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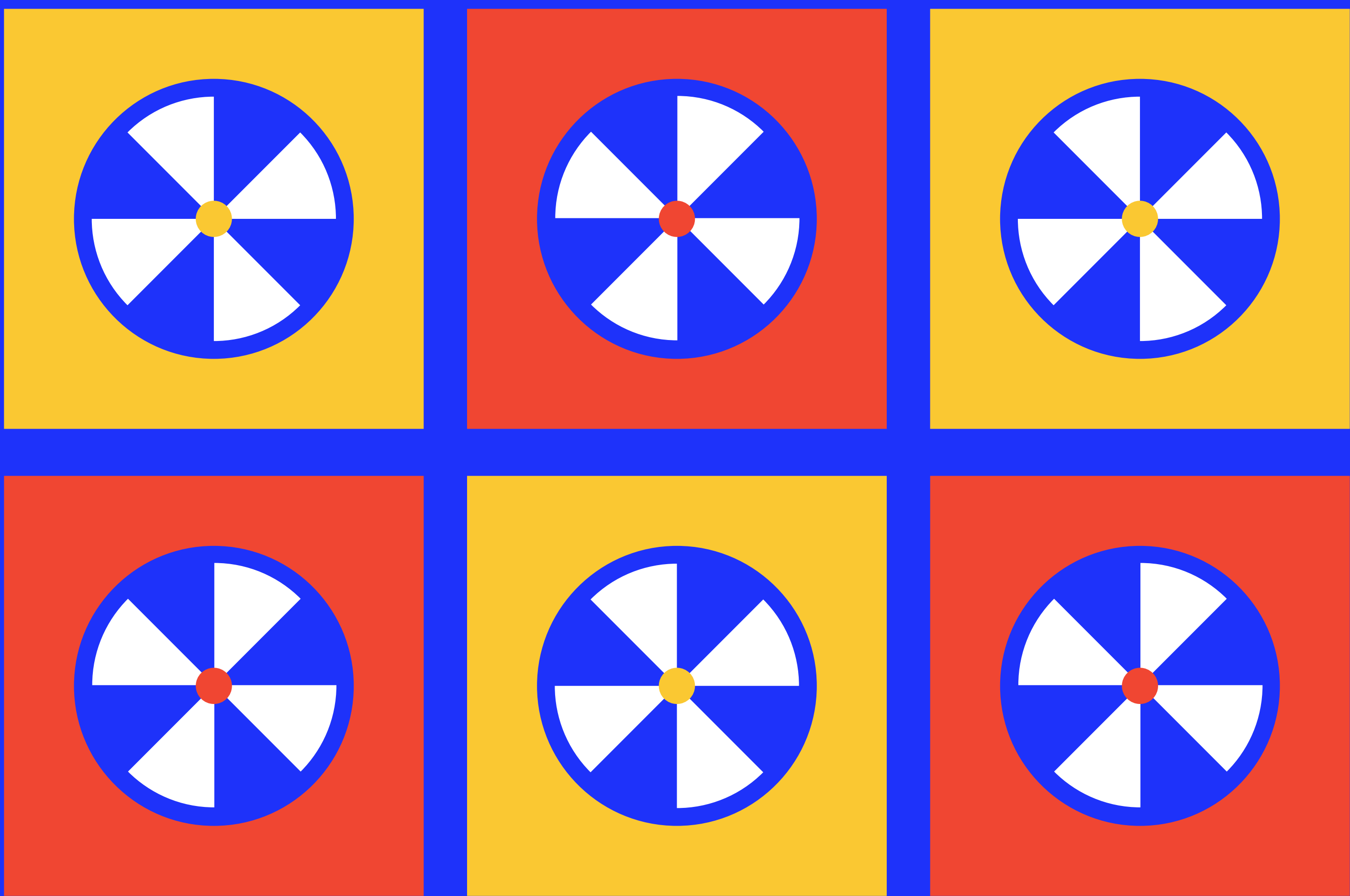
Direct Air Capture (DAC) and Storage (DAC+S)

Essential Components to Achieve Net Zero Carbon in Aviation



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Introduction

Aviation's ambitious climate target of net zero carbon emissions by 2050 (Fly Net Zero) is focused on reducing in-sector greenhouse gas (GHG) emissions and recognizing the need to counterbalance the remaining emissions with permanent removals. The Air Transport Action Group's (ATAG) Waypoint 2050 and IATA's Fly Net Zero strategy set out the pathways to decarbonize, highlighting the requirement for a combination of different decarbonization levers to achieve this goal. Primarily, Fly Net Zero is expected to be achieved by operational efficiency improvements, the deployment of radical new aircraft technologies, and the use of Sustainable Aviation Fuels (SAF) as the main solution.

The industry is confident that these decarbonization levers will provide long-term solutions that ensure the sustainable growth of the aviation industry. But the transition can only be achieved through partnerships between the industry, governments, and the public/private sector over the coming decades.

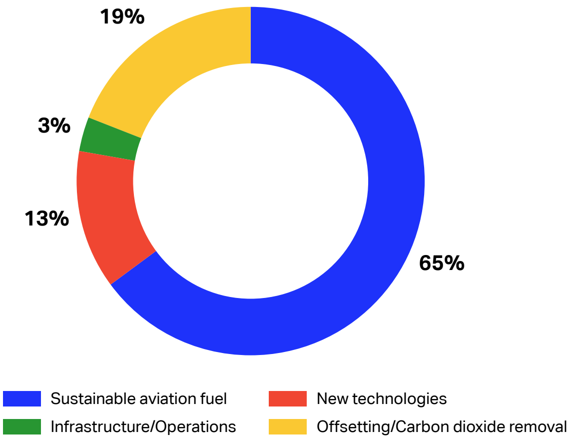
Although the 2050 goal is net zero, the sector recognizes that between today and 2050 out-of-sector carbon offsets must be utilized to reach interim targets. This includes ICAO's Carbon Offsetting Reduction Scheme for International Aviation (CORSIA) mechanism, the only global market-based measure to fill any remaining emissions gap until all investments into in-sector abatement have matured. Investments in high quality carbon offsets are frequently linked to a range of socio-economic co-benefits that help address a variety of United Nations Sustainable Development Goals, such as creating jobs, improving the health of local communities, and helping with gender equality.

The use of high-quality carbon offsets under CORSIA will be critical to achieve carbon neutral growth, with airlines investing in offset projects around the world that avoid, reduce, or remove emissions from the atmosphere. Although offsets may be used in the interim, it is widely recognized that, in line with the Oxford Offsetting Principles, a gradual shift toward permanent removals rather than offsets will be required to counterbalance residual emissions and meet the net zero commitment.

IATA's net zero strategy outlines the share of the main contributions toward aviation's bold target of net zero CO_2 emissions by 2050. The largest share of emissions reduction will come from the use of SAF (65%). This is followed by emission neutralization through offsetting (19%), or carbon removals.

Carbon Dioxide Removals (CDR) offer a pathway for an in-sector and net-zero compatible counterbalance to emissions that are technically or economically unavoidable. A clear scientific consensus suggests carbon removals are especially suitable for emissions from hard-to-abate sectors, such as the aviation industry.

Contribution to achieving Net Zero Carbon in 2050



There are a variety of ways to realize CDR, from short-lived methods based on photosynthesis and subsequent carbon storage in biomass to permanent removals using Direct Air Capture and Storage (DAC+S) and BioEnergy and Carbon Capture paired with permanent geological Storage (BECCS). When CDR is delivered using DAC technology and geological storage, it results in permanent removal. DAC technology is a viable option for an aviation in-sector application discussed below.

DAC works by capturing carbon dioxide directly out of the air. Ambient air is directed through a filter, where it is captured using a chemical sorption process to produce a high-purity CO_2 stream. The CO_2 can then be permanently sequestered in geologic reservoirs, resulting in permanent carbon dioxide removal.

BECCS, meanwhile, is a combination of point source carbon capture and the capture of biogenic feedstocks. These permanent carbon dioxide removals have been highlighted by the Intergovernmental Panel on Climate Change (IPCC) and leading experts as necessary to counterbalance hard-to-abate residual emissions and align efforts to limit global temperature rise as set out under the Paris Agreement.

As outlined above, by 2050, residual aviation emissions should still be expected. The aviation's sector decarbonization strategy heavily relies on the adoption of SAF and these fuels will have residual emissions associated with them. The remaining emissions can be addressed through atmospheric carbon capture via DAC or biogenic uptake, or by advanced SAF feedstocks, such as Power to Liquid (PtL) fuels that will rely on CO_2 capture (via DAC) and green hydrogen. By investing in permanent carbon dioxide removals early, airlines can accelerate their path to net zero while driving down costs on the technology learning curve. This will help to enable cost-efficient DAC technologies when they are needed most to provide i) the essential service of permanent removals and ii) a robust input stream for PtL SAF.

Carbon Removal Pathways for Aviation

The use of DAC as a carbon dioxide removal technology is a viable option for the aviation sector, provided such challenges as capacity and high costs can be addressed in a timely manner. The technology at scale has only been explored over the past few years, with current operations remaining on a kilotonne scale. The first megatonne- scale facilities have started construction, however, and are expected to become operational by 2025. Furthermore, several DAC providers have outlined credible roadmaps to reach gigatonne capture scales by 2050. As a result, the costs for removing CO_2 (at present between $600 and $900 per tonne), are ultimately expected to be comparable to the costs of other aviation decarbonization pathways, such as SAF, on a $/tonne abated basis. Most importantly, data from other technological processes make it clear that costs should fall with the deployment and scaling of technologies and a corresponding improvement in processes and value chains.

Pathway 1:
DAC as a Carbon Removal Tool

Most alternative fuels will yield residual emissions either due to production emissions or blend limits. The remaining emissions need to be counterbalanced by removing and durably storing an equivalent amount of CO_2 to reach overall net zero carbon. Carbon dioxide removal activities are a flexible tool to complete the transition to net zero air travel. Early investment in DAC as a CDR technology will help to rapidly move the technology down the cost curve and accelerate affordable, sustainable low carbon fuels using DAC CO_2 as a feedstock (further covered in option 2 below).

Not all removals are created equal and, to maintain environmental integrity, any compliance or voluntary pathway to CDR must be based on high integrity technology, featuring long-term (geologic time scale) storage. This requires removals to be verifiable, permanent, net (total emissions removed versus emitted), and based on a robust life cycle assessment. Fungibility of removal credits across market types (with strict rules to avoid double counting) will also help to unlock capital for carbon removal projects as the addressable market grows.

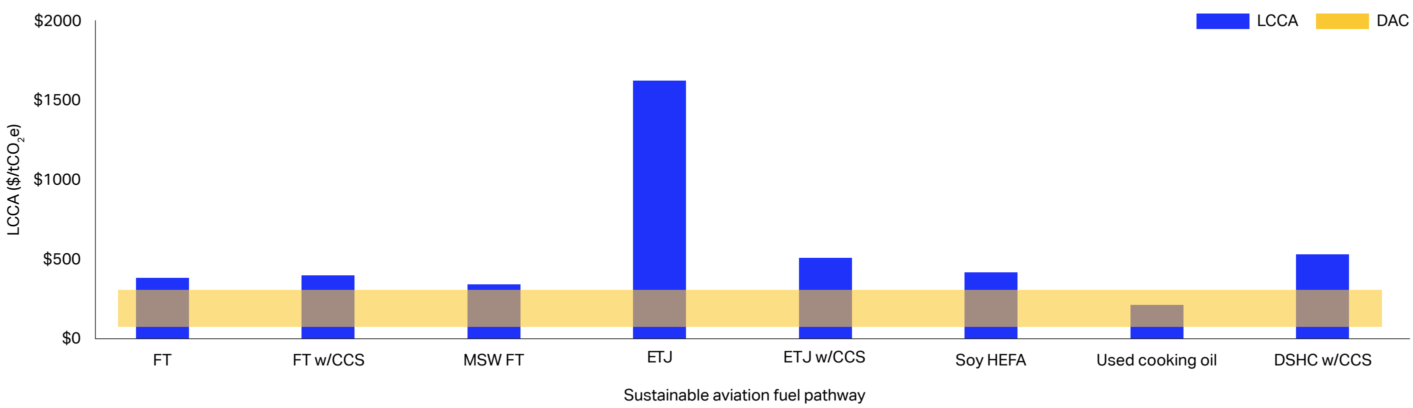
Recent analysis suggests that even a megatonne scale DAC facility can, under optimal circumstances, compete on a cost per tonne basis with other in-sector abatement options. Rather, the bigger challenge is scaling up DAC capacity quickly enough to ensure that sufficient volumes are available to reach net zero by 2050, as DAC capacity will be required for both removals and as feedstock for synthetic fuels.

Because removals are predicted to become a cost competitive decarbonization pathway for aviation, the sector can act as a catalyst to develop these technologies, driving down costs to prepare the industry for when the technologies are needed in much larger quantities to achieve net zero.

Commitment to offtake will be essential so that DAC technology can grow and mature to meet the increasing demand from the aviation sector and therefore should be considered a strategic investment for airlines.

Offtake agreements and early investment by airlines and corporates will create demand and spur investment in technology while generating broader acceptance with governments and the public.

LCCA between SAF pathways compared to First-of-a-Kind DAC+S facility



FT= Fischer Tropsch CCS=Carbon Capture & Storage MSW=Municipal Solid Waste ETJ=Ethanol to Jet HEFA= Hydroprocessed Esters and Fatty Acids DSHC=Direct Sugars to Hydrocarbons

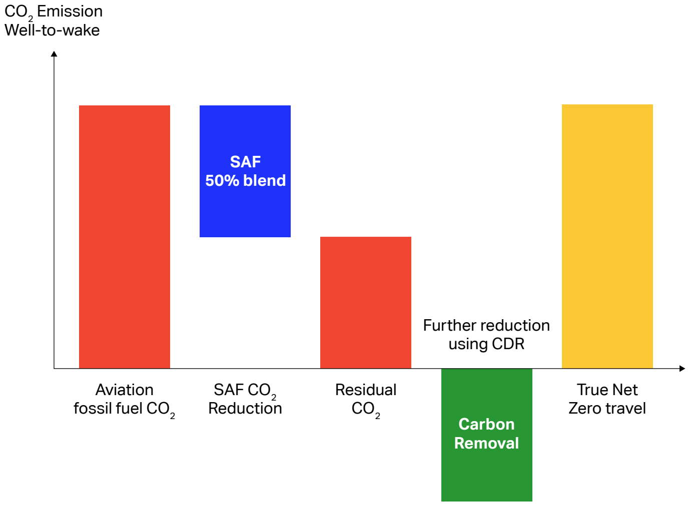
Pathway 2:
DAC Use in the Production of Power-to-Liquid (PtL) Fuels

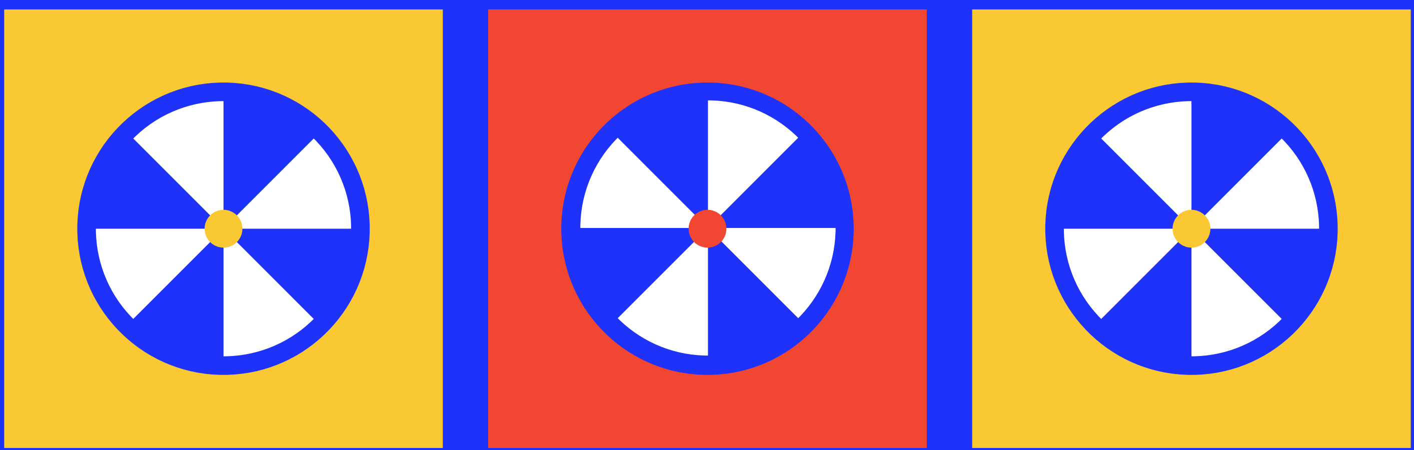
SAF will be the major contributor to aviation's decarbonization efforts. IATA's Fly Net Zero commitment suggests that 65% of emissions reduction will be achieved by shifting away from conventional Jet A-1 toward SAF. Furthermore, the Waypoint 2050 analysis foresees that by 2050 over half of all SAF production capacity will use PtL pathways.

PtL fuels are synthetically produced hydrocarbons. The main energy source and feedstocks for the production are electricity, water, and carbon dioxide. To produce the hydrocarbons, renewable electricity is used to split H2O into its component hydrogen and oxygen. Then, the hydrogen is combined with CO_2 (stemming from DAC) to produce a synthesis gas. The gas is then further processed into kerosene.

DAC offers a scalable and sustainable path to source atmospheric CO_2 as a feedstock that can be combined with green hydrogen and renewable electricity to produce near carbon neutral fuels. DAC-derived carbon feedstocks do not rely on flue stack CO_2 or arable land for biomass and therefore do not face the supply constraints of other SAF feedstocks. DAC-based fuels should therefore be recognized by policymakers as soon as possible to facilitate their phase-in when economically practicable.

Net Zero Illustration Using DAC





Achieving DAC-Based Carbon Dioxide Removals and SAF—the Role of Governments, Airlines, and Corporates

To make the investment and use of DAC technology for both CDR and SAF a viable option for aviation, enabling policies and airline and corporate champions are needed.

Government incentives can trigger more investment and the scaling-up of DAC technologies to achieve cost reduction while addressing the capacity constraints that exist. On the policy front, governments and international organizations must recognize the need for an immediate scale up of DAC technology to make it part of the aviation decarbonization strategy. Related actions may include:

- Recognition of permanent carbon dioxide removals as an in-sector decarbonization pathway and a viable part of aviation's decarbonization roadmap.
- Acknowledging that the decarbonization of aviation should be founded on a robust allocation-based, cradle-to-grave lifecycle assessment that accounts for all CO_2 molecules and their origin.
- Provision of clear policy that evaluates SAF based on their carbon intensity reduction performance as informed by a robust and complete lifecycle analysis. This is expected to lead to substantial volumes of DAC-based SAF by 2030 and to DAC-based SAF being a significant portion of total SAF by 2050.

Besides government incentives, airlines and corporates play an equally important role in increasing DAC-based options within the aviation sector. Related actions may include:

- Engaging early with DAC-based CDR as an efficient way to scale up DAC capacity for both removals and fuels.
- Incentivizing DAC deployment by direct purchases or collaborative, advanced market commitments.
- Strategically securing supply via long-term contracts or acquiring options for future supply.
- Pioneering work for the deployment of DAC-based SAF in the form of lighthouse projects.

Conclusion

CORSIA and the investment in high quality eligible carbon offsets will be essential for the aviation sector to reach net zero by 2050. This has been confirmed by ICAOs Long Term Aspirational Goal and the Fly Net Zero commitment. In general, investments in carbon offsets are considered an important contribution to climate financing. For offset projects around the world to achieve the required CO_2 reductions, and to support local communities with a range of social and economic co-benefits, these funds are urgently needed so that projects can continue to operate and generate the expected benefits for the environment.

When the step up in carbon removal technology and corresponding drop in costs is combined with action from public and private players, a transition from carbon avoidance to technology-based carbon removal should occur. This will offer aviation the opportunity to invest in solutions that benefit the sector directly, including the production of SAF. For the sector to become truly net zero, carbon removals will play an integral role alongside the other in-sector decarbonization levers.

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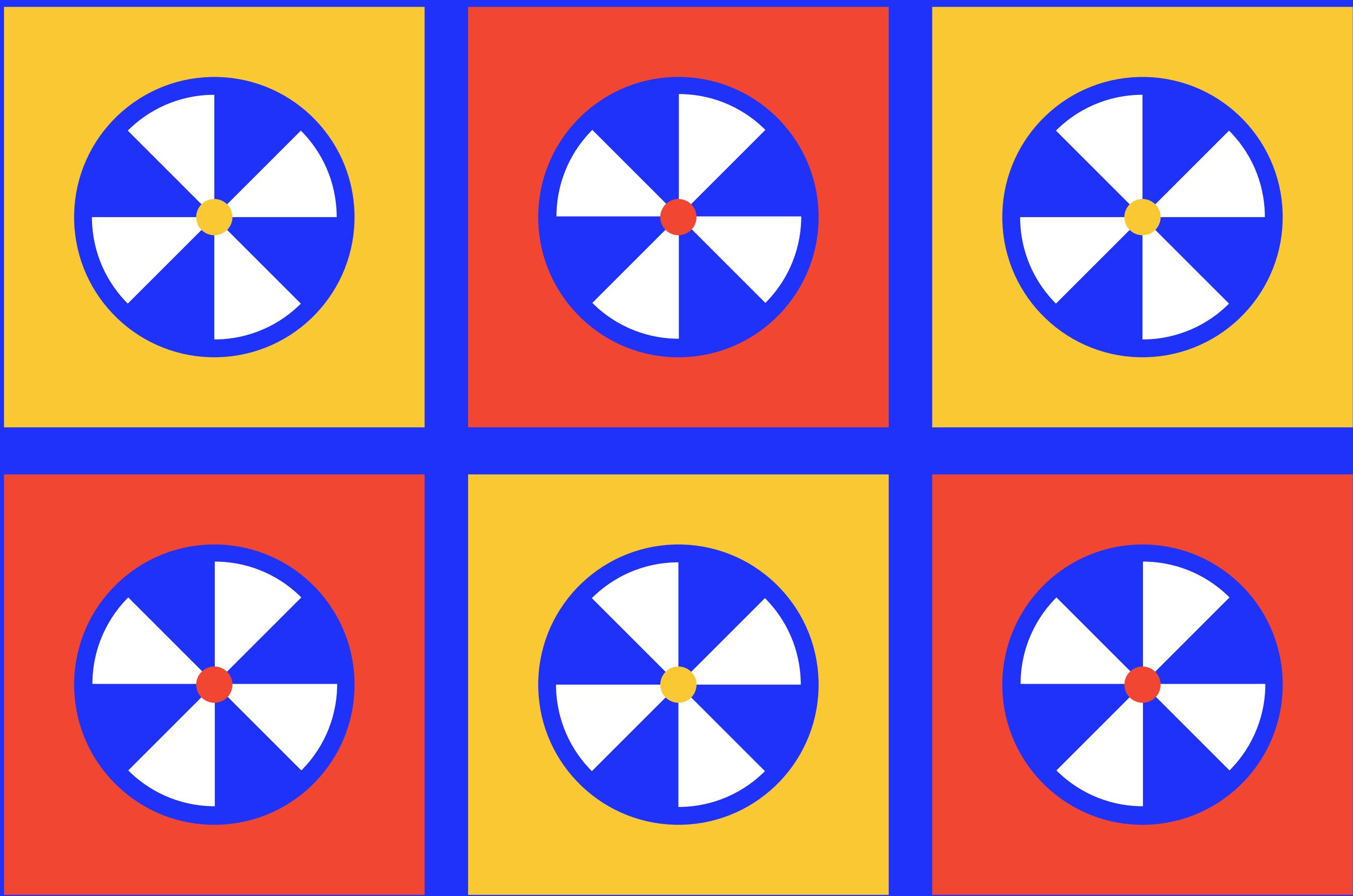

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