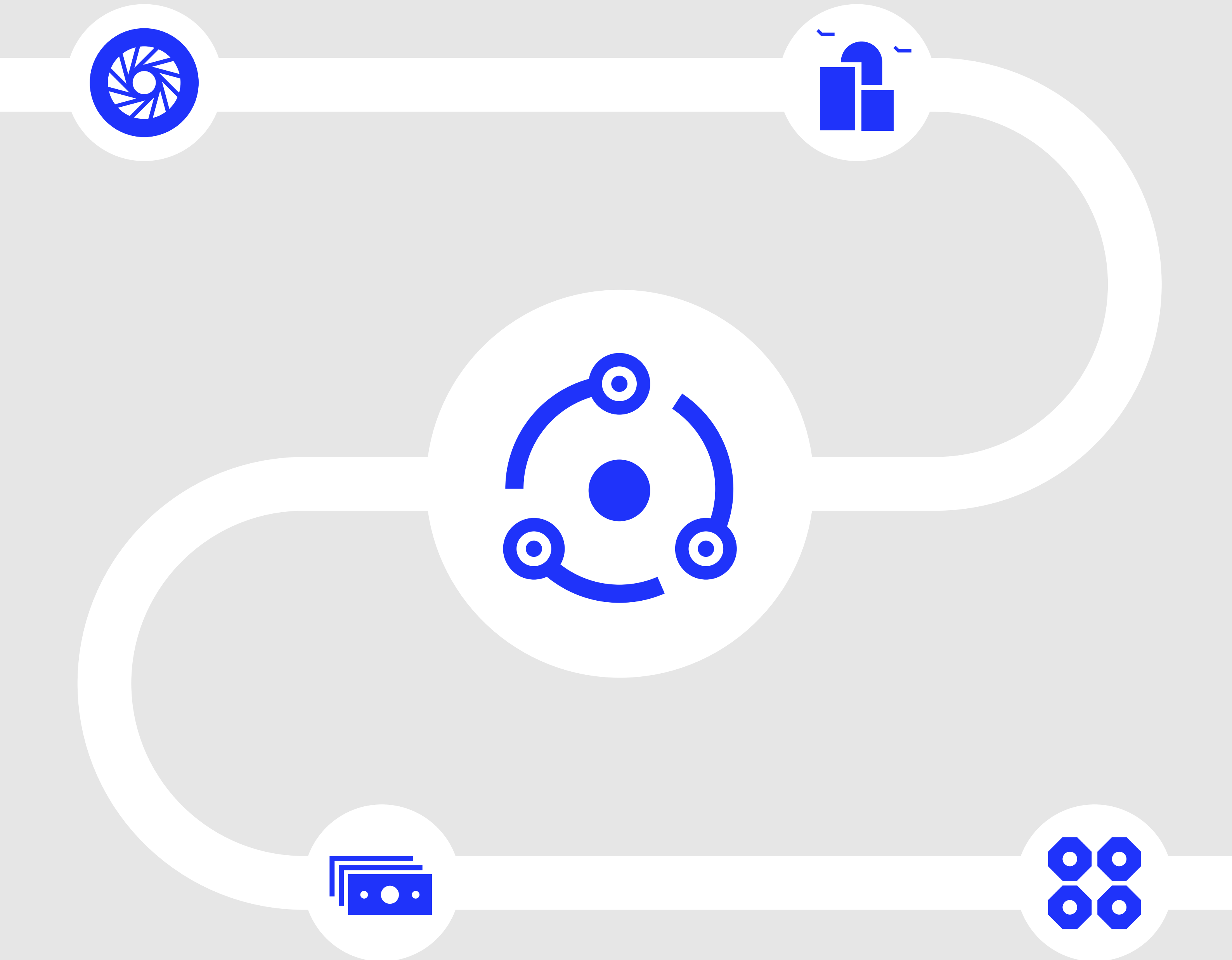
September 2024

Executive Summary
Net Zero CO_2 Emissions Roadmap

IATA Sustainability and Economics



The Net Zero Roadmaps

In 2021, the aviation industry took the momentous decision to commit to reaching net zero carbon dioxide (CO_2) emissions by 2050 [1]. At the 41st Assembly of the International Civil Aviation Organization (ICAO) in October 2022, Member States adopted the Long-Term Aspirational Goal (LTAG) for international aviation of net-zero carbon emissions by 2050 [2]. Governments and the aviation industry took these steps to ensure that international aviation continues to develop in a sustainable manner in recognition of the vital role which it plays in global economic and social development. ICAO further acknowledged international aviation's contribution to 14 of the 17 United Nations Sustainable Development Goals (SDGs), including SDG 13: "Take urgent action to combat climate change and its impacts".

The importance of this co-commitment between governments and the aviation industry to achieve net zero CO_2 emissions by 2050 is difficult to exaggerate because airlines have scant control over most of the developments upon which success will hinge. Airlines do not produce their own fuel and multiple parties own or operate the corresponding supply chain. Airlines do not build aircraft but either buy them from Original Equipment Manufacturers (OEM) or lease them from lessors. Airports have varying ownership and operating models. Air Traffic Management (ATM) is under government responsibility who designate their Air Navigation Service Providers (ANSP). Ground handlers may or may not be airline owned. Every participant in this complex chain which together allows people and products to flow freely in our global economy must be united in this quest to achieve net zero emissions, and equally called upon to fulfil its obligations in order to bring about this historic transformation of international civil aviation. Aviation's options to mitigate its climate impact are constrained by three main variables:

- **Aircraft have a long useful life.** Aircraft remain in service for 20-30 years, and the fleet renewal process therefore spans decades.

- **Aircraft have lengthy development times.** Due to strict certification requirements and uncompromising safety standards, the development of aircraft incorporating the latest technology and the associated certification times can take up to 10 years, further delaying the implementation of technological advancements.

- **Aircraft use a large amount of energy.** Aircraft move passengers and goods faster than any other type of transport. Moving passengers at nearly 1,000 km/h and elevating them 10+ km above the ground requires a considerable amount of energy. Very few energy storage solutions can provide the energy-to-weight ratio that fossil fuels can, at this point in time.

These constraints make aviation one of the hardest sectors to decarbonize. As other sectors speed up their journeys to reach their net-zero carbon objectives, aviation could lag, and increase its share of the total global emissions. To avoid this, there are three levers of action that the sector can use to reduce, neutralize, and eliminate its emissions:

Reduce aircraft energy use. More efficient aircraft that use less energy will emit less CO_2 even if powered by conventional aviation (fossil) fuel. While the sector transitions to other fuels (Sustainable Aviation Fuel (SAF), hydrogen, or batteries), reducing the energy consumption in flight and on the ground will directly translate into energy savings all along the supply chain of the fuel. Furthermore, improvements in air traffic management and other operations at the airport will provide additional opportunities to reduce energy consumption.

Change the fuel and reduce its carbon footprint. More than 99% of the aviation fuel used today is from fossil origin. For aviation to reach and sustain net zero emissions by 2050, this fuel must be replaced by net-zero and true-zero alternatives. Any fuel or energy storage solution used in flight must be manufactured on the ground (whether this be fossil or renewable kerosene, batteries, or hydrogen). Refineries require energy to convert crude oil into jet fuel, SAF producers need energy to collect and process the feedstocks and convert them into a liquid fuel, and green hydrogen providers require energy to make hydrogen from water. The electricity required to make aviation fuels must be decarbonized from today. As aviation transitions to new energies, emissions may move upstream in the supply chain, and only a holistic fully carbon neutral solution will help the sector reach net zero CO_2 emissions. New solutions which enable retrofitting aircraft to be compatible with new fuels could accelerate this transition. Nevertheless, given their drop-in characteristics, SAF solutions are still expected to provide the majority of aviation's carbon abatement through to 2050.

Re-capture all the carbon dioxide which could not be avoided. As the sector moves through long development cycles and technological programs to enable the uptake of new fuels for aircraft, airlines will continue to rely on conventional fossil-based aviation fuel for the near- to mid-term. Many sustainable replacements of conventional aviation fuel will neutralize the in-flight emissions, but these will still have a residual carbon footprint associated with their manufacture. The CO_2 emitted from the combustion of fossil fuels and the manufacture of near carbon-neutral fuels will need to be neutralized by atmospheric carbon capture and credible carbon offsets.

IATA's five Net Zero Roadmaps are set out to articulate in detail the developments that are necessary to bring about sustainable aviation on the 2050 horizon, identifying important milestones on the way. The roadmaps chart a possible course towards net zero for the aviation industry, by leveraging all the possible technological, infrastructural, operational, financial, and policy levers in an integrated way. Furthermore, the roadmaps are scenario dependent, and the scenarios defined today might differ from the pathway the sector will follow, as this will be influenced by the ever-advancing research in all the five areas that the roadmaps address: aircraft technology, energy infrastructure, operations, finance, and policy. As a result, the roadmaps are dynamic in nature and will be updated regularly, as were the Finance and Policy roadmaps in September 2024. Chart 1 depicts how the five Roadmaps cover the three levers to reduce, neutralize or eliminate emissions.

Overall, the Roadmaps show it is possible to achieve the net zero CO_2 emissions goal in civil aviation by 2050. Success will depend critically on early policy support, which should be globally harmonized and technology agnostic, and include targeted financing to accelerate the transition.

The greatest challenge in terms of making civil aviation sustainable is not related to any specific solution, but to the pace at which it needs to happen.

Chart 1: The five net zero roadmaps and the areas which they contribute to

	Aircraft Technology Roadmap	Operations Roadmap	Infrastructure Roadmap	Policy Roadmap	Finance Roadmap
Reduce in-flight energy use	○	○		○	○
Change the fuel	○		○	○	○
Re-capture emitted CO_2			○	○	○

Source: IATA Sustainability and Economics

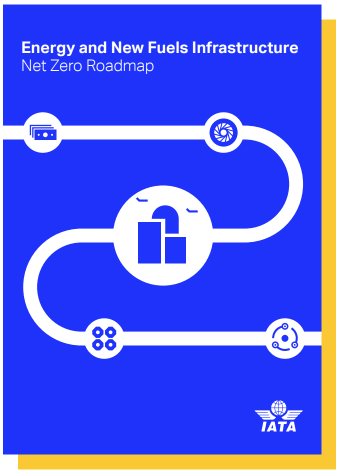
The Aircraft Technology Roadmap

Most emissions in the aviation sector come from fuel burn and the Aircraft Technology Roadmap addresses the critical issue of how new aircraft and engine technologies can deliver more efficient aircraft which use less energy. Jet fueled aircraft could still gain15-20% in terms of efficiency compared to the best technology available today. Efficiency improvements through new aircraft technology could avoid 125-140 million tonnes (Mt) of CO_2 by 2050, cutting aviation in-flight energy needs by 7-10% by that year. These new next generation aircraft will be enabled to operate on 100% Sustainable Aviation Fuels (SAF).

Further development milestones include revolutionary aircraft which will be operated with hydrogen or batteries, fully eliminating carbon emissions from their operations. These aircraft could avoid an extra 35-125 Mt of CO_2 by 2050, depending on how fast they enter the market, how far they can fly, and how many passengers they can carry on board.

The milestones we have identified are backed-up by announced investment and demonstrator programs, including new engines, aerodynamics, aircraft structures and flight systems. Technologies will advance on the Technology Readiness Level (TRL) scale from individual technology testing to system demonstrators, to full-flight tests. All these steps will need to occur before a new aircraft is ready for entry into service. As such, there are multiple possible technology development pathways for more efficient and zero-carbon aircraft, each equally dependent upon the need to proceed at an unprecedented pace to maximize their effect on emissions reductions by 2050.

The Energy and New Fuels Infrastructure Roadmap



The next generation of aircraft will require SAF infrastructure upstream from the airport (for feedstock collection, refining, and blending) to substitute conventional aviation fuels with SAF. Our central scenario requires SAF to represent 80-90% of aviation fuel use in 2050, reducing aviation emissions by 62%. IATA's analysis supports estimates of 5,000-7,000 biorefineries required for aviation by 2050. Most SAF pathways will also require hydrogen for their production. In fact, in all our scenarios, most of the hydrogen demand by 2050 will be used for SAF production. The sector could require close to 100 Mt of hydrogen by 2050, an amount comparable to all hydrogen production worldwide in 2023.

A smaller share of the hydrogen used in aviation in 2050 (4-14 Mt) will be used in its pure form to power zero-carbon aircraft. Hydrogen aircraft will require additional infrastructure at the airport to store and distribute the new fuel as well as new procedures and ground supporting equipment.

Carbon capture infrastructure will also be needed to remove residual CO_2 from the atmosphere, as well as to use atmospheric CO_2 as a feedstock for SAF. More than 700 Mt of CO_2 will need to be extracted from the atmosphere with carbon capture facilities. A common requirement to all solutions will be renewable energy which will enable the sector to meet its in-flight energy demand by 2050 with fuels which need to be manufactured on the ground.

The Operations Roadmap

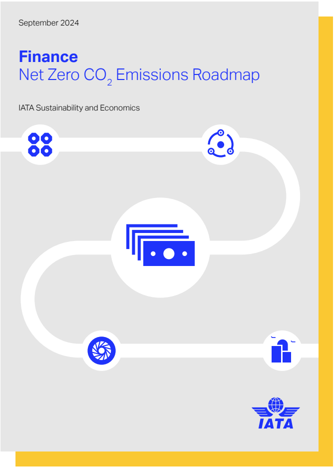
Air Traffic Management is a key part of national infrastructure, and it needs to be prioritized in the overall strategy for bringing about sustainable civil aviation. Without alignment of the investments plans of airlines, airports, and ANSPs, other operational benefits will remain elusive, and any new ATM program will not deliver its promised objectives. Moreover, airspace is increasingly a scarce resource as well as a common resource and needs to be addressed as such.

Today, the ATM system features inefficiencies which result in unnecessary fuel burn and emissions. While organizational and institutional efficiency gains will not tip the balance regarding aviation's CO_2 emissions – that pivotal role clearly lies in the new energy space – the exciting part with operations is that efforts could make a difference in the very near term.

Several approaches can be used to accelerate the implementation of the different elements included in the roadmap:

- Use of local and regional projects as proof of concept for the development of global standards and highlighting benefits and costs.
- Environment and performance benchmarking to measure progress and showcase best practices for implementation towards Trajectory Based Operations (TBO).
- Regional and local consortia for implementation which ensure that the needs of airspace users are considered in the planning and implementation phase.

The Finance Roadmap (Sept 2024 update)



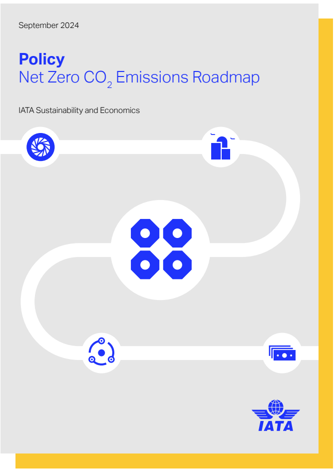
The Finance Roadmap offers a detailed view of the required investments to reach net zero CO_2 emissions by 2050, and the costs involved to airlines in procuring the new solutions. Identifying the number of new biorefineries that need to be built and highlighting that their product output will benefit all industries' energy transition, should help focus minds and promote the unity of purpose among policymakers that is necessary for a successful transition.

Highlights include:

- Required Average Annual Investments: to reach net zero by 2050, the annual average capex needed to build the new facilities over the 30-year period is about USD128 billion per year, in a best-case scenario, significantly less than the estimated total sum of investments in the solar and wind energy markets at USD280 billion per annum between 2004 and 2022. Success would be facilitated by governments redirecting subsidies away from fossil fuels and toward renewable energy production, of which SAF is just one type of product.

- Annual Transition Cost, meaning the cost that comes on top of that of jet fuel as a result of procuring SAF, hydrogen, and other key levers, is estimated at USD1.4 billion in 2025. In 2050, the transition cost could be as high as USD744 billion, based on IATA's analysis. These numbers highlight the need for speed and scale in bringing solutions to market so that net zero CO_2 emissions can be achieved.

The Policy Roadmap (Sept 2024 update)



The Policy Roadmap emphasizes the importance of strategic policy sequencing and addresses the need for global collaboration, including beyond the aviation sector. The recommendations recognize that there is no one-size-fits-all solution, and policies must ensure that all countries can participate in the future global Sustainable Aviation Fuel (SAF) market.

Highlights include:

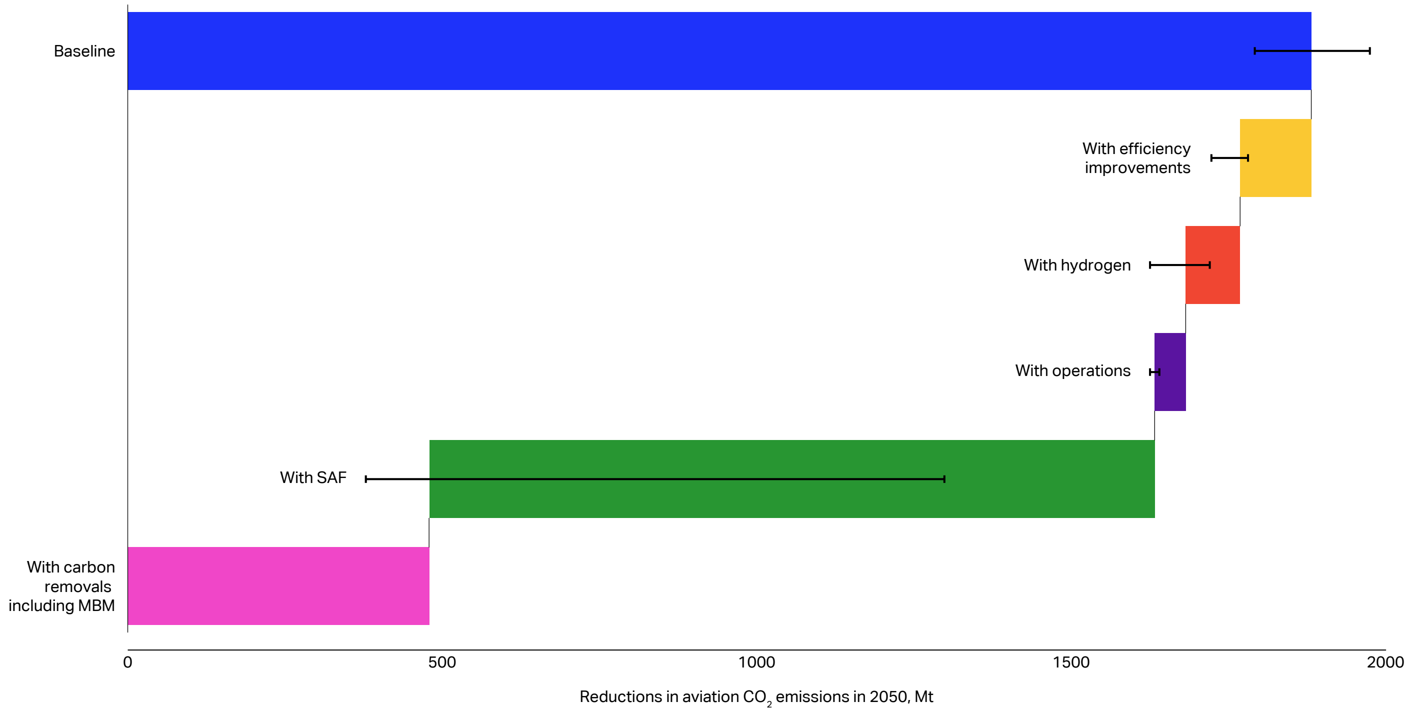
- Immediate Action is needed to unlock the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) Eligible Emissions Units (EEUs) and prioritizing SAF in the product mix at refineries.

- Strategic Policy Sequencing combining technology-push and demand-pull measures will be critical. Moreover, governments must foster global, liquid, and transparent markets for cleaner aviation energy.

- Transformative Collaboration between governments, the aviation sector, and across all sectors to remove existing barriers and promote investment in new technologies, SAF, and infrastructure. This recognizes that air transport's decarbonization is part of the broader global energy transition. The creation of a global SAF accounting framework is also essential to ensure transparency and prevent double counting of SAF's environmental benefits. Addressing the current fragmentation in certification processes for SAF and carbon offsets should be part of that endeavor as well.

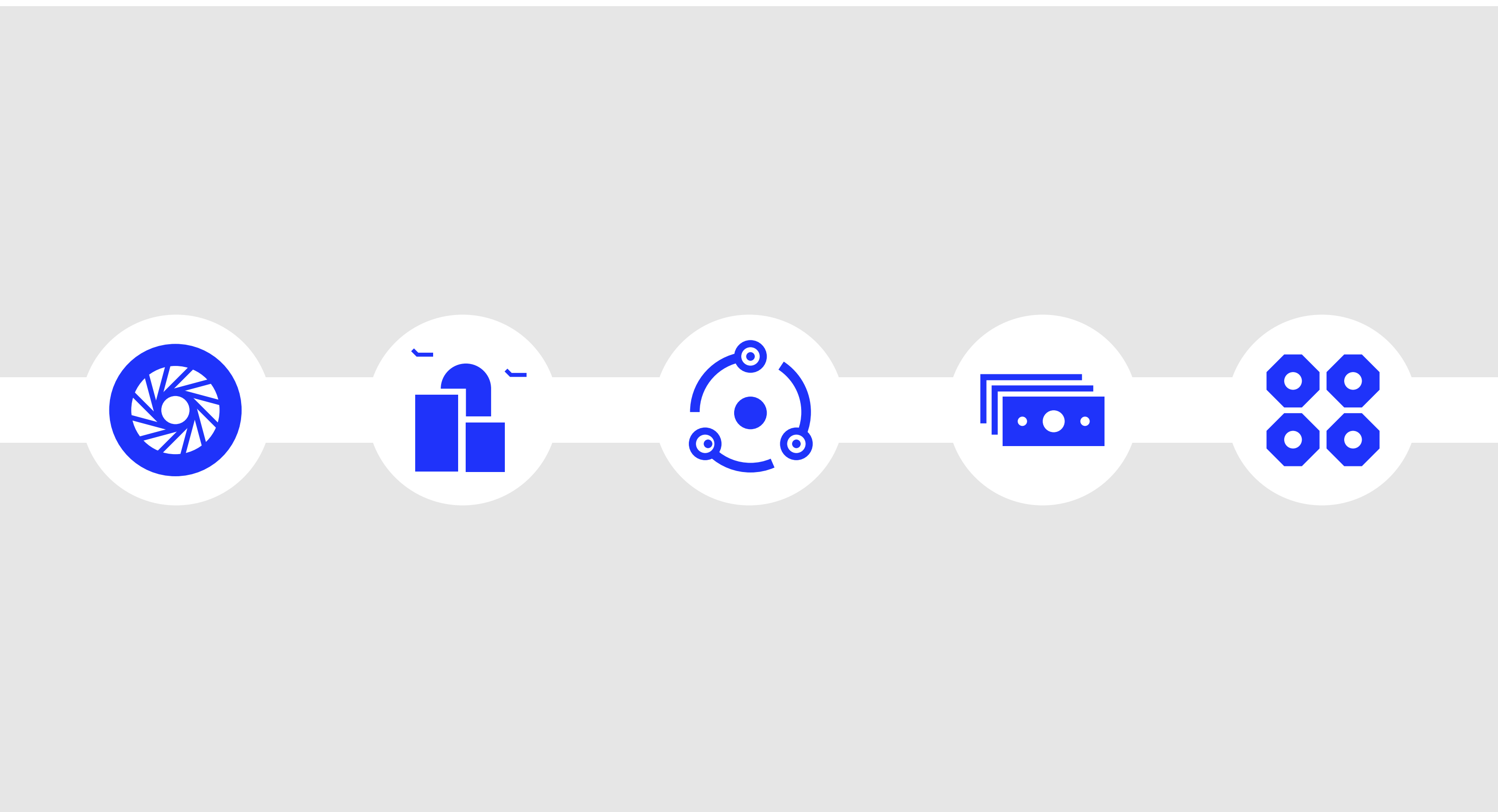
The actions outlined in the five roadmaps can progressively bring us to Net Zero CO_2 emissions by 2050 (Chart 2). IATA's targeted scenario is shown in the colored bars, while the black lines illustrate the potential range of outcomes, depending notably on the extent and pacing of financing and policy support. In all the scenarios modeled, even that where SAF fully replaces traditional jet fuel, there will be residual emissions which will need to be removed using carbon capture.

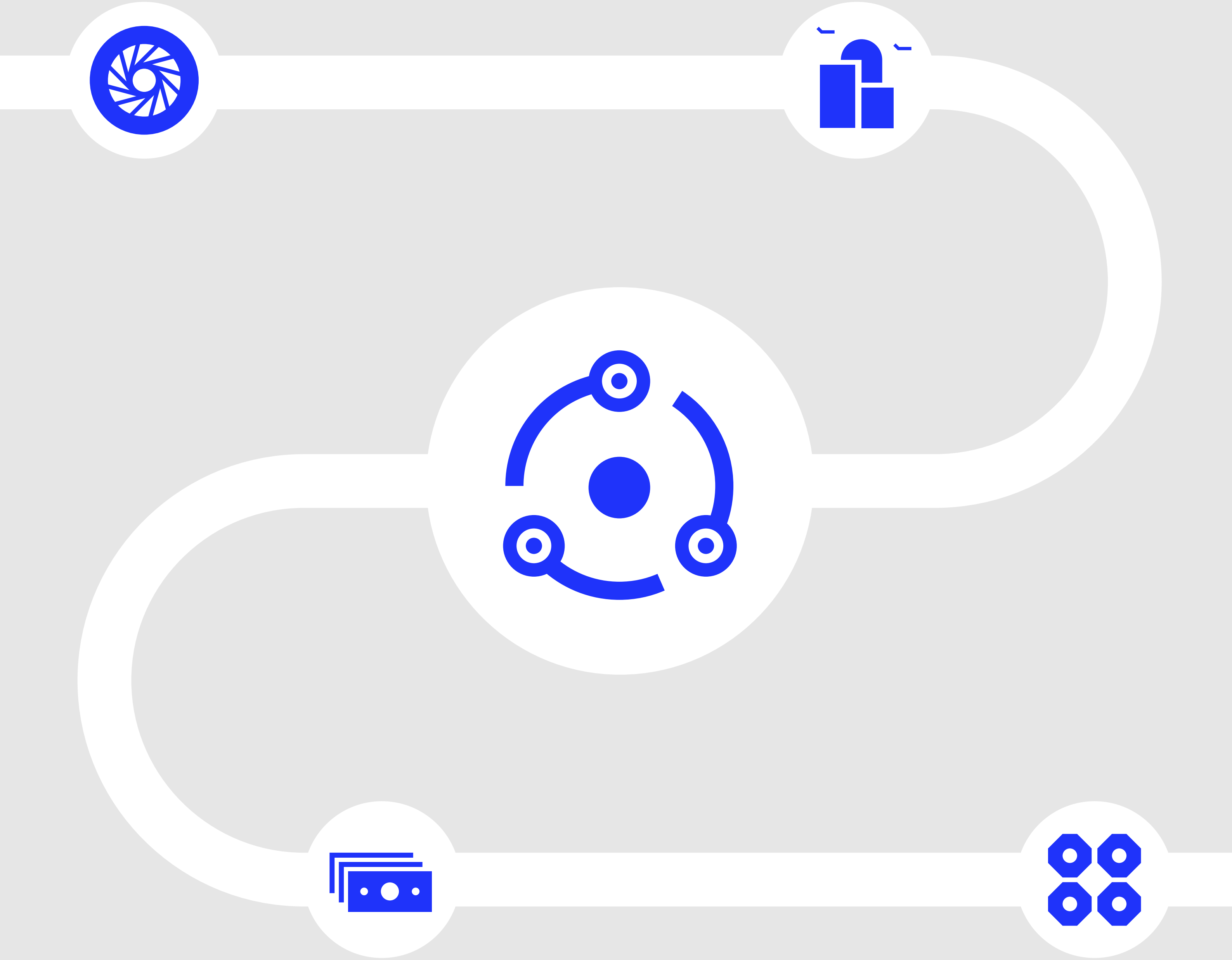
Chart 2: Reduction in aviation CO_2 emissions in 2050 achieved through the different levers of action. The solid bar indicates the central case and the black lines indicate maximum and minimum reductions based on the scenarios modeled.



Source: IATA Sustainability and Economics, ICAO LTAG SAF availability scenarios

[1] https://www.iata.org/en/iata-repository/pressroom/fact-sheets/fact-sheet----iata-net-zero-resolution
[2] https://www.icao.int/environmental-protection/Documents/Assembly/Resolution_A41-21_Climate_change.pdf





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