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RESEARCH BRIEF

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KEY POINTS FOR DECISION MAKERS

Large-scale use of SAFs will be required for aviation to meet climate goals. Even under our rosiest assumptions of reduced demand, aircraft efficiency, and use of electric and hydrogen-powered aircraft, there is enormous demand for net-zero emissions liquid fuels (biofuels or synthetic fuels)—volumes comparable to current global biofuels production.

Given current high costs and limited supplies of SAFs, policy and research would do well to prioritize creating affordable SAFs at scale. For biofuels, this implies higher conversion efficiencies and lower feedstock costs. For synthetic fuels, capital costs of electrolyzers and technological carbon capture are key.

Atmospheric removal technologies could be a more cost-effective solution to aviation emissions than SAFs. For example, permanent carbon removal costs of \$200-300/tCO_2-eq could compete favorably with SAFs costing of \$0.80-1.20/L.

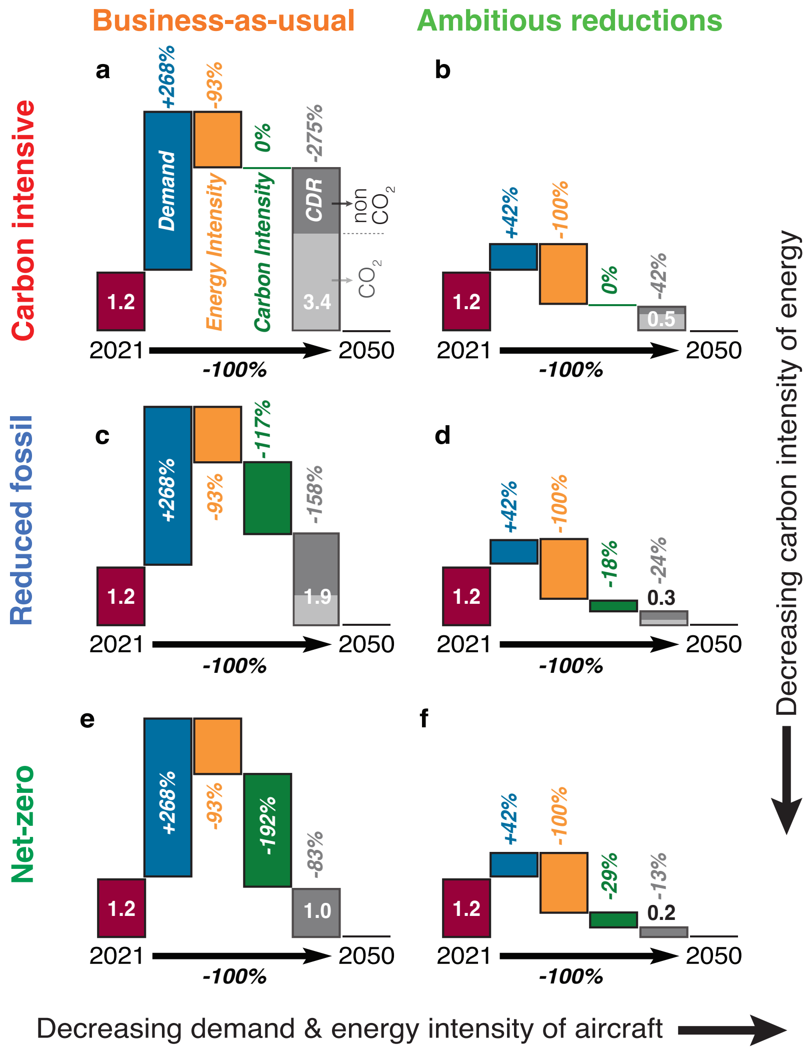
Net-zero emissions aviation will require widespread use of sustainable aviation fuels (biofuels and/or synthetic fuels) and large-scale carbon dioxide removal.

Flying will be particularly challenging to decarbonize because aircraft rely on energy-dense liquid hydrocarbons and flights also entail non-CO_2 radiative forcing. Nonetheless, some countries and air carriers have committed to net-zero emission targets consistent with stabilizing global climate.

We assess nine possible pathways to achieve net-zero emissions from aviation, including changes and trade-offs in demand, energy efficiency, propulsion systems, and alternative fuels for both passenger and freight transport, as well as atmospheric carbon removal to offset non-CO_2 radiative forcing.

Reductions in use of air transport (e.g., by behavioral changes or switches to high-speed rail) could substantially limit future increases in demand, and improvements in aircraft efficiency might meaningfully reduce the energy required per passenger-km. But even assuming large decreases in demand and energy intensity, eliminating all emissions from aviation will require 4 EJ/yr of "drop-in" sustainable aviation fuels (SAFs)—roughly the total quantity of biofuels produced worldwide in 2019. And the most scalable SAFs are ~4 times more expensive than fossil jet fuel today.

Moreover, non-CO_2 forcing from contrails will need to be compensated for by hundreds of millions of tons (and up to 3.4 GtCO_2) of atmospheric carbon removal to completely avoid the sector's climate effects.



Contributions to changes in emissions from 2021 to 2050 (in Gt CO_2-eq). Each panel represents a different combination of demand and energy intensity (columns) and carbon intensity (rows). Colored bars show how historical emissions (red) and growth in demand (blue) must be counteracted by decreases in energy intensity of aircraft (yellow-orange), carbon intensity of fuels (green) and carbon dioxide removal (gray) to reach net-zero in 2050. Note that the darker grey shading of the CDR bar shows removal required to offset non-CO_2 radiative forcing in each scenario.

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