Reminder to join forces for decarbonization in aviation

AUTHORS

Tobias Breithaupt
Jürgen Döring
Ryan Hassoun
Anastasia Weidner

P3 GROUP

Stuttgart, Germany
Paris, France

Abstract.

The energy turnaround and the resulting decarbonization of transport, stationary power generation and storage, as well as the chemical industry and steel production, represent the central challenge of our generation. In road transport, emobility has become the primary path in recent years and has reached a substantial level of maturity and scale. Other transport sectors, such as shipping and aviation, are still in the early stages of implementing a targeted, technically and economically viable decarbonization strategy. The need for green energy, the availability and maturity of appropriate infrastructure and last but not least technology is enormous and requires determined actions.

Regulation around the world emerged with diverging priorities. European Com-mission initially envisages the gradual use of synthetic fuels, socalled Sustainable Aviation Fuels (SAF), considering today's low maturity level of "zero carbon" technologies. Other regions, such as the American market, are focusing on SAF as well, but with higher focus on biogenic feedstock. Major airlines are already pushing ambitious targets and their own supply systems with SAF. However, the market structure and availability of synthetic fuels is at a low level of maturity and SAF will be a scarce commodity for a long time.

Against this background, current legal framework, technical solutions and market challenges of decarbonization in aviation are exemplarily described in order to renew the call for action for each stakeholder in the aviation ecosystem.

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1.1 The growing CO2 problem of the aviation sector

As climate change progresses, the aviation industry and different governments intensify their actions towards carbon neutrality, setting goals and targets to limit their emissions. One of the main targets across all industries is to restrict global warming to a maximum of 2°C and to pursue keeping it below 1,5°C (according to COP21 in Paris)[1] Carbon neutrality until 2050 represents the overall goal.

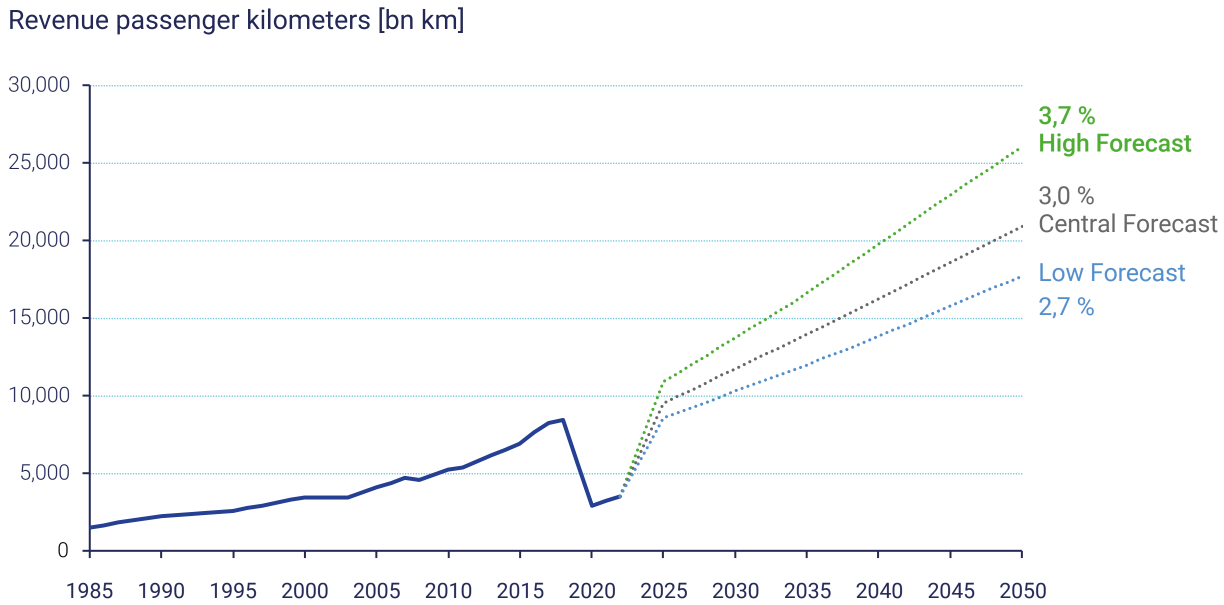


Figure 1: Air Passenger Traffic Forecast 1985-2050 (ICCT) shows further exponential growth after recovery from Covid-dip

The aviation sector currently contributes to roughly 2,5% to 3% of GHG emissions[2]. That means there are 25 years left for the transformation of the whole sector with key figures not being in favor for this endeavor: According to ICCT the aviation sector faces a continuous, probably an exponential growth of 3% per year of flight kilometers.

While other sectors like the road sector also expect an increase in traffic[3], their emission levels will most likely show a more optimistic trajectory[4], thanks to the increasing rollout of electric vehicles. Consequently, the aviation sector has to react even more ambitiously to lower CO2 emissions compared to adjacent industries.

1.2 Current Regulation falls behind 2050 net-zero goal

To reduce the emissions, different insector measures are being developed, including technological and operational improvements as well as the use of Sustainable Aviation Fuel. But considering the growth of flight kilometers[5] and the known pathways today, even the most aggressive scenario from ICAO[6] (2019) does not cross the finish line.

International Aviation CO2 Emissions [Mt CO2]

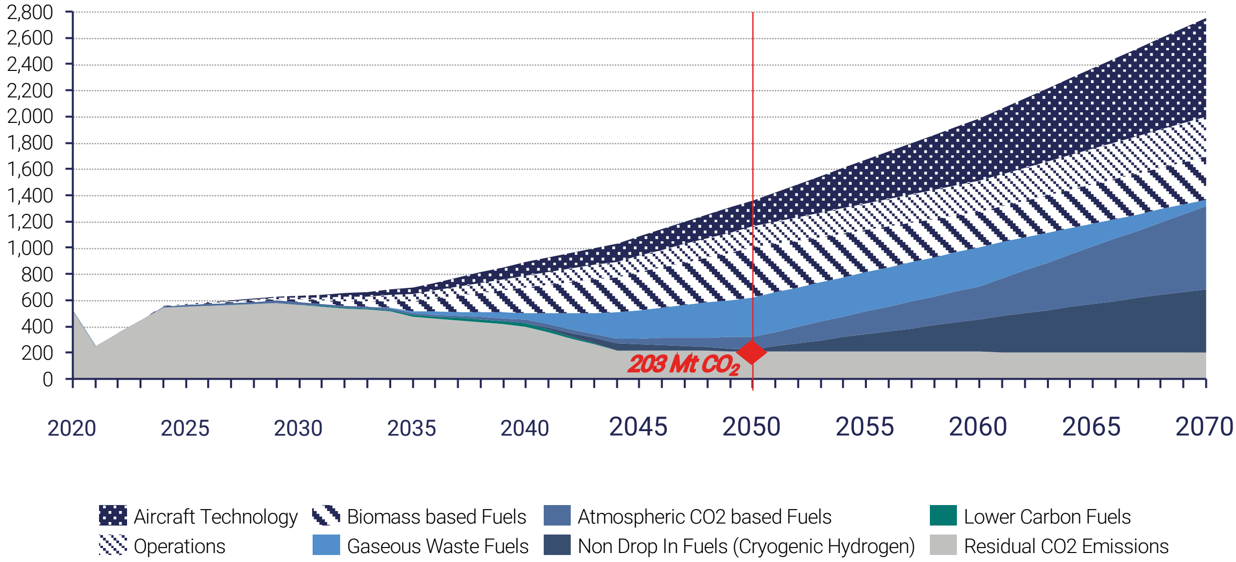


Figure 2: Even the most optimistic scenario from ICAO surpasses the net-zero 2050 goal by still showing significant CO2 emissions in 2050

Why is that? Isn't the world united in this intent? Apparently not yet, because today's regulations vary across countries and continents.

The European "Fit for 55" climate protection law includes full carbon neutrality of regional aviation until 2050. The rules of ReFuelEU Aviation regulation are set to require aviation fuel suppliers to supply a minimum share of sustainable aviation fuels or SAF at EU airports, starting at 2% of overall fuel supplied by 2025. This will rise to 6% by the end of the decade, before climbing to 70% by 2050[7] (Air travel: EU agrees to the 'world's largest green fuels mandate')[8].

In the United States of America, decarbonization is stimulated by subsidies. SAF with biogenic raw materials is used. The opportunity is seen to advance both the decarbonization of aviation and the promotion of the agricultural economy. SAF with a CO2 reduction rate of at least 50% are subsidized by the Inflation Reduction Act with a tax benefit of $1.25 per gallon.

The government and the departments involved have published ambitious targets. By 2050, the production of SAF is expected to be 35 billion gallons per year. A nearterm goal of 3 billion gallons per year is established as a milestone for 2030.[9]

The focus of the funding is currently on the use of cookingoil and the use of corn energy crops. However, there are also lobbying efforts to ensure that alcoholbased SAF benefits from the subsidies.

China has announced it will strive to peak carbon dioxide emissions by 2030 and achieve carbon neutrality by 2060.[10]

The Civil Aviation Administration of China (CAAC) published a new roadmap for the 14th Five-Year Plan period (2021-2025): According to that paper, by 2025, the specific carbon emission intensity of China's civil aviation will continue to decline, the proportion of lowcarbon energy consump-tion will continue to rise, and the utilization efficiency of civil aviation resources will improve.

The CAAC plan also puts forward eight quantitative predictive indicators for airlines and airports.[11] By 2035, the green and low-carbon development system of civil aviation will have been optimized and airport carbon dioxide emissions will have peaked, according to the roadmap[12]. (New green and low-carbon development for China's civil aviation).

Global regulation is not only inhomogeneous on a global level and too lax, but too generous as well. On the calculation sheet, SAF is partly defined as carbon neutral, neglecting the carbon emissions generated during production. As can be seen, the regulative approach has to be even more ambitious to trigger the required investments and resulting effectiveness.

SAF blend target in % of total fuel consumption

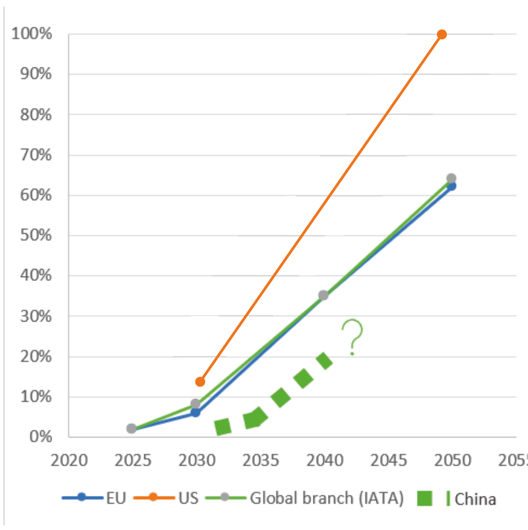


Figure 3: SAF blend targets [in %] vary globally with the US in the lead

2 Today's technical solutions to reduce CO2 emissions

2.1 100% green technologies are on the rise but not sufficiently developed, yet

There are different solutions to reduce CO2 emission from aviation propulsion systems that are and will be applicable. The use case of each system will mainly depend on distance coverage and size of the aircraft. Long haul flights unsurprisingly dominate the energy demand and resulting CO2 emission intensity. They will be therefore the most challenging to fully decarbonize.

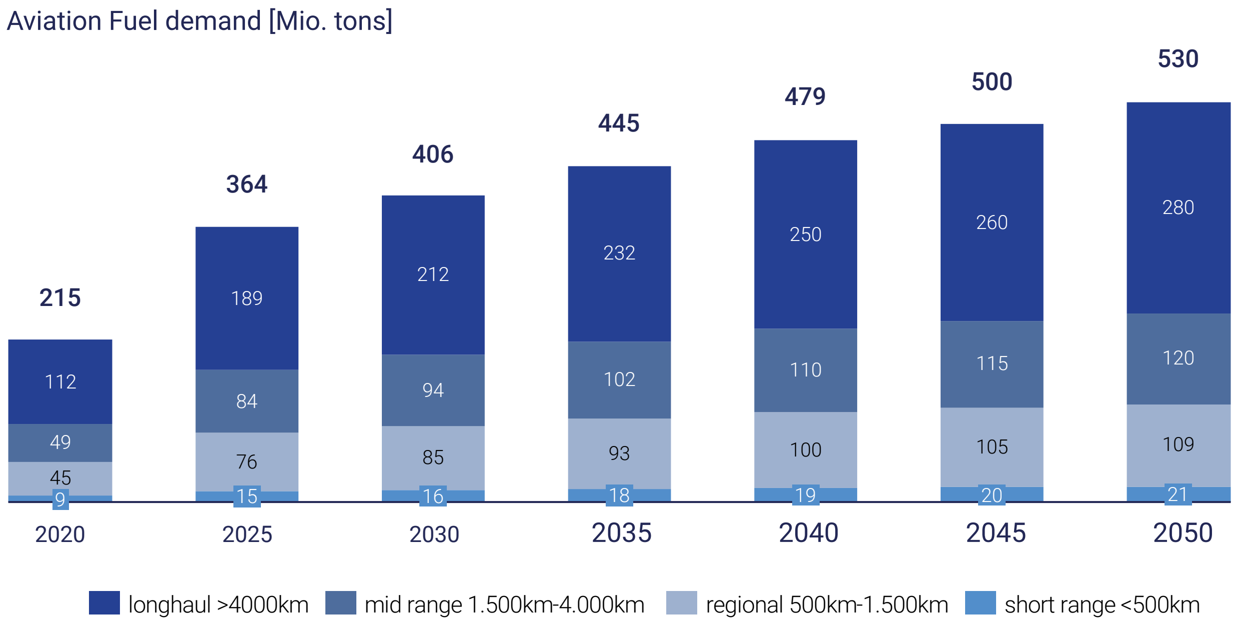


Figure 4: Fuel demand in aviation 2020-2050 increases, with largest share taken by longhaul flights (without change in propulsion technology)

Basically, there are two energy options on offer to tackle carbon free flights: electricity and hydrogen. The electric energy can be stored in batteries or produced inflight with fuel cells and will power electric motors, optionally with gearboxes. Direct hydrogen combustion in the turbines is the other option.

These all come with challenges regarding technology maturity, lead time for aviation certification and cost. Currently, the most mature technology in aviation is battery electric propulsion. More than 700 players around the world work on urban air mobility (covering inner city routes) and short regional electric flights. Battery electric aircrafts are limited in distance, though. The poor energy density of batteries simply leads to too much overhead weight for long range flights.

The next step on the 100% carbon free ladder is hydrogen. Fuel cells could enable short to middle range flights whereas direct hydrogen combustion would open the door to long range flights. But the bigger the distance, the bigger the challenges yet to solve.

The big Picture

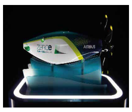
Technology	Benefits	Actual status (example)	Key challenges	Addressable range	Earliest communicated launch date
H2 combustion	• 2,5x more energy per kg than kerosene • In principle applicable to modern jet turbine technology	Rolls-Royce run on hydrogen on AE 2100-A engine, Nov 28th 2022 	• 4x less energy density / volume than kerosene • Cryogenic storage • Manage high temp., injection flow, NOx reduction	New widebody concepts to cope with storage space	2030 (e.g. Rolls-Royce & Ryanair)
Fuel Cell (FC)	• Delivers continuous power • High efficiency electrical powertrain • Potentially applicable to all prop and turboprop application	Airbus; 1MW fuel cell prototype (Nov '22) ZeroAvia 	• Weight of fuel cells • Power requirements for take-off (use of additional batteries) • Certification	Electrical propulsion	2026 (e.g. ZeroAvia)
Battery Electric	• Low energy conversion losses • Refilling by charging (no new logistics/infrastructure needed) • Mature battery supply chain	Many new playersworking on concepts for eVTOL and regional purposes  	• Low energy density of batteries [currently ~200kWh/kg on pack level] • Certification requirements • Cycle times	UAM, short range	2024 (e.g. Joby)

Figure 5: Innovative propulsion systems are on the rise but will come with limitations com-pared to the use of fossil fuels.

Having the right technology available is the first chapter but not the full story, yet. The Ramp-up of production capabilities, setting up new infrastructure for hydrogen (including production, storage, distribution), completely convert all vehicles to green technology and finally replace the existing fleet in the market – that all takes time.

Share of aviation Fuel demand per segment [%]

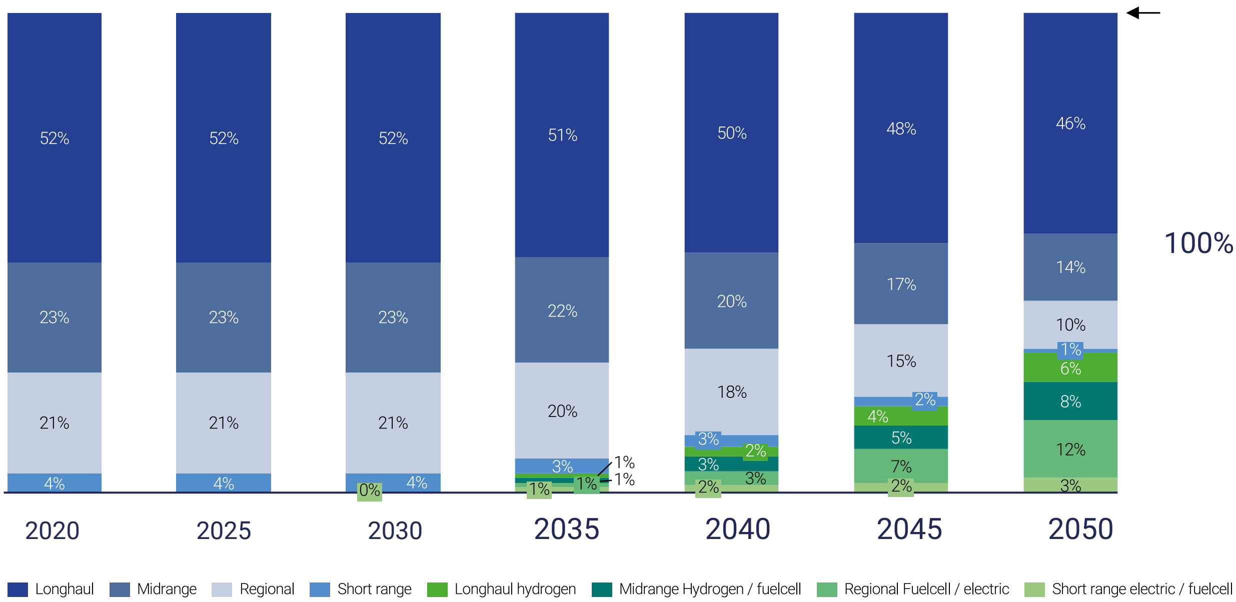


Figure 6: Fleet penetration of the green technologies takes time, especially for longhaul flights [P3 analysis]

2.2 SAFs represent the key enabler towards short term carbon reduction

That leaves us with SAF (sustainable aviation fuel) to cope with the remaining emissions. There are four main options to generate SAF (although there are many more variants based on feedstock, procedures, etc.). Please consider, that the high efficiency of HEFA is only due to the fact, that the energy needed to produce the (used) oils and fats is not taken into account.

Feedstock	Availability	Most promising Pathway	Well-to-fueltank Effiency [%]	Energy medium	Powertrain	Well-to-wheel	Evaluation
Vegetable oils and animal fat	~40 MT	HEFA	74%	Drop-in jet fuel	Jet turbine [39%]	29%	Best short term SAF-pathway but strictly limited by feedstock availability
Sugar and starch crops		Alkohol-to-Jet	39%			15%	High availability of Feedstock especially in US and South America. Conflict with food feedstock.
Lignocellulosis		FT/Gas	38%			15%	Highest availability of feedstock, low landuse conflict.
Water + CO2	∞	Power-to-Liquid (DACPSC)	43%			17%	Carbon neutral eSAF. Energy intensity will increase if switch to DAC

Figure 7: Efficiency of different SAF pathways is comparable.

Downsides come along with them as well. Landuse and water demand differ considerably and will limit the maximum capacities.

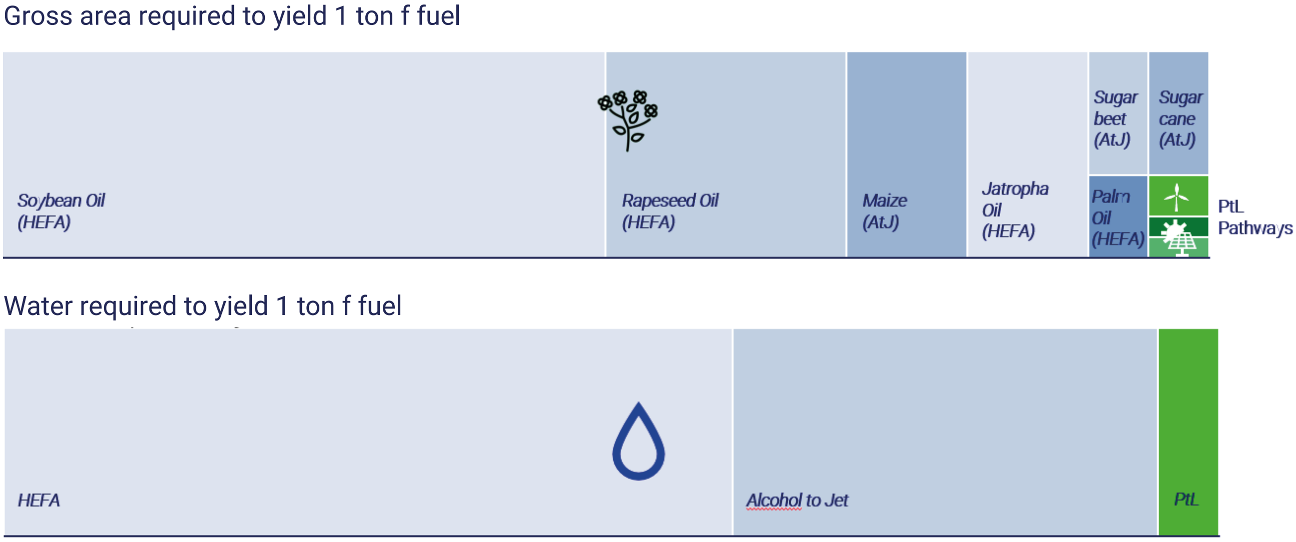


Figure 8: Qualitative overview for area and water requirements to yield one ton of fuel per year shows further inefficiency for some SAF pathways

From a physical point of view, power to liquid is the only technology that eventually has the potential for full carbon neutrality (depending on the source of CO2). Point source capture of CO2 will be a good bridging technology for the start, later direct air capture powered by renewable energy has full potential for neutrality. Unlimited supply combined with minimal land use are valid advantages, too.

Yet, the challenge is that PtL is currently the costliest option and requires huge amounts of renewable energy and green hydrogen. The scale of rampup required is unprecedented.

2.3 Many industries rely on green hydrogen as feedstock

Market forecasts by IEA , IRENA and further sources assume a strong volume increase of the hydrogen market by 2050 to more than 300 Mt p.a. ("NetZero" scenarios assume even > 600 Mt p.a.) which corresponds to minimum tripling of the hydrogen demand that exists and that is today based on CO2 intensive grey hydrogen. This market growth is driven on the one hand by chemical applications that have no other option than to decarbonize with "green" hydrogen, such as ammonia synthesis or steel production. From a certain hydrogen price level, other hydrogen applications, such as in energy and transport, are also becoming relevant.

Energy applications have possible alternatives to decarbonization, e.g., batteryelectric in road transport, stationary large-scale storage for regulating power, etc. heavy duty transportation applications (heavy duty truck, off highway, marine, aviation) will likely require hydrogenbased systems either through fuel cells, hydrogen combustors or synthetic hydrocarbons.

The share of green hydrogen supply is currently below 1% of the market demand. Ramp-up planned in various countries, larger productions in the GW range are planned in places with good availability of renewable energies like Australia, Kazakhstan and Saudi Arabia. Hydrogen projects and investments are especially based on secured takeoff agreements (NEOM Helios in Saudi Arabia).

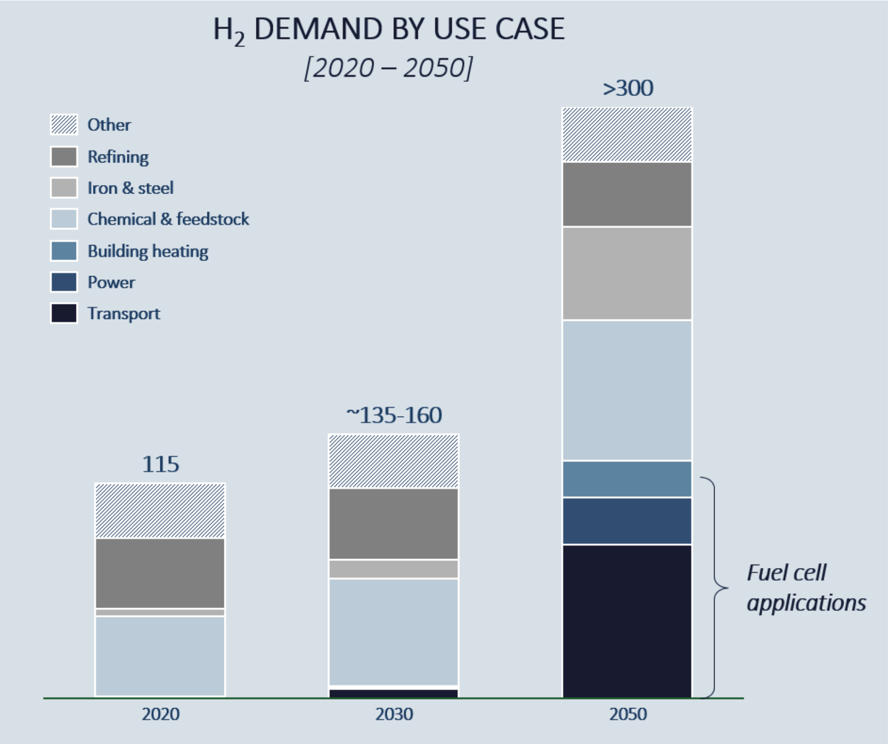


Figure 9:

Outlook shows high competition in demand across industries in future hydrogen market.

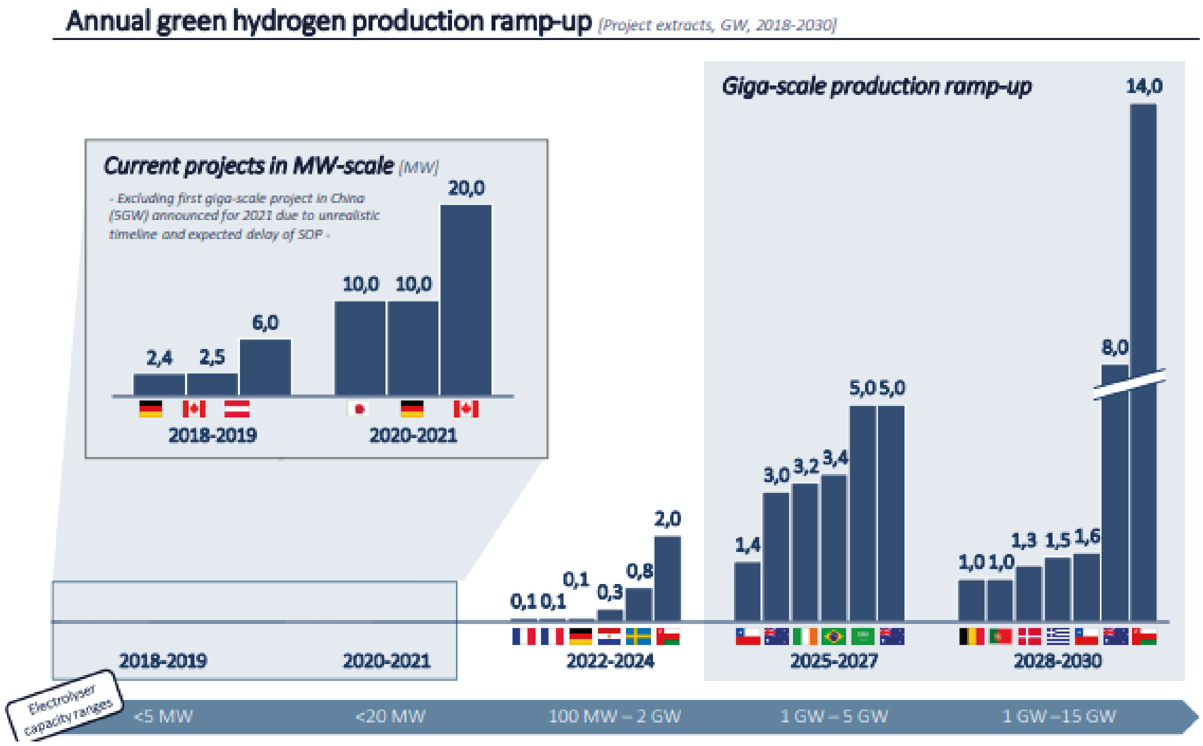


Figure 10: Annual green hydrogen production will ramp-up significantly

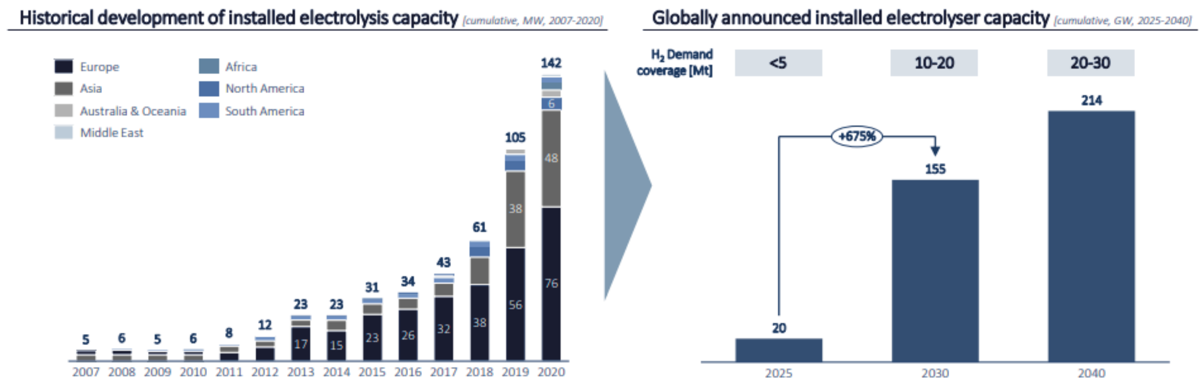


Figure 11: Outlook on electrolysis capacity shows high growth but still too low overall market share

Despite the rapid growth in announced initiatives, for many years to come the supply will be significantly lower than the demand from all dependent industries. Because the development of such projects takes at least four years, a timely (co-)invest should be considered.

3 What you can do…

In order to secure your needs and stakes in the SAF market, there are two options regarding when and where to act:

3.1 Option 1: The regulators will solve the problem, act when the market is mature

Unfortunately, regulations do not tend to deliver the best solution. Not only are they too lax in general but create heterogeneous supply chains around the word. Targets differ, domestic feedstocks and with that the according pathways and infrastructure are favored and subsidies are designed to support local companies and needs. This framework will be faster for the start but will produce negative side effects regarding land use, water demand and maximizing permanent CO2 savings. Players betting on this scenario will face raising carbon fees in the upcoming decades and even worse will arrive at the buffet when nothing is left. The devil takes the hindmost. Analogies from the transformation in other industries show, that waiting too long played out badly for incumbents.

3.2 Option 2: Push and invest proactively

As a player in the ecosystem, you could take your fate in your own hands. Some airlines currently take the lead, by committing to larger SAF shares. The early adopters not only bet on rising customer awareness regarding carbon footprint but save their share of the limited HEFA-product.

KLM	- KLM and partners in Clean Skies for Tomorrow announced: 10% SAF by 2030
DELTA	- Delta SAF commitment: 10% SAF by 2030 (or 400 million gallons annually)
CATHAY PACIFIC	- Cathway Pacific commitment: 10% SAF by 20230 (or 1.1 million tonnes of SAF over 10 years)

Figure 12: Example of airlines setting ambitious SAF targets

However, every Dollar, Euro and Yuan that is invested in pathways with longterm dis-advantages, can't be spent on the most efficient solution. Scattered investments hinder the upscaling of gold standard solutions and with that the fastest track to price reduction.

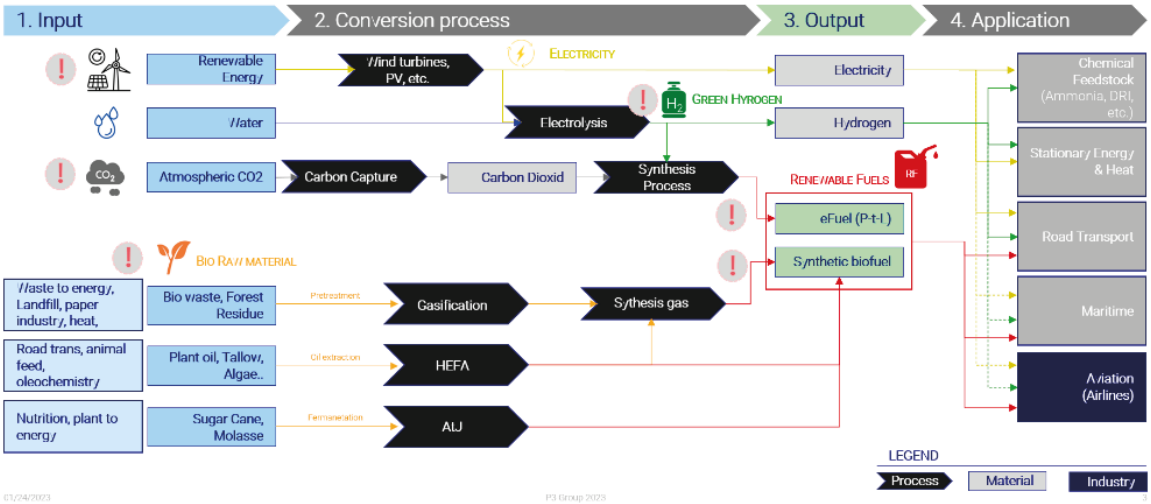
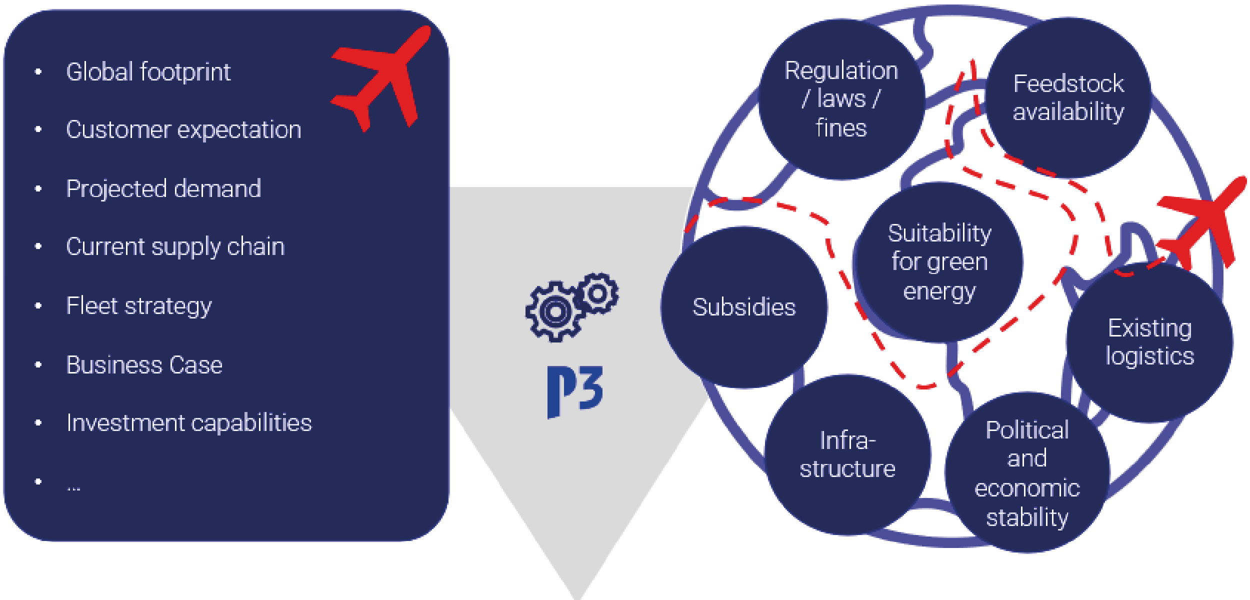


Figure 13: Simplified Renewable Fuels Supply Chain: Most important challenges concern the feedstock availability, the improvement of conversion processes as well as the cross-industry concurrence

It is therefore beneficial to evaluate each step along the supply chain thoroughly and build broad partnerships and cooperations inside as well as outside the aviation industry partnerships across regions. Customers and technology providers in developed economies should work closely with landowners, regulators and project developers in developing economies to build high output global supply chains.

Your **specifics** need to match **regional pre-conditions**



- Identify the right (cross-industry) **partnerships**
- Design best value for money **global supply chain layout** (considering subsidies and regulation)
- Define longterm **investment strategy** (direct investments, purchase agreements, …)

Decarbonization of aviation represents a challenge of many aspects. Each player has specific needs and restraints combined with a unique global footprint that requires a customized approach to effectively allocate the limited investments. But only through strong partnerships and a robust network the unprecedented growth rate for (carbon free) SAF can be achieved.

So, if you want to challenge or expand your current strategy we are happy to get in touch with you!

4 Contact

P3 group, as one of the leading consultancies and service providers for sustainable mobility, has deep insight into technology trends along the whole value creation chain, energy market and the status of global regulation and laws. Combined with proven exvpertise on how to design and manage global supply chains, P3 can contribute effectively to your endeavor.

Tobias Breithaupt
PARTNER AND HEAD OF FUTURE MOBILITY
Tobias.Breithaupt@p3-group.com

Jürgen Döring
SENIOR ADVISOR
Juergen.Doering@p3-group.com

Ryan Hassoun
EXPERT HYDROGEN
Ryan.Hassoun@p3-group.com

Anastasia Weidner
RESEARCH ANALYST
Anastasia.Weidner@p3-group.com

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