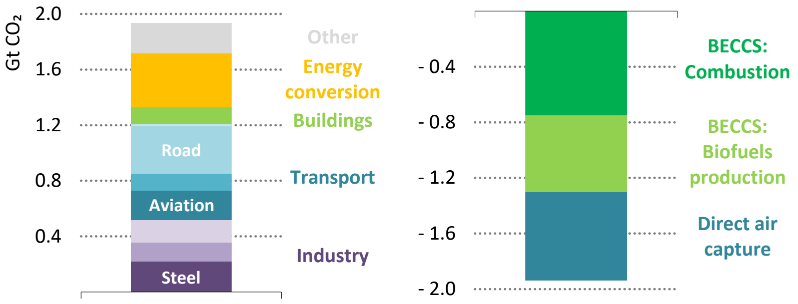

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FIGURE 1: Residual CO_2 emissions by sector and of negative CO_2 emissions by carbon removal technology in the NZE, 2050
Note: BECCS = bioenergy with carbon capture and storage. Source: IEA (2021), Net Zero by 2050, IEA, Paris[3]

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[1] IEA (2021), Net Zero by 2050, IEA, Paris https://www.iea.org/reports/net-zero-by-2050 . The IEA disclaims that the Roadmap describes one pathway but that is not the only pathway that can lead to net zero in 2050 depending on different variables and uncertainties, including significant uncertainties arising from the ongoing Covid-19 pandemic and the recent Russian invasion of Ukraine.

[2] IEA (2021), ETP Clean Energy Technology Guide, IEA, Paris https://www.iea.org/articles/etp-clean-energy-technology-guide

[3] https://www.iea.org/reports/net-zero-by-2050

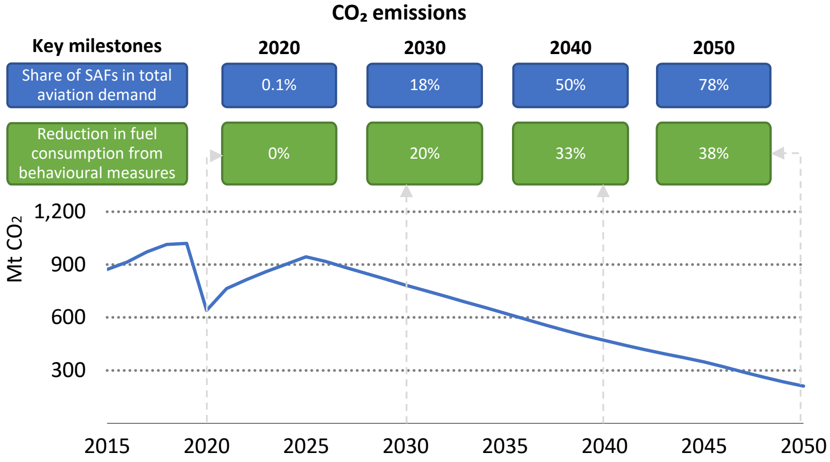

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FIGURE 2: CO_2 emissions trajectory and key milestones for the aviation sector in the NZE, 2015-2050. Source: IEA (2021), Net Zero by 2050, IEA, Paris[4]

hybrid or even full electric propulsion, or running directly (whether via direct combustion or with fuel cells) on hydrogen, are likely to become commercial in the 2030s at the very earliest. In addition to accelerating innovation, the IEA analysis (Figure 2) emphasises the importance of reaching key milestones in improving energy efficiency, increasing adoption of sustainable aviation fuels and managing demand to meet the NZE trajectory.

The IEA pathway recognises the centrality of SAFs in reducing in-sector aviation emissions. In the IEA's NZE, SAFs, mostly bio-kerosene, represent already around 15% of aviation fuel demand in 2030, increasing to 80% in 2050. Direct use of hydrogen and electricity also plays a role in short-haul flights in the NZE, each contributing around 1% to final aviation demand.

The basis of the analysis in the NZE developed in 2021 is that passenger aviation demand grows more than threefold by 2050 in the absence of demand management. In the NZE, measures that require change of individual's behaviour – keeping air travel for business and long-haul flights for leisure at 2019 levels, plus modal shift from short-haul flights to high-speed rail – can lead to a 50% reduction in emissions while reducing the number of flights only by 12%. The IEA continues to assess the potential for measures to reduce overall demand such as limits on airport capacity expansion, frequent flier levies and supporting high-speed rail, as preferable to out-of-sector offsets in terms of providing wider societal benefits and having less risk of leakage, enforcement, or less complex verification.

Making energy supply fit for net zero aviation

Bio-kerosene production from advanced[5] feedstocks is prioritised over other feedstocks in the NZE, even if in the short term certain conventional feedstocks are more economically competitive and readily scaled up. Bio-kerosene based on waste lipid feedstocks using the hydrogenated esters and fatty acids (HEFA) is already commercialised, and is the dominant SAF in the NZE in the near-term. However, HEFA bio-kerosene is limited by the supply of waste oils. Expanding bio-kerosene production to the volumes within the NZE hinges on commercialising technologies to convert woody biomass feedstocks into liquid biofuels (such as biomass gasification with Fischer-Tropsch and alcohol-to-jet). Additionally, these pathways can be paired with Carbon Capture Utilisation and Storage

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[4] https://www.iea.org/reports/net-zero-by-2050

[5] Advanced feedstocks refer to waste and residues feedstocks as well as nonfood energy crops (*e.g* miscanthus, poplar, jatropha) grown on marginal lands, minimizing impacts on food prices, land availability, biodiversity, soil health, and fresh water systems.

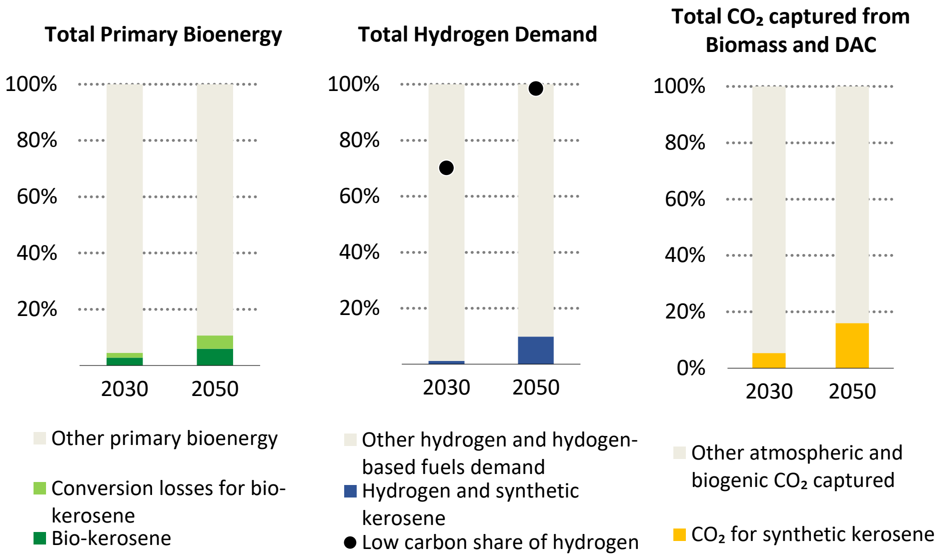

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FIGURE 3: Share of aviation use in key metrics of energy and CO_2 supply in the NZE, 2030 and 2050. Note: DAC = direct air capture. Source: IEA (2021), Net Zero by 2050, IEA, Paris[6]

(CCUS) at relatively low costs.[7] Production using advanced woody feedstocks is mostly under development today; projects currently in the pipeline are critical in ensuring bio-kerosene is ready to scale up by 2030. Improvements in collecting and sorting residue feedstocks (such as organic municipal solid waste, crop residues) and experience in cultivating nonfood energy crops on marginal lands are equally important to ensuring the sustainable scale up of bio-kerosene. While bio-kerosene could reach production costs of 110-140 USD/bbl by 2050 in the NZE (and potentially lower with a carbon price),[8] costs are strongly dependent on highly uncertain biomass feedstock costs. In 2050, around 11 EJ of primary bioenergy[9] is converted into 6 EJ of bio-kerosene for aviation.

Synthetic kerosene, produced from CO_2 and electrolytic hydrogen, is further away from commercialisation than bio-kerosene from woody feedstocks. In the NZE, synthetic kerosene is produced at scale starting in 2040. While components of synthetic kerosene production are already commercialised today (such as synthesis[10]) full system integration including carbon-neutral CO_2 and renewable electrolytic hydrogen remains in the development phase. Additionally, production costs are very high today (300-700 USD/bbl), mostly driven by renewable electricity costs and inherently low conversion efficiencies. As the cost of renewable electricity as well as electrolysers for hydrogen and direct air capture for CO_2 fall with greater deployment in the NZE, production costs could decline to 130-300 USD/bbl by 2050. The scale-up of synthetic kerosene is not limited by the same resource constraints as bio-kerosene, however, and use of biogenic carbon sources, and eventually direct air capture in concert with additional renewable energy may (Figure 3) lead to greater life-cycle CO_2 reduction potential than “pure” biomass-based production pathways without CCUS.

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[6] https://www.iea.org/reports/net-zero-by-2050

[7] Both biomass gasification and Fischer-Tropsch as well as ethanol production produce relatively pure streams of CO_2 that can be captured and stored to produce negative emissions, or utilised, for example to produce synthetic kerosene.

[8] For example, assuming a feedstock cost of 6 USD/GJ, a carbon price of 150 USD/t CO_2 in 2050 could lead to bio-kerosene production cost of 70 USD/bbl for the biomass gasification and Fischer-Tropsch route with carbon capture and storage, producing negative emissions.

[9] In the NZE, around 100 EJ of sustainable primary bioenergy is considered to be available. For more information, please refer to: IEA (2021), What does net-zero emissions by 2050 mean for bioenergy and land use?, IEA, Paris https://www.iea.org/articles/what-does-net-zero-emissions-by-2050-mean-for-bioenergy-and-land-use

[10] Synthesis refers to the process of converting syngas (consisting of CO, CO_2 and H_2) into hydrocarbons such as methane, diesel or kerosene.

Recommendations

Policy instruments will need to simultaneously provide certainty for a rapid technology development and scale up of SAF production while progressively prioritising those SAF production pathways that can demonstrate verifiable cost-competitive greenhouse gas emissions reductions on a life-cycle basis. Decisions will be needed by 2025 at the latest on how best to create markets for SAFs and close the cost gap between SAFs and fossil fuels, considering mechanisms such as low-carbon fuel standards, biofuel mandates, CO_2 prices and CO_2 removal credits. Governments also need to define their strategies for low-carbon fuels in aviation by 2025, given the slow turnover rate of the fleets, after which they should rapidly implement them. International co-operation and collaboration will be crucial to success. Priority action should target the most heavily used airports so as to maximise the impact of initial investment.