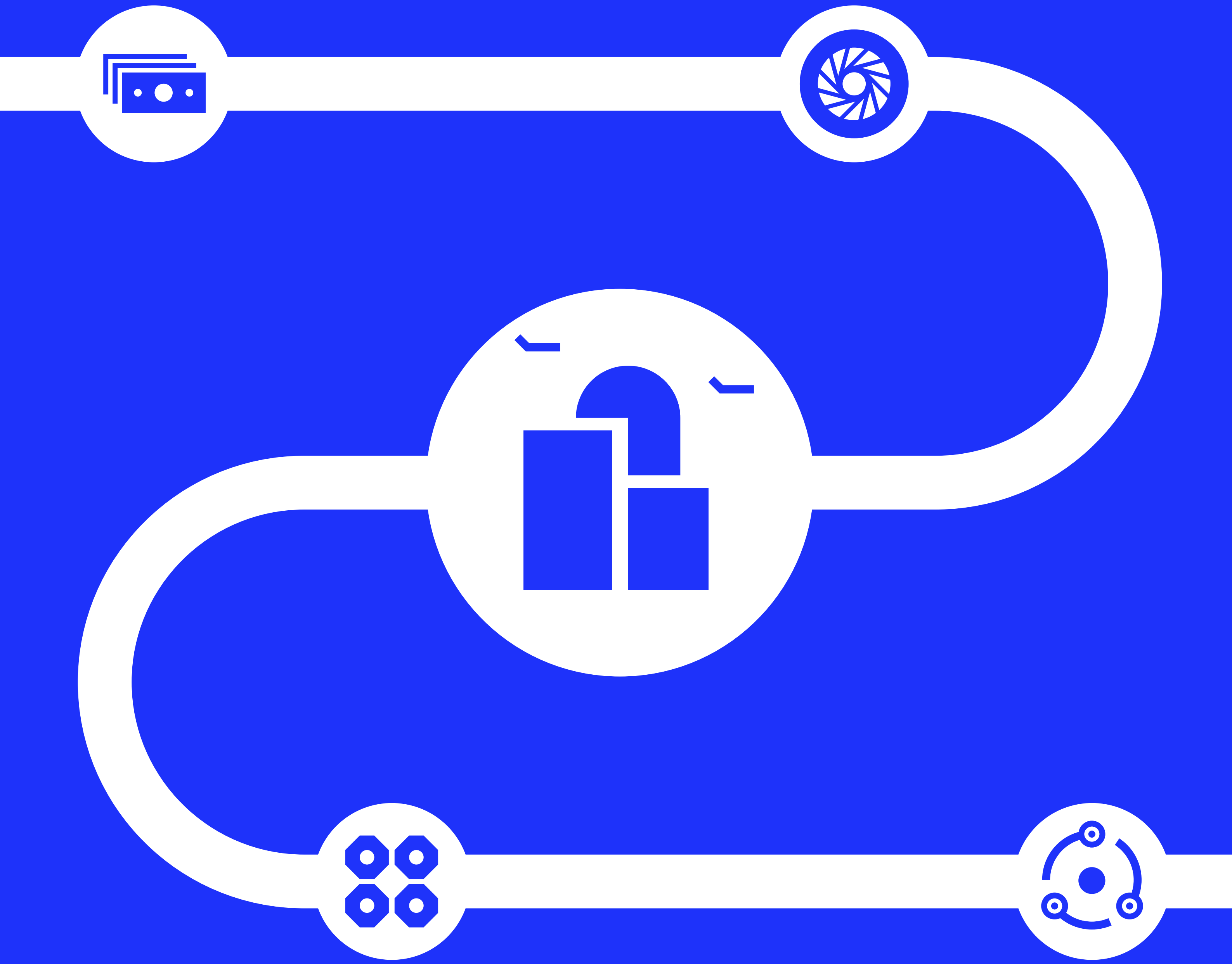
Energy and New Fuels Infrastructure

Net Zero Roadmap



Introduction

The aircraft technology roadmap highlights the need to develop more details on the pathway that aviation can follow to reach net zero CO_2 emissions by 2050. The roadmap explains how the combination of aircraft's long useful life, their long development times and the large energy density they need, puts constrains on the sector's ability to achieve fast decarbonization.

Furthermore, three levers of action are identified: Reduce aircraft energy use, change the fuel and and re-capture all the carbon dioxide which could not be avoided.

This report focuses on the infrastructure roadmap to enable two of the three levers: Changing the fuel and re-capturing emitted CO_2 emissions. The infrastructure roadmap provides milestones for the ground infrastructure required to enable the use of net zero and zero-carbon aircraft.

Infrastructure Roadmap

This Infrastructure Roadmap follows the Aircraft Technology Roadmap and sits in our framework of five roadmaps as per the illustration below.

A next generation of aircraft will require Sustainable Aviation Fuel (SAF) infrastructure upstream of the airport (for feedstock collection, refining, and blending) to substitute conventional aviation fuels by SAF. Hydrogen aircraft will require infrastructure at the airport to store and distribute the new fuel as well as new operational procedures and ground supporting equipment. A common requirement to all solutions will be the availability of 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 Infrastructure Roadmap shows specific milestones to be achieved to enable the operation of next generation aircraft and the fuels that will power them.

The need for green energy

While this document does not provide a specific roadmap for low-carbon electricity generation, this is an absolute requirement for aviation to reach net zero CO_2 emissions by 2050. The International Energy Agency (IEA) estimates that global electricity demand could be 75%-150% higher than today, depending on the decarbonization pathway followed [4]. Making alternative aviation fuels could increase the industry's electricity demand by up to 10,000 TWh (36EJ) by 2050, adding roughly the equivalent of half of all electricity produced globally in 2021 [1] [2] [3]. Aviation could require, by 2050, 20% of the world's electricity production. This gives a sense of the magnitude of the infrastructure that will be needed globally to generate and connect renewable energy to grids, production sites, and households – and for aviation to airports and aircraft.

Artist's rendering of carbon capture facility

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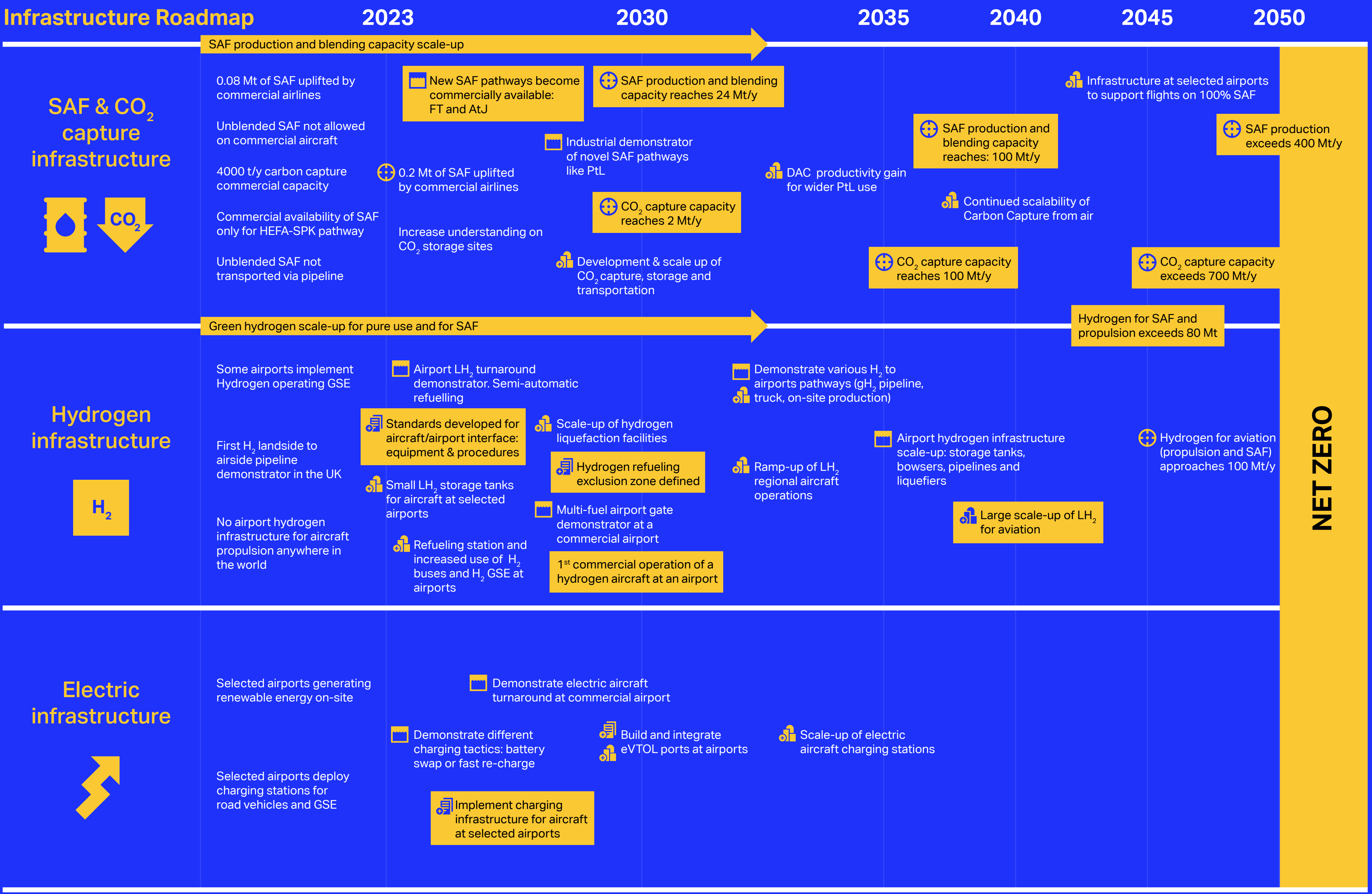


Infrastructure Roadmap

SAF & CO_2 capture infrastructure

SAF production and blending capacity scale-up

- 0.08 Mt of SAF uplifted by commercial airlines
- Unblended SAF not allowed on commercial aircraft
- 4000 t/y carbon capture commercial capacity
- Commercial availability of SAF only for HEFA-SPK pathway
- Unblended SAF not transported via pipeline
- New SAF pathways become commercially available: FT and AtJ
- 0.2 Mt of SAF uplifted by commercial airlines
- Increase understanding on CO_2 storage sites
- SAF production and blending capacity reaches 24 Mt/y
- Industrial demonstrator of novel SAF pathways like PtL
- CO_2 capture capacity reaches 2 Mt/y
- Development & scale up of CO_2 capture, storage and transportation
- DAC productivity gain for wider PtL use
- CO_2 capture capacity reaches 100 Mt/y
- SAF production and blending capacity reaches: 100 Mt/y
- Continued scalability of Carbon Capture from air
- Infrastructure at selected airports to support flights on 100% SAF
- SAF production exceeds 400 Mt/y
- CO_2 capture capacity exceeds 700 Mt/y

Hydrogen infrastructure

Green hydrogen scale-up for pure use and for SAF

- Some airports implement Hydrogen operating GSE
- First H_2 landside to airside pipeline demonstrator in the UK
- No airport hydrogen infrastructure for aircraft propulsion anywhere in the world
- Airport LH_2 turnaround demonstrator. Semi-automatic refuelling
- Standards developed for aircraft/airport interface: equipment & procedures
- Small LH_2 storage tanks for aircraft at selected airports
- Refueling station and increased use of H_2 buses and H_2 GSE at airports
- Scale-up of hydrogen liquefaction facilities
- Hydrogen refueling exclusion zone defined
- Multi-fuel airport gate demonstrator at a commercial airport
- 1st commercial operation of a hydrogen aircraft at an airport
- Demonstrate various H_2 to airports pathways (gH_2 pipeline, truck, on-site production)
- Ramp-up of LH_2 regional aircraft operations
- Airport hydrogen infrastructure scale-up: storage tanks, bowsers, pipelines and liquefiers
- Large scale-up of LH_2 for aviation
- Hydrogen for SAF and propulsion exceeds 80 Mt
- Hydrogen for aviation (propulsion and SAF) approaches 100 Mt/y

Electric infrastructure

- Selected airports generating renewable energy on-site
- Selected airports deploy charging stations for road vehicles and GSE
- Demonstrate different charging tactics: battery swap or fast re-charge
- Implement charging infrastructure for aircraft at selected airports
- Demonstrate electric aircraft turnaround at commercial airport
- Build and integrate eVTOL ports at airports
- Scale-up of electric aircraft charging stations

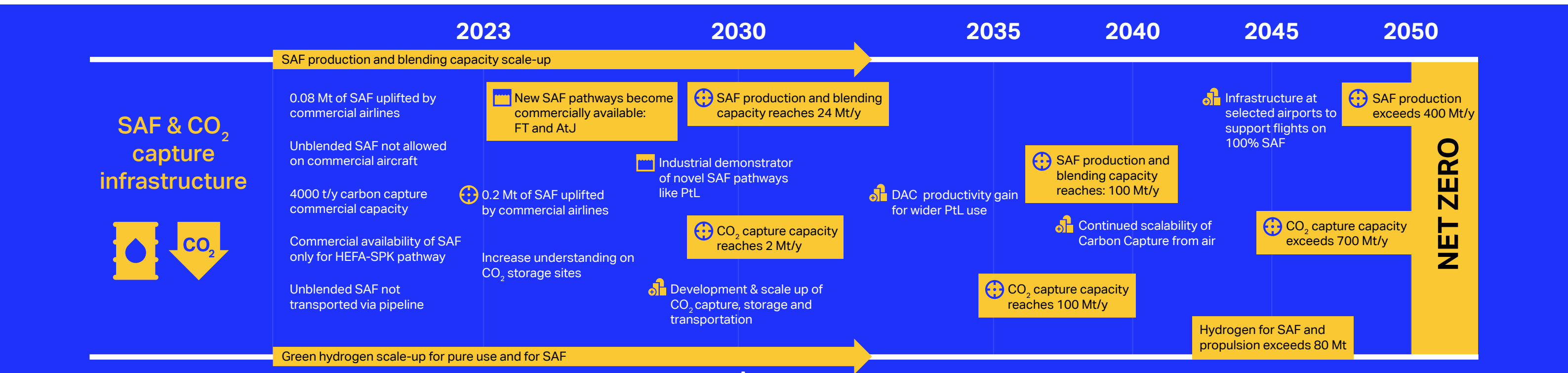
New procedures
New infrastructure
Demonstrators
Target
Major milestone

Acronyms

SAF: Sustainable Aviation Fuels
HEFA: Hydroprocessed Esters and Fatty Acids
FT: Fischer Tropsch
AtJ: Alcohol to Jet
PtL: Power to Liquids
GSE: Ground Support Equipment
gH_2: Gaseous hydrogen
VTOL: Vertical Take Off and Landing

Infrastructure Roadmap

SAF & CO_2 capture infrastructure



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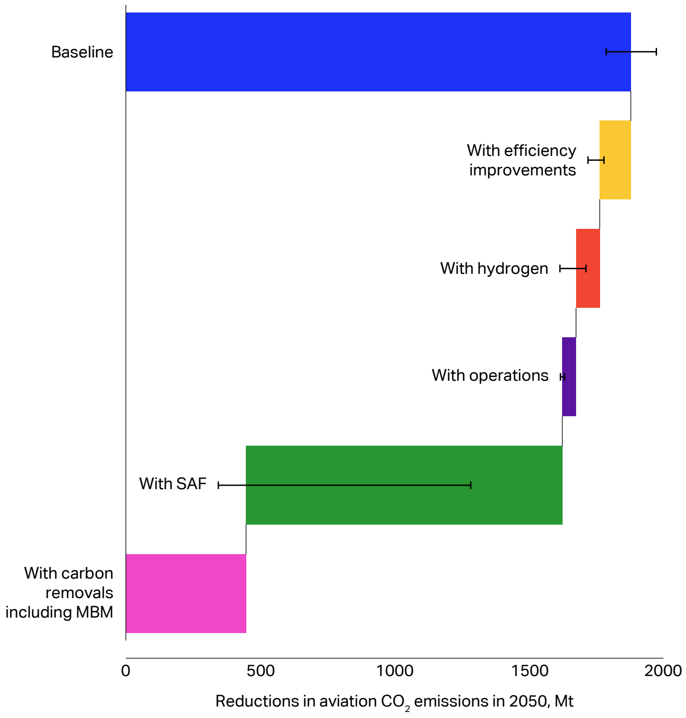
Sustainable Aviation Fuel and carbon capture infrastructure

Today, blended SAF is fully “drop-in” and compatible with current airport installations and aircraft, which means no additional infrastructure is needed at the airport. However, new infrastructure is required to gather the feedstocks, transport to a refinery, and produce liquid fuel. SAF is made from three ingredients: carbon, hydrogen, and input energy to form the hydrocarbon chains. The hydrogen infrastructure requirements for SAF refining are part of the hydrogen infrastructure roadmap. The SAF roadmap presents infrastructure requirements to capture the carbon and to convert this feedstock into a liquid fuel. These requirements are pathway-specific, and can vary greatly. Power-to-Liquid (PTL) fuels will require carbon capture to get the carbon feedstock from the air (DAC) or a CO_2 source point. The Hydroprocessed Esters and Fatty Acids (HEFA) derived SAF will require infrastructure to transform the fats, oils and greases into a liquid blend that can be mixed with jet fuel.

This part of the infrastructure roadmap highlights the steps required to produce and scale-up new SAF pathways, some of which are not commercially available today. To be on a trajectory to net zero emissions by 2050, IATA estimates that 24 million tonnes of SAF will be required by 2030, and most of that is likely to come from HEFA pathways based on the scheduled development of renewable fuel refineries. Other pathways, not yet mature at scale today, will progressively take on a greater role [5] [6]. Promising emerging solutions include Advanced Biofuel pathways such as Alcohol-to-Jet and Fischer-Tropsch. These can be derived from a wider array of sustainable feedstock, and help ease future supply constraints in the currently dominant Fats Olis and greases (FOG)-HEFA combinations. This broader SAF feedstock portfolio will increasingly include municipal solid waste, agricultural and forestry residues, as well as restorative energy crops grown specifically on marginal lands, or as cover crops, during non-traditional harvest seasons.

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.



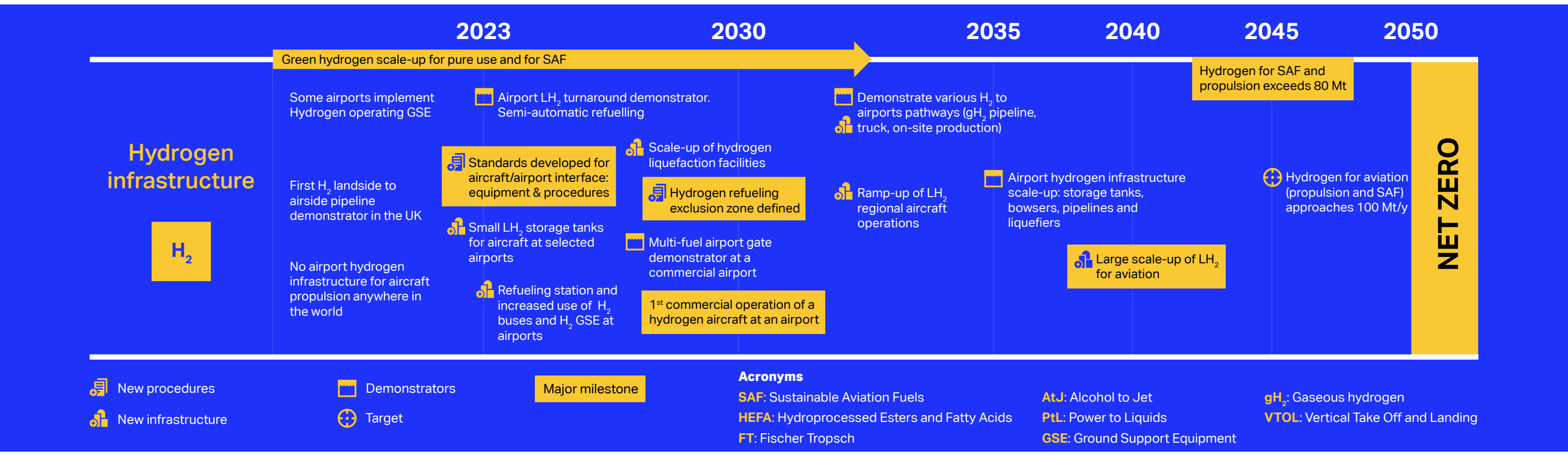
Source: IATA Sustainability and Economics, ICAO LTAG SAF availability scenarios

IATA modeled the potential reductions from the use of SAF based on ICAO's LTAG SAF availability scenarios (F1, F2, F3) and associated life cycle emissions reductions factors (details in Appendix) [7]. Based on scenario F2, replacing 80-90% of conventional aviation fuel by SAF, would result in a 62% reduction in global aviation CO_2 emissions, depending on the aircraft technology scenario by 2050. This requires that about 40% of the SAF used is made with gaseous CO_2 as a feedstock, either from point source or from atmospheric capture. While full replacement of jet fuel with SAF would result in an emissions reduction of 78% (ICAO-LTAG-scenario F3), a low uptake SAF scenario (ICAO-LTAG-scenario F3) with fewer incentives and technology developments would result in only 18% reduction, leaving close to1,500 Mt still unabated.

In all the scenarios modeled, even those where SAF fully replaces traditional aviation fuel, there are residual emissions which need to be addressed with carbon removals. Moreover, Direct Air Capture infrastructure will be needed to produce SAF from atmospheric CO_2.

Direct Air Capture infrastructure will not only be required to form SAF from atmospheric CO_2 capture, but will also be needed to remove residual CO_2 from the atmosphere and to permanently store it, or to neutralize the residual CO_2 footprint of the SAF manufacturing processes. Each carbon capture technology has a different CO_2 removal potential, different energy requirements and different efficiency. For more details on the role that Carbon Removals, Direct Air Capture and Utilization or Point Source Carbon Capture can have on decarbonizing aviation please refer to IATA's publications on this topic [8]. The largest carbon capture plant in the world in 2023 had a 4,000 tonne per year (t/y) nominal capacity but Climeworks, the company behind the project, has plans for a plant ten times that size to start operating in 2025. Carbon Engineering is another company with a plant under construction with an expected carbon capture capacity of 500,000 t/y. The firm also has future projects with a planned capacity of 1 million t/y by 2026. The PtL route alone will need more than 500 million t/y in terms of captured carbon inputs by 2050, showing the size of the scale-up required.

Hydrogen infrastructure



2023 2030 2035 2040 2045 2050

Hydrogen infrastructure

H_2

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Hydrogen is an input to almost all SAF pathways. The quantities of hydrogen are significant: aviation could require in excess of 100 million tonnes of hydrogen by 2050 (about as much as the whole global hydrogen production today), and most of this would be used to make SAF fuels from all pathways [1] [3]. Furthermore, about 99% of all hydrogen used today is not green, and the current hydrogen producers will also be pursuing decarbonization. The scaling-up of green hydrogen production from this very low base is absolutely necessary for aviation to reach its net zero goals, whether the hydrogen is used to produce SAF or for hydrogen-powered aircraft.

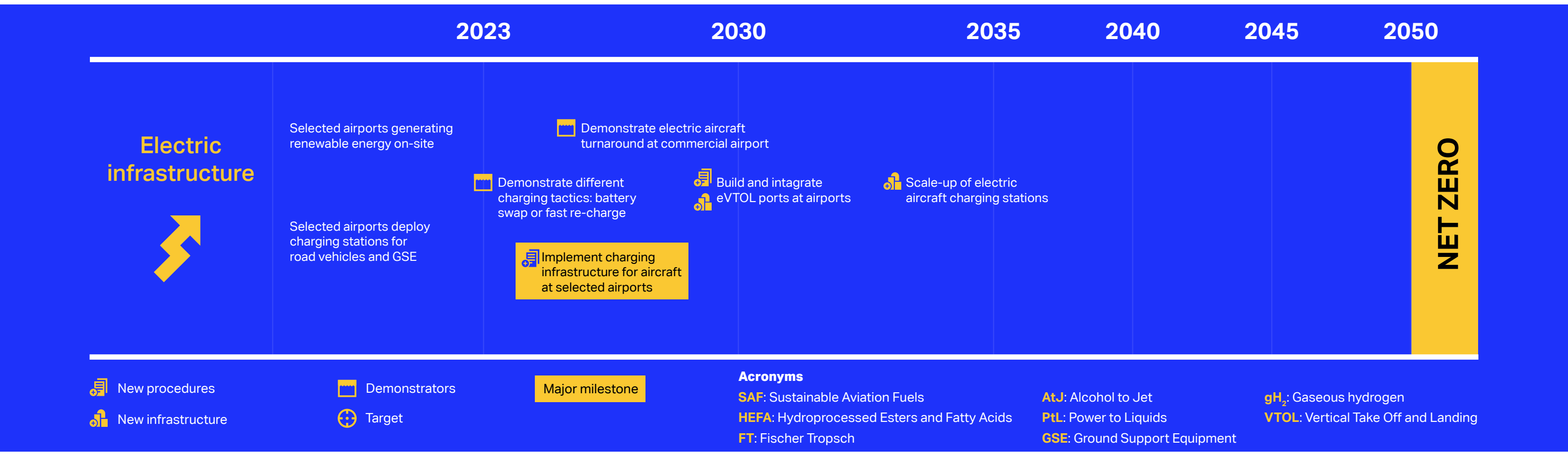
Hydrogen-powered aircraft, however, will have particular requirements which are absent for aircraft using conventional aviation fuel. For example, if hydrogen is used and scaled-up as an energy carrier for aircraft, it must be stored in liquid form on the aircraft. While the use of hydrogen today is quite widespread (mainly for fertilizers and oil refining), the use of liquid hydrogen is very rare and only for niche applications, such as the space industry. Scaling-up hydrogen and liquefaction facilities is therefore an important condition to be met before aircraft can operate on this source of energy. The liquefaction technology at large scale is fully demonstrated and operating (for example, Air Liquide's 30 tonne per day plant in Nevada, US or the 90 tonne per day plant in South Korea planned by the end 2023). For hydrogen propulsion, IATA's scenarios result in 4-14 Mt of liquid hydrogen required in 2050.

New infrastructure to store and distribute the hydrogen at airports will be needed. The airport strategy for receiving hydrogen will be unique to each case, as happens today with kerosene. Some airports might bring the hydrogen in its gaseous form via a pipeline and liquefy and store it on-site, and in other locations it could be more feasible to transport the liquid hydrogen by truck or rail [9] [10] [11] [12]. It is likely that the delivery method will change over time, starting with truck deliveries for the initial period and transitioning to pipeline once larger quantities are required. The routes for bringing energy sources into the airport will all have to be demonstrated, proven, and certified to strict airport safety requirements. In addition, the capacity to distribute hydrogen within the airport (with liquid hydrogen pipelines or bowser trucks) must be demonstrated.

Other solutions, such as Universal Hydrogen's aircraft concept, could minimize airport infrastructure requirements by providing the aircraft with pre-charged exchangeable hydrogen pods, so that the whole aircraft tank is exchanged instead of refuelled. Certain airports might be able to produce or liquefy hydrogen on-site (requiring extra electrical energy, an electrolyzer plant, a liquefier, and storage tanks). However, airport land is a very scarce resource, making this an option limited to airports with the right space capacity and means to bring in large amounts of energy.

The roadmap highlights the need to define an exclusion zone for hydrogen refueling. Developments in liquid hydrogen transfer technologies are required to ensure that safety zones during refueling and the duration of the refueling operation are similar to current references, in order to avoid a loss of aircraft utilization for the operators [10]. Work will also be required regarding the standardization and certification of the coupling devices, and the safety equipment necessary during the refueling procedure. Most of these milestones will need to be met before these aircraft enter service and will have to be scaled-up and adopted as the fleet increases. In Europe, the Alliance for Zero Emissions Aviation is bringing together different stakeholders to advance this work. In the UK, the Connected Places Catapult has launched a Zero Emission Flight Infrastructure (ZEFI) Standards Advisory Group to progress on gathering current hydrogen standards and adapting them or developing them to be suitable for aviation [13].

Infrastructure for electric aircraft



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It is expected that electric aircraft remain very limited in range and passenger capacity in the transition to net zero emissions by 2050. However, some regions might still support this solution as being fit-for-purpose under specific circumstances. This will also require a scale-up of electricity availability at airports, charging stations, and commonality in charging connectors [14]. Some electric aircraft concepts could require up to 2-3 MW of energy for fast recharging. In comparison, mid-sized airports use 30-50 MW of power. Even a small fleet of all-electric aircraft could possibly require a scale-up in renewable energy availability at the airport with associated infrastructure needs.

Companies designing electric aircraft will have to finalize their charging strategy and communicate it to airports and operators (whether this will be done by battery swap or by fast recharge stations). New safety procedures for storing batteries, or for quick chargers, will need to be in place as will training of personnel, fire fighting, and rescue teams (this applies to hydrogen as well).

Regarding the charging equipment for electric aircraft, learnings from the automotive sector can be incorporated into aviation. For example, the MCS (Megawatt Charging System) standard was developed to satisfy the charging requirements of heavy-duty road electric vehicles such as trucks and buses, within a reasonable time. Electric aircraft, including the Heart Aerospace's ES-30 concept, are being designed to have full commonality with these standards and systems, and as such progress on the road transport sector provides important enabling steps for electric aviation.

Conclusions

Even in a scenario where neither SAF nor hydrogen are deployed, by 2050 the sector would still require more aircraft, more manufacturing facilities, new equipment, more oil refineries and supply chains of fuel to airports. The fuel farm capacity at airports would need to be increased, perhaps building new fuel depots. The aim of the Infrastructure Roadmap is to highlight a path where all new investment in infrastructure, technology development, and manufacturing capacity is reallocated towards achieving the net zero carbon goal.

This will require close to 7,000 SAF bio-refineries by 2050. More than 700 million tonnes of CO_2 will need to be extracted from the atmosphere in 2050 with carbon capture technologies, either to produce SAF, or for permanent carbon removals. The largest projects in the pipeline today are planning on delivering a carbon dioxide removal capacity of 0.5-1 million tonnes per year, showing the scale of the challenge ahead. Over 100 million tonnes of low-carbon hydrogen will also be needed, mostly for the production of SAF, with 4-14 million tonnes dedicated to hydrogen aircraft.

Encouragingly, the transformation has already started. More than 100 new projects for renewable fuel are in planning or construction stages. The right policies and incentives, highlighted in the Policy Roadmap, will be needed to make sure that this capacity is optimized for aviation fuel. Before the end of the decade, projects for carbon capture such as the Stratos carbon capture facility will break records on capacity, and this is only projected to grow. The word's largest hydrogen electrolyzing and liquefying facilities are being built, tapping on the benefits of new technologies and economies of scale. While this is a good start, future requirements will need a ramp-up of capabilities at a speed and scale that is unprecedented and possible only with supporting policies and investments.

As the world now aims to move away from fossil fuels, the aviation ecosystem, including aircraft manufacturers and operators, airports, energy providers, governments, and all other stakeholders, must work in close collaboration to write another energy transformation story.

Appendix

List of contributing organizations to the technology and infrastructure roadmaps

AEROSPACE TECHNOLOGY INSTITUTE

Cranfield University

AIRBUS

DLR

Air Liquide

GE Aerospace

ACI
AIRPORTS COUNCIL INTERNATIONAL

GKN AEROSPACE

ATAG
AIR TRANSPORT ACTION GROUP

Jacobs

Air Transportation Systems Lab @ UCL
www.ATSLab.org

NASA

BlueSky
DATA 2 DECISIONS

to70

BOEING

Universal Hydrogen

Carbon Engineering

ZEROAVIA

climeworks

SAF modeling assumptions

IATA built three SAF uptake scenarios to 2050 based on ICAO's LTAG SAF availability scenarios (F1,F2,F3) [57]. Combined with the 10 technology scenarios, this resulted in 30 SAF deployment pathways. The base scenario (ICAO-LTAG-F2), "provides increased policy enablers for technology evolution to enable more widespread use of waste gases for SAF production as well as electrification of ground vehicles, which further increases SAF availability for aviation". This scenario assumes a very high SAF production outlook with ramp-up of new facilities which would require substantial policy and financial back-up. This results in 62% of emissions reductions by 2050 and replaces between 80-90% of jet aviation fuel by 2050, depending on the technology scenario to which these SAF quantities are applied.

Further policy and finance incentives as well as fast adoption of 100% SAF-enabled aircraft, and deployment of fully formulated SAF, could result in 100% replacement of conventional aviation fuel with SAF by 2050, under the most aggressive SAF availability scenario. This would reduce air transport CO_2 emissions by 78% by 2050, through SAF.

In contrast, the ICAO-LTAG-F1 scenario, in which policy and investments are insufficient to develop new technologies fast enough, the use of SAF would be limited and deliver only 18% of the CO_2 emissions reductions needed by 2050. The volumes of SAF from 2025 to 2050 in 5-year intervals (through biomass/waste, and gaseous CO_2), as well as the life cycle emission factor, are all reported for three scenarios in the ICAO LTAG Fuels report (appendix M3) [7]. The ICAO-LTAG report builds on ICAO's historical work on alternative fuels Technology, Production and Policy (TPP). "The TPP group developed market diffusion models to model future SAF fuel volumes employing current knowledge on existing and announced SAF production facilities" [7].

Description of roadmap milestones

Infrastructure Roadmap

#	Timeline	SAF + CO$_2$ capture infrastructure		Hydrogen infrastructure		Electric infrastructure	
		Milestone	**Description**	**Milestone**	**Description**	**Milestone**	**Description**
1	**Before 2023**	Unblended SAF not allowed on commercial aircraft.	Pure paraffinic SAF is not certified ASTM 1655 currently not allowed in commercial operations.	Some airports implement Hydrogen operating GSE.	Examples: Kansai Airport, Memphis Airport, Edmonton Airport. Mainly for forklifts.	Selected airports generating renewable energy on-site.	Some airports like Edmonton Airport in Canada, currently generate renewable energy on-site.
2		SAF from: HEFA-SPK pathway only.	Only commercially available SAF pathway today. Other pathways being trialed.	First H$_2$ landside to airside pipeline demonstrator in the UK.	ZeroAvia Cotswold Airport pipeline for gaseous hydrogen. Demonstrator only.	Selected airports deploy charging stations for road vehicles and GSE.	Many airports have deployed electric charging stations for vehicles. Learnings on road transport can be transferred to aviation.
3		Unblended SAF not transported via pipeline.	Pure SAF is not transported via pipeline anywhere in the world. In California there is an example of blended SAF transported via pipeline to SFO.	No airport hydrogen infrastructure for aircraft propulsion anywhere in the world.	There is infrastructure at airports but not for aircraft propulsion. As above hydrogen infrastructure is for road transport only so far.		
4		0.08 Mt/y of SAF uplifted by commercial airlines.	Uplifted capacity 2022.				
5	**2023 – 2030**	New SAF pathways become commercially available: FT and AtJ.	Advanced feedstocks become commercially available for aviation. These have much higher capacity for scale-up and potentially lower emission reduction factors.	Liquid hydrogen trucks developed for airport applications	There are hydrogen trucks today but not built specifically for airports.	Demonstrate different charging tactics: battery swap or fast re-charge.	A re-charge strategy will need to be defined, whether swapping batteries or recharging them. This will need to be consistent for all operations.
6		0.2 Mt of SAF uplifted by commercial airlines.	Aspirational scale-up by the middle of the decade.	Standards developed for aircraft/ airport interface: equipment & procedures.	Many standards will need to be developed for hydrogen equipment and its use on aircraft. The CPC in the UK is already leading work on this area so is AZEA.	Demonstrate electric aircraft turnaround at commercial airport.	After the selection of the re-charge strategy, this will have to be demonstrated in a real-world environment.
7		Increase understanding on CO$_2$ storage sites.	For direct air carbon and storage, more knowledge on potentially long-term CO$_2$ storage sites is required.	Hydrogen refueling exclusion zone defined.	At the moment kerosene exclusion zone is 3 m while refueling an aircraft. Hydrogen could require changes to this.	Implement charging infrastructure for aircraft at selected airports.	Charging infrastructure for batteries will be needed, whether these batteries are charged on the aircraft or remotely.
8		SAF production and blending capacity reaches 24 Mt/y.	2030 Target for SAF production and blending capacity, aligned with ATAG's Waypoint analysis.	Airport LH$_2$ turnaround demonstrator. Semi-automatic refuelling.	Demonstrate refueling at an airport. Semi-automatic because hose will be much larger and heavier, will need to be operated by a robot, or an assistance system.	Build and intagrate eVTOL ports at airports.	Some airports will have to integrated eVTOL to their operations.
9		Industrial demonstrator of novel SAF pathways like PtL.	Large demonstrators of PtL plants required. For example, Nordic electrofuels plans to build 8,000 t/y with future160,000 t/y capacity.	Small LH$_2$ storage tanks for aircraft at selected airports.	Liquid Hydrogen storage at airports for propulsive and non-propulsive applications.	Scale-up of electric aircraft charging stations.	As described.

Infrastructure Roadmap

#	Timeline	SAF + CO$_2$ capture infrastructure		Hydrogen infrastructure		Electric infrastructure	
		Milestone	**Description**	**Milestone**	**Description**	**Milestone**	**Description**
10	2023 – 2030	CO$_2$ capture capacity reaches 2 Mt/y.	Required carbon capture capacity for PtL SAF and for carbon removals.	Refueling station and increased use of H$_2$ buses and H$_2$ GSE at airports.	Increased use of non-aeronautical hydrogen can help airports on increasing the understanding of hydrogen handling, and build confidence prior to its use on aircraft.		
11		Development & scale up of CO$_2$ capture, storage and transportation.	Develop infrastructure for Direct Air Carbon Capture, storage and transportation to contribute towards reducing aviation's emissions and for the manufacture of PtL fuels.	Scale-up of hydrogen liquefaction facilities.	Liquid hydrogen will be a unique requirement for aviation. Large scale-up and efficiency improvements on liquefaction facilities will be required.		
12				Multi-fuel airport gate demonstrator at a commercial airport.	Demonstrate that a hydrogen and a kerosene aircraft can be refueled side-by-side.		
13				1st commercial operation of a hydrogen aircraft at an airport.	As described.		
14	2030 – 2035	DAC productivity gain for wider PtL use.	As PtL fuels increase in volume to meet net zero, DAC capacity will need to increase.	Demonstrate various H$_2$ to airports pathways (gH$_2$ pipeline, truck, on-site production).	Demonstrate that hydrogen can arrive to airports via gaseous pipeline, via trucks or generated on-site.	Scale-up of electric aircraft charging stations.	More electric stations for battery-powered aircraft will be required at some airports.
15				Ramp-up of LH$_2$ regional aircraft operations.	Regional aircraft operation on hydrogen are expected to ramp-up on this decade.		
16	2035 – 2040	SAF production and blending capacity reaches: 100 Mt/y.	Interim SAF target according to aviation decarbonization requirements, based on required SAF quantities.	Airport hydrogen infrastructure scale-up: storage tanks, bowsers, pipelines and liquefiers.	As described.		
17		Continued scalability of Carbon Capture from air.	More capacity to capture CO$_2$ for PtL and for carbon removals required.	Large scale-up of LH$_2$ for aviation.	Scaling liquefaction capacity will be a fundamental requirement for hydrogen aircraft.		
18		Infrastructure at selected airports to support flights on 100% SAF.	100% paraffinic SAF will require special infrastructure for its storage and handling at airports. Following the EIS of 100% enabled aircraft, there could be airports supplying 100% SAF to these aircraft.	Hydrogen for SAF and propulsion exceeds 80 Mt.	Milestone refers to hydrogen required for the production of SAF and for hydrogen propulsion.		
19	2040 – 2050	SAF production exceeds 300 Mt/y.	Interim SAF target according to aviation decarbonization needs.	Hydrogen for aviation (propulsion and SAF) approaches 100 Mt/y.	Milestone refers to hydrogen required for the production of SAF and for hydrogen propulsion. Between 4-15 Mt would be for hydrogen aircraft by 2050.		
20		CO$_2$ capture capacity exceeds 700 Mt/y.	CO$_2$ capture capacity required for PtL fuels and carbon removals.				

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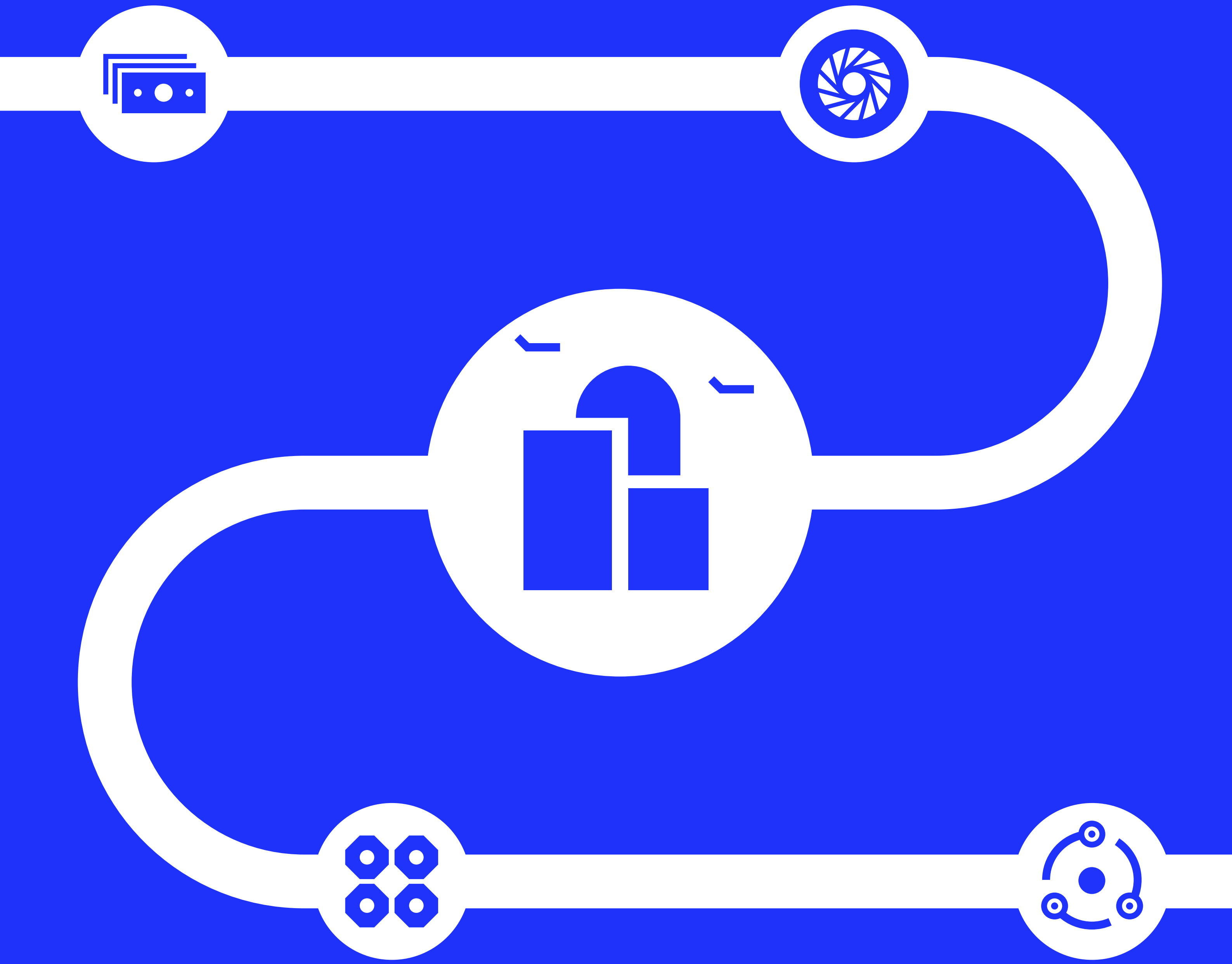

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