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From feedstock to flight

How to unlock the potential of SAF

PwC

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We would like to thank Neste and Spark e-Fuels for their guest posts detailing specific challenges they have encountered in the ramp-up of SAF.

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EXECUTIVE SUMMARY

Sustainable Aviation Fuels (SAFs) are among the most important facilitators of decarbonization in the aviation industry[1]. However, current supply is inadequate and huge investment will be required to address growing demand and fulfill regulatory targets. With a potential future demand of about 325 million tons of SAF to achieve net zero by 2050, up to €1,000 billion in capital expenditure will be needed simply to establish SAF refineries.

This is a huge investment, especially considering that currently the SAF industry is still in a stage of uncertainty. Concluding on discussions with industry representatives and deep-dive interviews with Neste and Spark e-Fuels, the current roadblocks need to be removed by five main actions.

1. **Investment in demonstration facilities and plant development projects** to prove that the technology can produce at mass scale
2. **Diversification of feedstock** to reduce dependence on availability and price fluctuations
3. **Hedging of financial risk** to ensure significant investment
4. **Clarification of regulations** to provide greater certainty for ecosystem stakeholders
5. **Further upskilling of corporate customers to increase** awareness around SAF and attract new investment

A single stakeholder group cannot remove the roadblocks. Rather, this requires a concerted industry effort of all stakeholders – established and nascent, private and public to fully unlock the potential of SAF and yield the environmental benefits before it is too late. Time is of essence.

1 Other options to decarbonize the aviation industry are: Avoidance/ shift to other mode of transport, technological innovation, operational efficiency and infrastructure improvements, and market-based measures

INTRODUCTION

Aviation currently contributes around 2.5% of global anthropogenic (human-derived) CO_2 emissions, rising to around 5% of emissions if non-CO_2 contributors are included. Decarbonizing aviation will play an important role in curbing worldwide greenhouse gas (GHG) emissions. But this requires the proactive participation today of stakeholders right across the aviation ecosystem.

Sustainable aviation fuels are among the most promising vehicles through which to reduce GHG emissions in aviation, and awareness of and demand for SAF is soaring accordingly. SAFs are a sustainable alternative to fossil jet fuel with the potential to reduce emissions in aviation by 66 to 94%. Derived from sustainable resources, SAF can be manufactured through a variety of production processes, most notably Hydrotreated Esters and Fatty Acid (HEFA)-based fuel, or the emerging Power-to-Liquid (PtL) processes.

Yet, currently there is insufficient SAF supply to meet forecast demand. One example is the EU with some of the strictest targets for tackling climate change. According to a supporting study for the ReFuelEU Aviation initiative, a quota of 2% SAF by as early as 2025, and of 6% by 2030, will be required for all flights departing from EU airports. Assuming that all current offtake agreements of the last 10 years in the EU can be accounted towards this quota, current supply is just sufficient to reach the 2% target. However, to reach the targets of 2030 a tripling of production capacities would be needed in half of the time. To further satisfy the current aim to reach net zero by 2050 across all sectors, those quotas would need to rise to 15% SAF in 2030 and 75% in 2050[i].

Decarbonizing aviation will play an important role in curbing worldwide greenhouse gas (GHG) emissions

So what is going on?

> "Today, the SAF industry is struggling to get off the starting blocks. Without the assurance of a return, investors are in a state of inertia. Without investment, innovative technologies and pathways will only develop so far."
>
> **Dr. Jan Wille, PwC Strategy& Germany, EMEA Aerospace and Defence Leader**

Further barriers include global regulatory uncertainty and feedstock scarcity. To support a ramp-up of SAF supply in this context, a cost-effective ecosystem for SAF technologies and value chains must be established, underpinned by confident investment.

We have looked closely at how the market dynamics are evolving; the roadblocks that are emerging along the supply chain; how the various stakeholders are tackling and overcoming these barriers to SAF supply and adoption; and the potential business models that might give rise to an optimal industry ecosystem. The results build on our findings in **The real cost of green aviation study**, published in 2022.

Taking SAF from a nice-to-have to a viable mainstream fuel source will require a concerted cross-industry effort. This will need to factor in new players including ambitious startups; address the reality of affordability; and provide greater certainty to potential investors that expanding supply will be matched by demand and a tangible, sustainable return on investment.

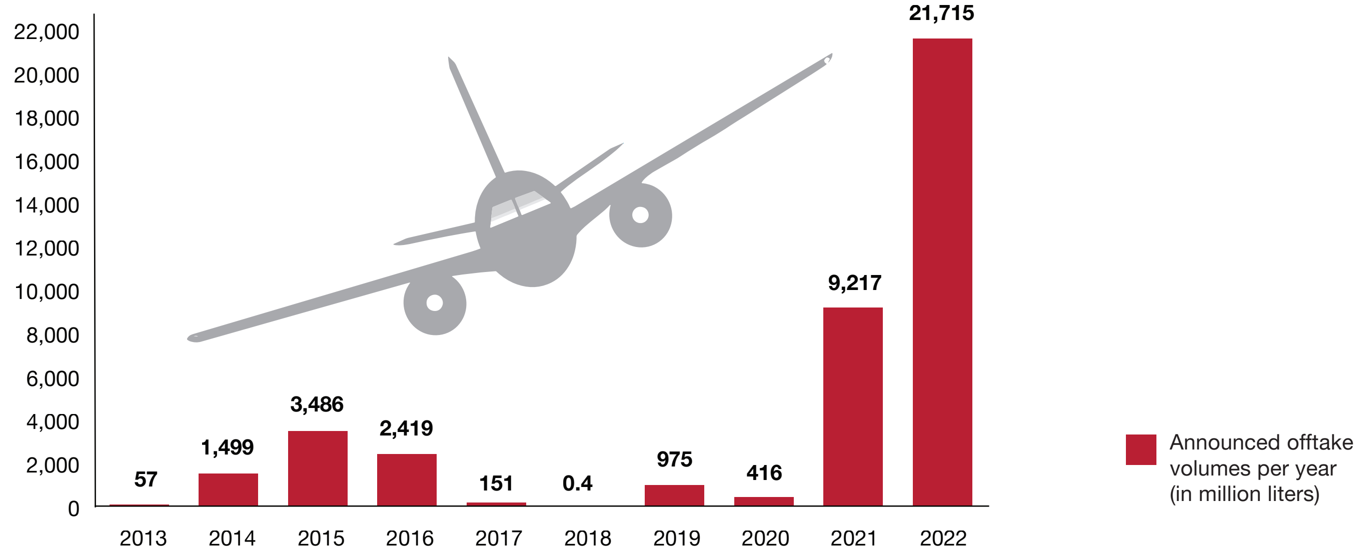
Taking SAF from a nice-to-have to a viable mainstream fuel source will require a concerted cross-industry effort

SECTION 1

Current SAF market dynamics: supply and demand

That SAF has become an important topic for the aviation industry is reflected in a growing number of press announcements, as well as published details of offtake agreements. These currently account for a total of around 40 billion liters of SAF in volume worldwide until 2022, with the number of announcements soaring over the last couple of years (*see Exhibit 1*)[2].

EXHIBIT 1
Announced offtake volumes per year (million liters)



Source: ICAO, 2023

Increasing offtake volumes are driven both by market demand[3] to reach environmental goals, such as the aviation industry's target of net zero by 2050, and stricter regulation internationally. Current published quotas exist for Europe (ReFuelEU targets of 6% SAF on all flights by 2030); the UK (10% of produced jet fuel to be SAF by 2030); India (1% for domestic airlines by 2025); and Japan (10% for international flights by 2030)[II].

2 When interpreting the volumes of offtake agreements, it is important to bear in mind that these do not correspond to the annual production or utilization volumes. Offtake agreements are usually concluded over several years. This means that an offtake agreement, which is counted here as 100% for the year 2019, can extend over several years and is only tanked proportionally in the respective years.

3 Currently, the voluntary SAF market volume is still very volatile, making it difficult to estimate future volumes. Although several companies aim to reduce their emissions from e.g., business travel to achieve their science-based targets (SBTi) via SAF, there are often cheaper options for those organizations to reduce their carbon footprint, such as use of renewable electricity in their buildings.

The ReFuelEU targets also set out a blending mandate in reference to biofuels and synthetic aviation fuels (PtL), in line with the Renewable Energy Directive (currently RED III). The quotas, now provided in an agreement between the EU Parliament and Council, include a sub-quota for PtL (*see Exhibit 2*).

EXHIBIT 2

EU SAF quota

	2025	2030	2032	2035	2040	2045	2050
SAF share	2%	6%	6%	20%	34%	42%	70%
thereof PtL	/	1.2%	2%	5%	10%	15%	35%

Source: European Parliament (2023)

These mandates provide a good level of certainty around investments in the development of SAF production capacities, since non-compliance is associated with significant penalties. Yet where some countries have agreed on quotas, others have not. This introduces another basis for uncertainty, related to international competition.

To establish an overview of worldwide SAF demand, we selected the International Energy Agency (IEA) Net Zero Pathway as the basis for our analysis, as in our previous study. It is the most widely accepted normative cross-industry scenario currently, describing a pathway to reach the Paris Agreement climate targets spanning all regions worldwide.

To reach the IEA Net Zero Pathway by 2050, the SAF quotas shown in *Exhibit 3* would be required:

EXHIBIT 3

Minimum required SAF share following the IEA Net Zero Scenario[VII]

	2025	2030	2035	2040	2050
SAF share	2%	15%	32%	50%	75%
thereof PtL	/	2%	7.5%	15%	30%

Source: IEA (2021)

The presented figures are modeled based on assumptions that are subject to considerable uncertainty, so they merely offer an indication of the magnitude of requirements. To reach the IEA goal of net zero by 2050, we expect an annual global SAF demand of roughly 325 million tons by that deadline for passenger flights[4]. The figure could be higher if consumer-driven demand rises for more sustainable air fuel.

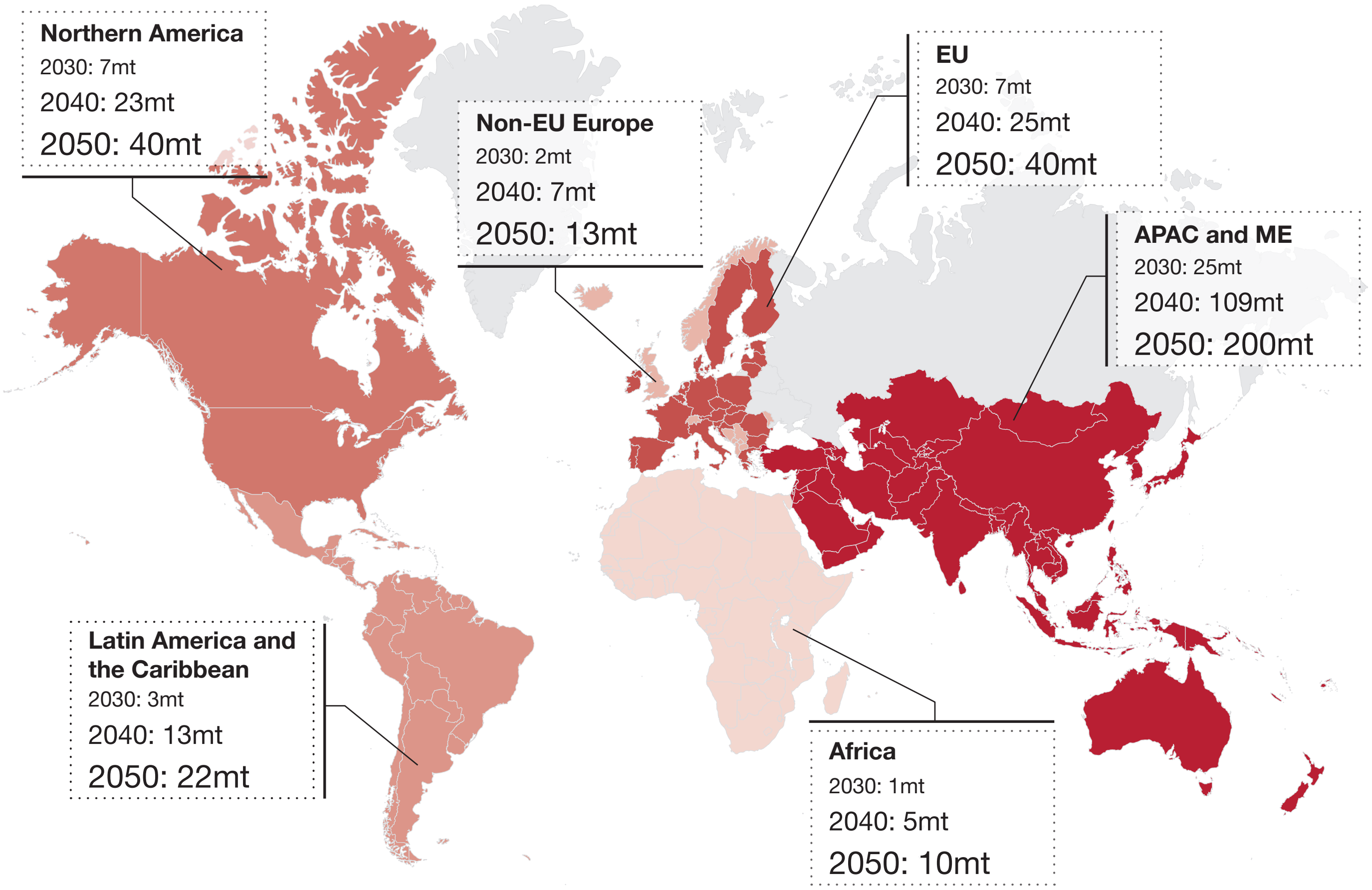
Taking into account the projected number of flights, this global SAF demand can be split across the regions, as shown in *Exhibit 4*. Here, it should be noted that uncertainties and differences in regulation, regional pre-conditions for production, the existence of a certificate system, and consumer-driven demand may have a significant impact on a region's SAF requirements too.

Looking at the expected distribution across regions, we can see that the fast-growing APAC and ME region requires a significant amount of SAF with a projected demand of around 200 million tons (mt) by 2050 to reach the goals of the IEA Net Zero Scenario. This makes the region by far the most important market in which the largest SAF volumes will be needed.

4 Presented figures are modeled based on assumptions that are subject to considerable uncertainty. These are meant to provide an indication of the magnitude of demand as opposed to exact numbers

EXHIBIT 4

Regional split of total SAF demand in IEA Net Zero Scenario (rounded figures)[1]



1 The regional split and growth forecast are calculated based on the projected numbers of trips. They do not differentiate between long-, medium-, or short-haul flights.
Source: Strategy& analysis, Sabre, IHS, Airbus (2023)

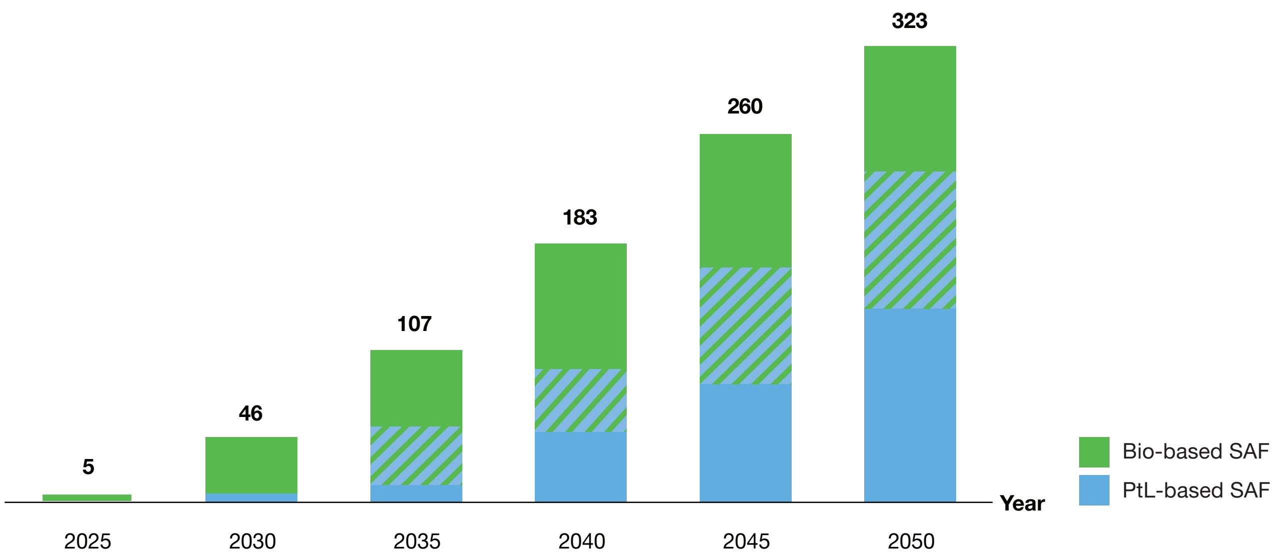
In addition to the likely regulation in APAC and ME, the good feedstock availability, both bio-based and renewable power for green hydrogen, will give rise to enormous opportunities for these regions to benefit economically from the growing SAF market.

Taking into consideration limited feedstock availability and demand competition for biofuels, we anticipate a split of bio-based and PtL-based SAF to meet worldwide demand, as shown in *Exhibit 5*. We have estimated the share of each SAF type over time by always using the maximum available capacity of the cheapest SAF type, as well as considering the required PtL quotas to reach the IEA Net Zero Scenario.

The underlying assumption is that both, producers and offtakers, are optimizing their cost by choosing the cheapest available SAF type. When, for instance, PtL becomes cheaper than HEFA or Advanced Biomass to Liquids (ABtL) – which is expected to be the case in the mid-2040s – PtL will likely be used increasingly. The expected quantities of HEFA and ABtL are estimated to decrease accordingly.

EXHIBIT 5

Split between bio-based and PtL-based SAF supply (in million tons)

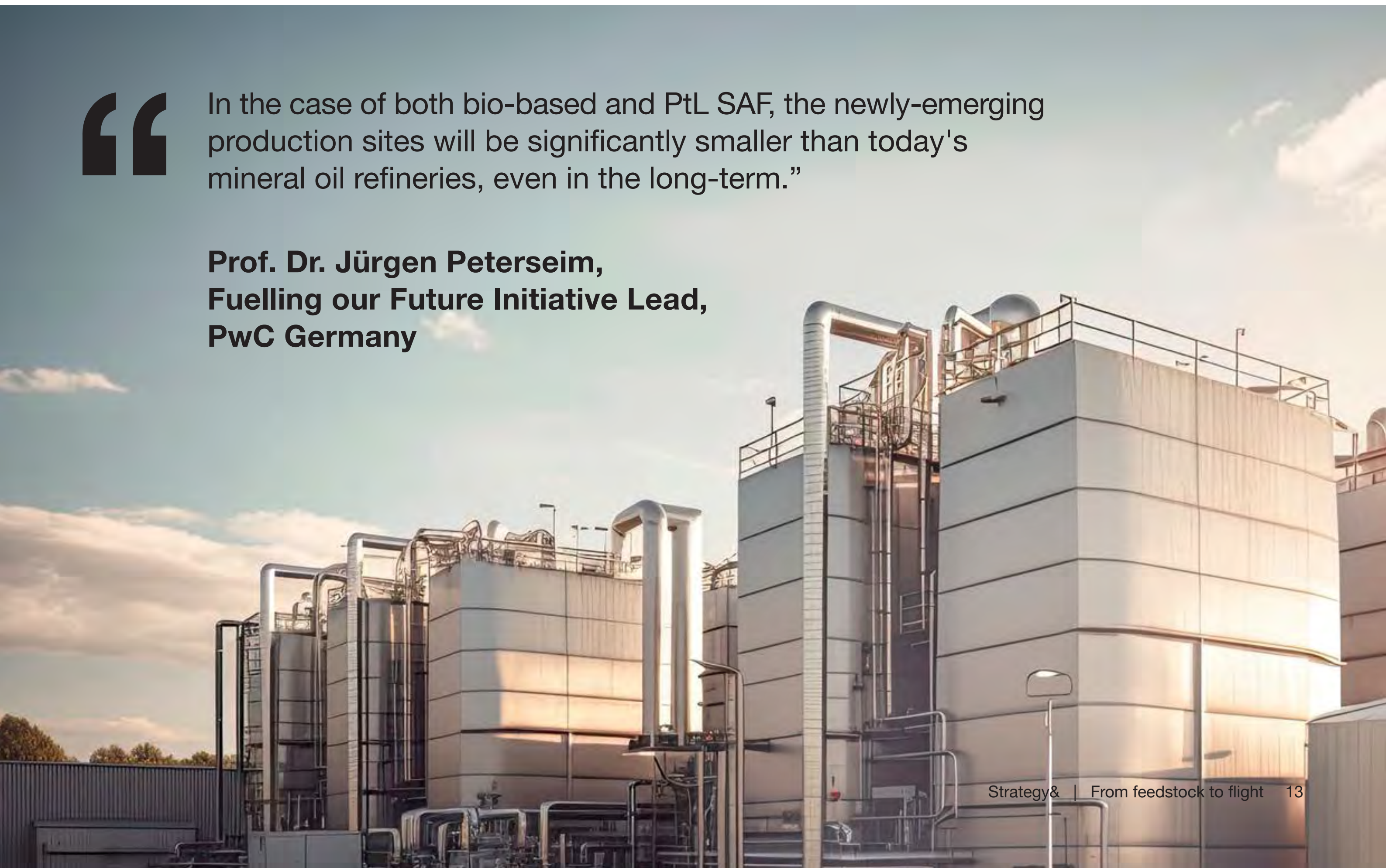


Source: Strategy& analysis

This development is likely due to two main reasons: First, CAPEX for electrolyzers and carbon capture plants is expected to fall significantly due to raising production volumes and increasing proficiency. Second, cost for renewable electricity production, especially when operated in best cost regions, are expected to be lower with 10-20 €/MWh compared to 70-90 €/MWh in central Europe. This highlights the competitive advantage of countries with excellent renewable electricity resources in PtL production.

To respond to this development, HEFA and ABtL producers may have to lower their prices, shift their production volumes to other industries (e.g. marine shipping or chemicals), or gradually enhance their bio-based production facilities to stay competitive and make the most of their established capacity.

Achieving sufficient SAF supply has been a challenge up to now, and is expected to remain an issue at least in the short-term. We estimate that 100 to 200 SAF production sites will be needed by 2030 to meet projected global demand levels, as set out by the IEA's Net Zero Pathway. By 2050, this figure would increase to between 440 and 940 production sites. The corresponding CapEx for SAF producers will level off at a €1,000 billion price tag (cumulative, not discounted). To fulfill forecasted demand levels, SAF producers will need to make significant investments to grow supply – especially given that according to recent publications of the IATA, only 11 SAF production sites are in full operation today.



“In the case of both bio-based and PtL SAF, the newly-emerging production sites will be significantly smaller than today's mineral oil refineries, even in the long-term.”

Prof. Dr. Jürgen Peterseim,
Fuelling our Future Initiative Lead,
PwC Germany

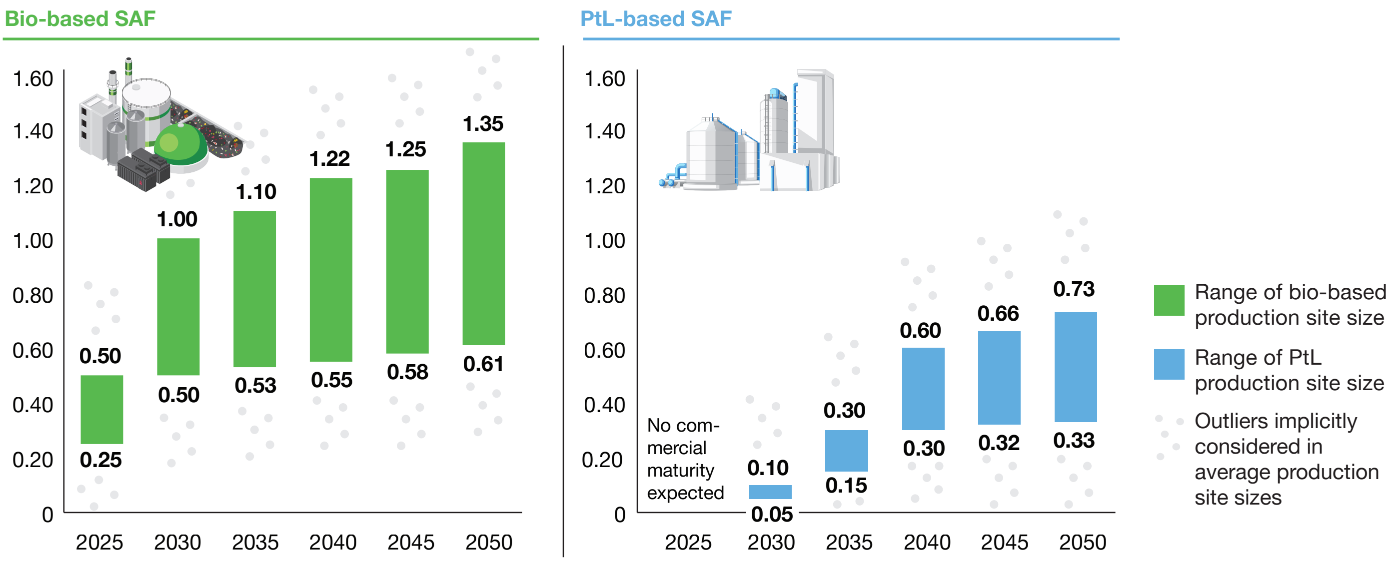
The number of production sites needed to meet the demand of course directly depends on on the average production size of these plants (*see Exhibit 6*).

Irrespective of whether existing refineries are converted to SAF production sites, or new greenfield plants are built, the required feedstock will not be available in sufficient concentration to supply very large-scale plants in the range of several million tons of SAF production per year.

Due to the uncertainty about future feedstock prices, and around the availability of waste feedstock as well as hydrogen and CO_2, it is currently only possible to speculate about the extent to which it will be more profitable to transport large quantities of feedstock to central, large-scale production sites, or whether more decentralized SAF production will develop close to the feedstock sources.

EXHIBIT 6

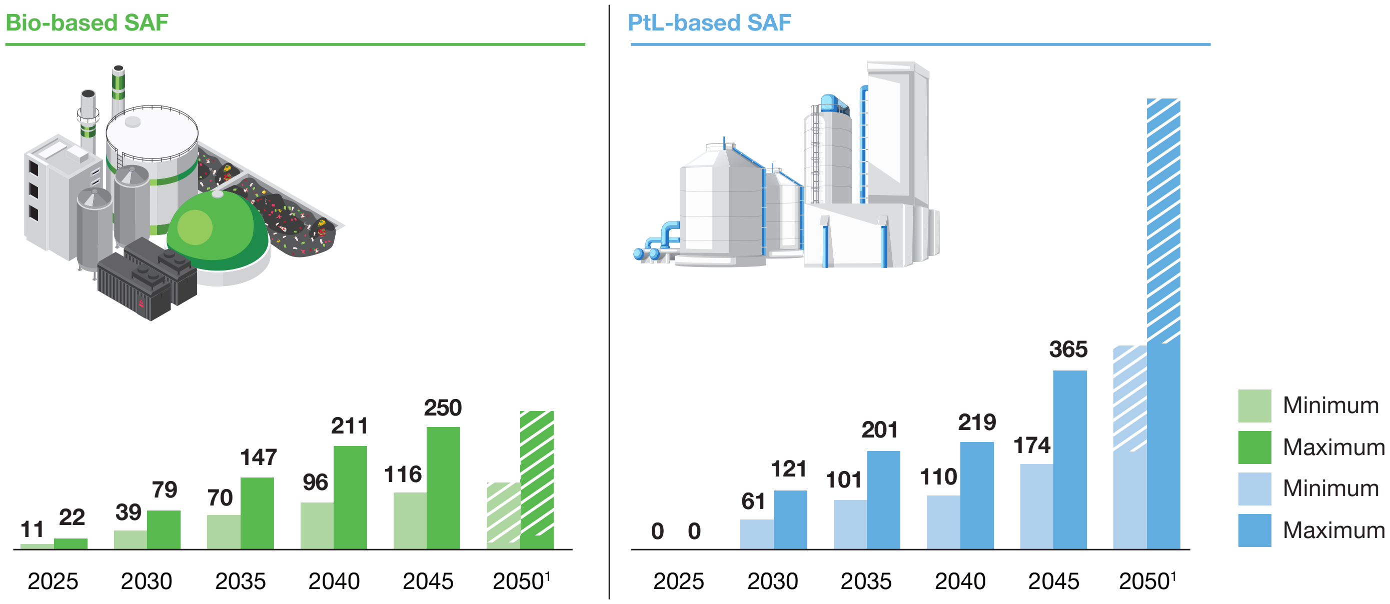
Size range of average size for SAF production sites (in million tons)



Note: Bars represent our estimate for the average size of SAF plants (i.e. the average size of a HEFA plant could be at least 0.25 million tons or at maximum 0.5 million tons in 2025). However, for sure smaller and probably also larger plants exist and contribute to this average size defined.
Source: Strategy& analysis

EXHIBIT 7

Number of required production sites when considering demand in combination with maximum and minimum average production site sizes, respectively (*see Exhibit 6*) (in million tons)

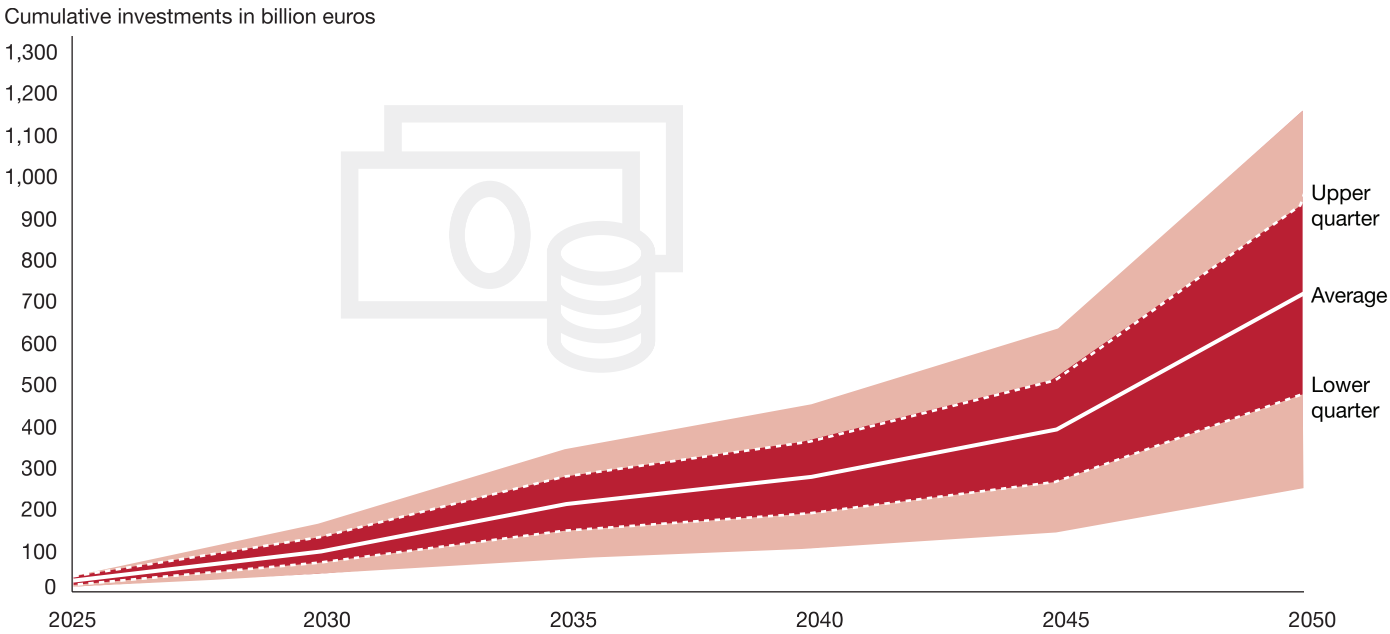


1 No new bio-based SAF production sites expected in 2050, number of required bio-based SAF production sites in 2050 subject to pricing and demand relative to PtL-based SAF
Source: Strategy& analysis

In order to reach this number of required production sites, considerable investments will be required as shown in *Exhibit 8*.

EXHIBIT 8

Required CapEx (in billion euros)



Source: Strategy& analysis

The importance of continued momentum in CapEx cannot be stressed enough. Any investment gap will inevitably result in inadequate production capacity and a shortfall against established quotas as the lack of capacity accumulates. This, in turn, could set back the transition to green aviation by a great many years.

Beyond the set-up of the production facilities themselves, meanwhile, the wider value chain needs to be ramped up and stimulated. In other words, more investment is needed across the entire ecosystem.

SECTION 2

The SAF value chain and its cost share distribution

A clearer understanding of where investments are needed can be gained by considering the different pathways through which sustainable aviation fuel can be produced, as each has its own relative strengths, weaknesses, and cost structures.

It is particularly important to distinguish between bio-based SAF and PtL-based SAF, so below we will discuss the primary pathways of HEFA as a representative pathway for bio-based SAF, and then PtL. Respectively, these represent the most cost-efficient and mature pathway (HEFA), and the most promising futureproof pathway (PtL)[5].

The HEFA value chain

The HEFA process currently represents the most mature bio-based fuel production pathway. It uses vegetable oils, animal fats, waste, or residue lipids. These are treated with hydrogen to remove oxygen and break down the compounds into appropriate hydrocarbon chains, which are then isomerized (transformed to a different structure or configuration, while retaining the same chemical composition) to create SAF.

With the HEFA process, it is possible to achieve emission savings of 74 to 84% compared with fossil-based jet fuel. Already certified, HEFA can be blended to a level of up to 50% with fossil kerosene without any modifications to either the aircraft or infrastructure. However, HEFA's biological origin sets a natural cap on the available feedstock. To be classified as SAF and ensure official accountability of associated emission reductions, the feedstock must fulfill high sustainability standards such as the EU's updated RED III to, for example, avoid deforestation and competition with food production.

5 Although other production pathways exist and may go on to play a role in time, as technology and infrastructure evolve, they are not included in our analysis here due to their early stages of development or limited scalability currently. Certainly, continued innovation in SAF production technologies and business models could significantly impact the future role of the different pathways such as advanced biofuels or Alcohol-to-Jet and the distribution of costs along the value chain

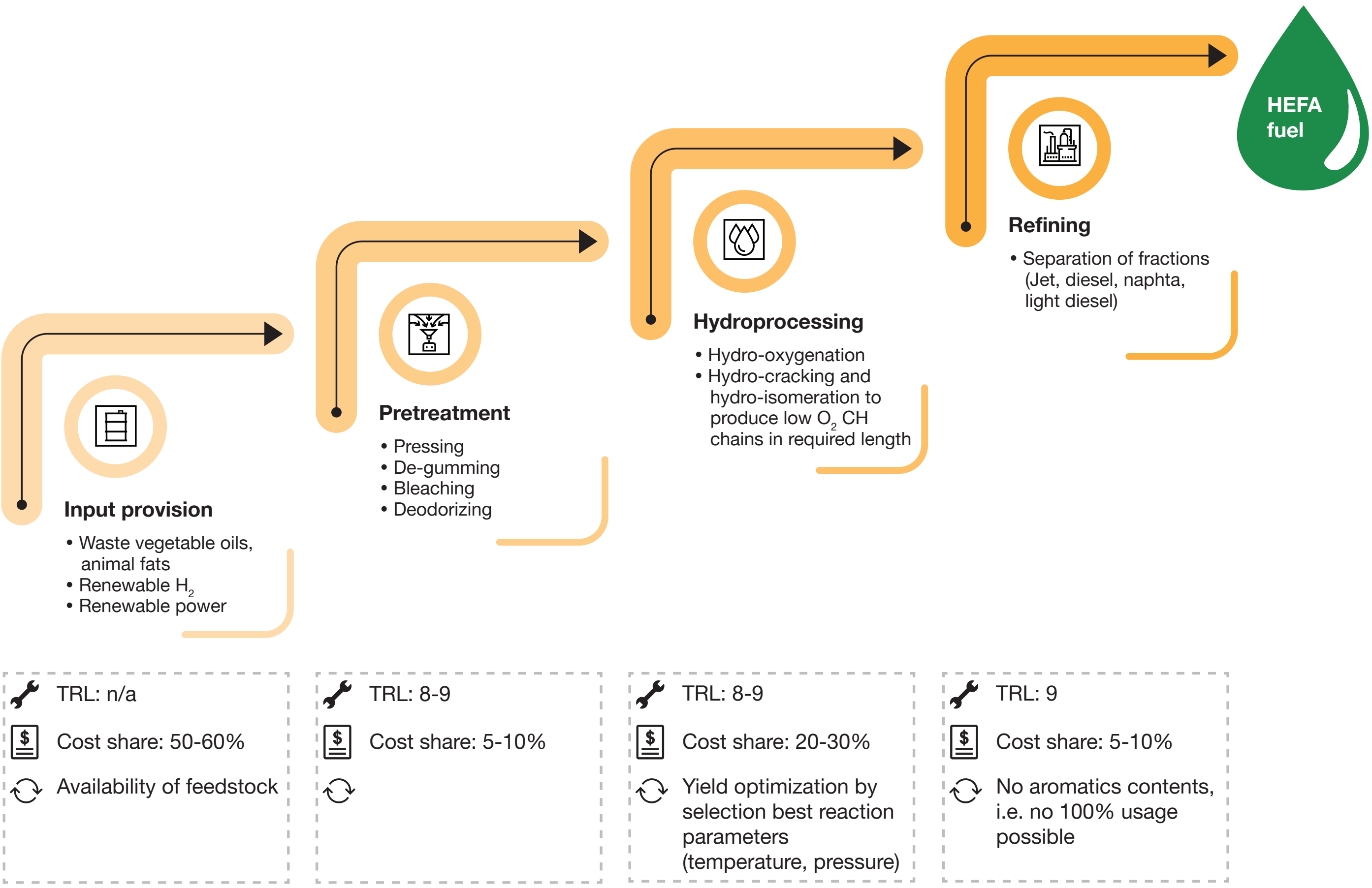
With the HEFA process, it is possible to achieve emission savings of 74 to 84% compared with fossil-based jet fuel

In terms of the overall chain (*see Exhibit 9*), the HEFA process already has a high technological maturity and is ready to be scaled up. Here, the highest investments are potentially required in setting up the facilities for pre-treatment and hydroprocessing. The biggest cost factor, meanwhile, is currently the feedstock, determined by limited availability.

EXHIBIT 9

The HEFA value chain and associated cost distribution

The HEFA process is technologically mature but sustainable feedstock availability might be limited



Source: Strategy& analysis

The PtL value chain

PtL-based SAF production converts green hydrogen from electrolysis, and CO_2 from sustainable carbon sources, into jet fuel and other hydrocarbon products – either via Fischer-Tropsch (FT) synthesis, or methanol synthesis.

The PtL process enables CO_2 emission savings of 89 to 94%. However, the PtL technology is still in its early stages of development and a series of challenges exists around large-scale production.

As with HEFA-based SAF, PtL production comes up against feedstock constraints. Although PtL's constituents – hydrogen, renewable energy, and carbon dioxide – are in theory almost unlimited, there is strong competition from other sectors for them. Additionally, environmental regulations in the EU, particularly around hydrogen production and permitted CO_2 sources, are currently quite strict. Under the EU's RED III, for instance, all hydrogen production, including the production of synthetic SAF, must comply with defined criteria regarding electricity production and CO_2 sources to be eligible for RED III and blending mandates. Other regions including the US, the Middle East, and Asia do not have such strict requirements which, at least in the short-term, could make those locations more attractive for SAF production.

Meanwhile, renewable SAF can only be produced where sufficient feedstock is available. Given that renewable energy source (RES) power generation fluctuates, this could affect a stable PtL production process, or require power storage. Limiting the amount of electricity that may be used increases the price of both the hydrogen and the resulting SAF. The situation is similar for renewable sources of CO_2. Here, the expensive method of direct air capture is favored, while the generally cheaper approach of capturing CO_2 emissions from industrial processes such as cement-making is only possible under very strict requirements for limited periods of time. Production costs, meanwhile, are subject to the cost of renewable electricity, the efficiency of the electrolysis process, and the availability and cost of carbon dioxide capture technologies.

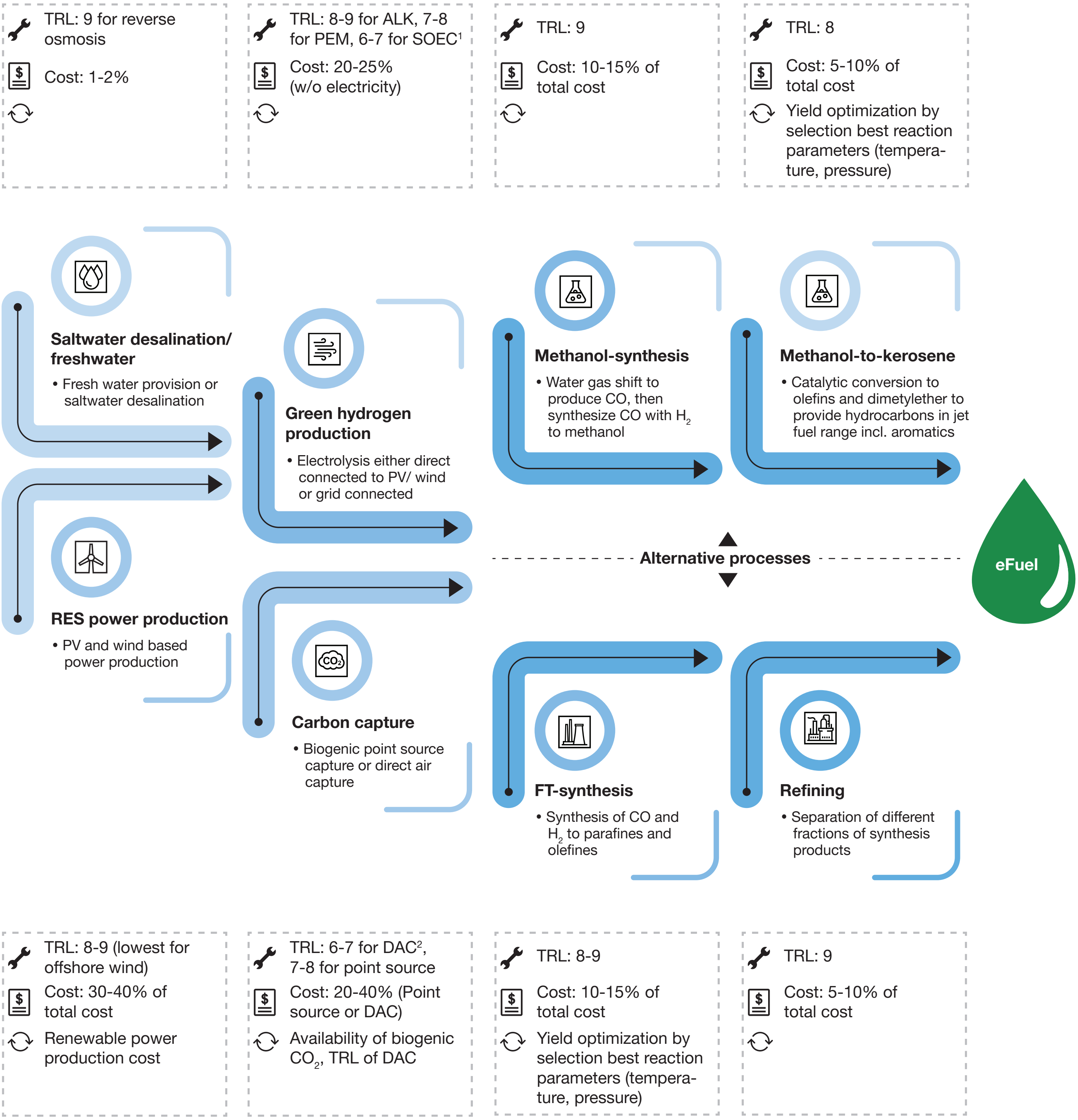
Given the nascent stage of the technology and associated infrastructure requirements, PtL fuel costs are expected to be higher than those associated with HEFA-based SAF. For PtL to become competitive in the future, significant investments will be needed along the value chain, particularly in developing the required feedstock technologies (especially Direct Air Capture (DAC)-related) and making their production flexible and efficient (*see Exhibit 10, next page*).

The PtL process enables CO_2 emission savings of 89 to 94%

EXHIBIT 10

PtL value chain

A thorough understanding of the PtL value chain and its challenges is required in order to foster its ramp-up



1 SOEC = Solid oxide electrolyzer cell
2 DAC = Direct air capture
Source: Strategy& analysis

Current roadblocks and levers in ramping up the SAF value chain

Across the different value chains, most of the relevant technologies for SAF production (with the exception of DAC) are at a high level of readiness and the cost structure is understood. Yet, the supply of SAF is currently insufficient.

So what can be done for a rapid and successful ramp-up of the supply chain? We consulted two market players, which are focusing on HEFA and PtL technologies respectively, to discuss the specific obstacles they are currently facing and how they plan to overcome them.

Opportunities to ramp up the HEFA value chain:

Neste

NESTE

The HEFA technology is currently the most mature production technology for SAF. Neste, the world's leading producer of HEFA-SAF and renewable diesel, has made a commitment to support its customers to reduce their CO_2 emissions by at least 20 million tons per year by 2030[III]. Here, Jonathan Wood, VP Commercial and Business Development for Renewable Aviation at Neste, outlines Neste's view on the path forward and key issues which need to be addressed to ensure the scale-up of SAF usage, and so make a major contribution to the decarbonization of the aviation industry.

What needs to be done to reach the required production volumes, in your opinion?
"Over recent years all players in the aviation industry have aligned around a goal to reach net zero by 2050. There have been many announcements of new SAF projects, and airline supply deals, but SAF usage in 2022 was still just ca 0.1% of total aviation fuel demand, as estimated by IATA. The higher cost of SAF compared with fossil jet fuel is a constraint on demand, as the CO_2 cost of fossil fuel is not recognised in the price.

This is why regulatory policy is so critical – providing certainty that there will be reliable, material, long-term demand for SAF is what is required to ensure the planned SAF production projects are financially viable – this will drive the required increase in supply.

The second driver to the long-term growth of SAF is the expansion of the renewable feedstock pool, which in turn will require the development and scale-up of new production technologies.

And the third driver to growing SAF usage is building the awareness, understanding and trust in SAF as a credible solution, with internationally accepted standards for measuring the emission reduction, and making it easy for customers to choose to fly with SAF."

Developments in regulatory policy to support the growth in SAF usage

"SAF regulation is emerging in different parts of the world, with different markets taking different approaches. In the EU for instance, the first mandates (obligating existing suppliers to deliver a defined and growing share of all aviation fuel as SAF) are already in place, and an EU-wide 2% SAF mandate will kick in in 2025, rising to 6% in 2030, and 70% by 2050. Likewise in the UK, a SAF supplier mandate is planned from 2025 onwards, growing to 10% by 2030. In the US, tax credits and incentives (linked to targets and mandates for the use of renewable fuels in other sectors) are currently the favoured regulatory approach. We also see similar policy proposals emerging in Asia, for example in Singapore and Japan, and in Latin America, notably in Brazil where biofuels are already widely used in road transport. Policies are not only providing demand certainty but also are essential to accelerate the growth in SAF supply – nurturing the development of new production technologies to access renewable feedstocks is capital intensive and high risk.

Suppliers, airlines and end customers will need to adapt to the relevant local regulatory frameworks, but in the end, aviation is a global industry, so a convergence of ambition levels and types of policy support will ensure a level competitive playing field for the airlines. This is where ICAO can play an important role in helping to ensure international agreements set the direction, policy frameworks and standards for the global aviation industry to achieve its net zero target."

Expansion of renewable feedstocks and production technologies

"SAF made from the HEFA production technology uses waste and residue oils and fats. There is significant potential for expanding the use of these raw materials, up to approximately 40 million tons by 2030 according to studies such as the World Economic Clean Skies for Tomorrow report. Utilising the full range of sustainable waste and residue materials will be key to scale SAF production further. This is where we see differences in approach across the different countries and regions. For example, in Europe the recently approved ReFuelEU legislation is strongly restricting the eligible feedstock pool for SAF, excluding even new sustainable feedstock sources like novel vegetable oils, which can be grown on otherwise unused land, can help regenerate soil quality and act as an additional source of income for rural communities. In the US in contrast, we see support for corn based 'alcohol to jet' production technologies. In summary, there is significant growth potential of approximately 150 million tons of additional sustainable raw materials, which do not cause land use change or impact biodiversity, which can be deployed with the HEFA-based production technology to scale up SAF supply.

Thereafter we see various feedstocks and technologies enabling the further growth of SAF supply, albeit they are not yet at the same technology readiness level of HEFA, with higher upfront capital investment but potentially less volatile feedstock costs. These include the use of lignocellulosic residues such as agricultural and forestry waste, the use of municipal solid waste with Fischer-Tropsch gasification, algae and ultimately the Power-to-Liquid technology where we use renewable power to combine green hydrogen with carbon from biogenic sources of captured from the air to enable the production of e-SAF.

It is essential that policy permits and supports the expansion of the feedstocks and production technology platforms to ensure we can ultimately displace fossil fuels with these different forms of SAF. Partnerships will also be necessary to bring together the different capabilities – renewable energy providers, feedstock suppliers, technology providers, companies in operating complex industrial scale processing plants, distribution, and marketing."

Awareness and trust in SAF as a credible way of reducing emissions

"All of us in the industry need to play our part in communicating and informing all stakeholders, and building the trust in particular of the end customers i.e. the passengers, and companies with business travel and air freight, about what SAF is, and why it is a credible way forward. We see that the credibility and integrity of carbon offsets are being questioned and need to guard against green-washing.

At present we have different calculation methods for the carbon emission reduction, different third-party verification requirements, different documents required for government authorities to provide assurance of mandate fulfillment or to claim incentives, and different documents provided to the customers who are ultimately paying for the SAF. All this needs to be harmonised, with trusted standards to calculate the emission reduction being achieved versus the fossil fuel alternative.

We also need to make it as easy as possible for customers who want to make a positive contribution by paying the SAF premium and enabling an emission reduction, with the required level of assurance that you are actually getting what you pay for. With SAF not yet being readily available in all airports around the world, we see approaches being developed to allow customers to pay the SAF premium, whilst the SAF may be delivered to a different flight or at a different location closer to the point of production. On the face of it, these so-called 'Book & Claim' solutions seem attractive to help customers who want to make a positive difference, but once again we need to ensure the guidelines are clear and the necessary systems are in place to provide the integrity and assurance that the emission reduction is being sold just once.

The good news is that the industry is committed to decarbonize, aviation is one of the hardest to abate sectors, the investment required will be significant, but we see multiple solutions which together offer a pathway to net zero, it is an opportunity, and all the players in the ecosystem are working together and stepping up to the challenge."

Opportunities to ramp up the PtL value chain:

Spark e-Fuels

Spark e-Fuels is a climate tech startup with a vision to create sustainable energy for everyone, anywhere. It has set out to address limited availability, and the high cost, of electricity-based sustainable aviation fuel (e-SAF) – by developing integrated e-SAF production systems that can be connected to the lowest-cost renewable electricity directly.

Here, Dr. Arno Zimmermann and Dr. Mathias Bösl, two of Spark e-Fuels' three founders, explain what needs to be done to ramp up PtL technology and realize its potential, noting that there are three main avenues for development that will help here:

Achieving investment security by increasing SAF demand and regulatory support

"While proposed SAF mandates provide a demand signal, this is not yet sufficient to ensure price stability. Without this, there is no way to measure the bankability of a project. Solutions to compensate for the initial cost disadvantage include establishing price stabilization mechanisms, such as clear penalties for non-compliance with mandates; ‘contracts for differences’ or a ‘buyer of last resort mechanism’; tax incentives based on CO_2 avoidance; and offtake agreements between airlines and fuel providers.

Collaboration between PtL technology developers and aviation industry stakeholders could also have an impact. Examples of associated pilot projects and commercial scale plants to increase PtL fuel supply include PtX Lab Lausitz, Kopernikus project, Advanced Fuels Fund (AFF) and DLR Technologie Plattform PtL.

Other facilitators could include public funding of demonstrator projects to limit technological risk and increase financial feasibility; and public CapEx grants for first commercial size facilities (FOAKs). Having more consistent regulatory frameworks globally would help enormously, too.”

Proving the technical readiness of PtL at mass scale

“PtL production still needs to prove its technological readiness at a large scale. A flexible production process that adapts to varying input factors such as renewable energy is required. Potential solutions here include setting up and financing additional demo and FOAK plants to push advancements in catalysts, electrolyzer technology, and fuel synthesis processes and advances in carbon capture and off-grid technologies to access the lowest-cost renewable electricity.”

Achieving sufficient availability of feedstock: electricity and CO_2

“Limited availability of renewable electricity affects energy-intensive PtL fuel production. Current on-grid technologies for PtL production require stable electricity input and compete with other electricity offtakers. Technologies for off-grid e-fuels production that can access fluctuating renewable electricity in locations with low electricity prices are under development but need further funding.

Potential solutions include the implementation of supportive policies and incentives to encourage the adoption and production of renewable energy by governments (such as feed-in tariffs, tax credits, grants and subsidies for renewable energy projects); and investment in technology development. On grid, this would include the implementation of long-term grid stabilization and energy storage; off-grid options include the development of technologies for direct offtake of renewable energy in locations with low-cost renewables.

Given the relatively small quantities of PtL initially, CO_2 availability is not a problem. Over time, competition for usable CO_2 sources will intensify – yet, by 2030, biogenic CO_2 sources will be perfectly adequate for e-fuel production. The EU has also determined that, up to 2041, industrial point sources of CO_2 will also be usable. Globally, discussions around the origin of CO_2 are much more open than in the EU. In the US to date, there are no regulations concerning the origin of CO_2. That said, to scale sustainable PtL SAF for the long-term, it will be important to focus exclusively on biogenic or unavoidable CO_2 sources. This means there is no way around direct air capture.”

What can be done to overcome these roadblocks?

Drawing from the discussions in these guest posts, we have identified the following six main roadblocks which need to be overcome to ramp up SAF production:

1. Regulatory complexity and uncertainty

Most governments around the world see an urgent need to either mandate or incentivize increased use of SAF. However, considerable variance exists between the regions here, as well as a lack of clarity. Until regulators align on clear goals, airlines, investors, and fuel producers will likely remain hesitant in their sustainability strategies, unwilling to spend more than they need to.

Ideally, there should be a coordinated international approach – both in the mandating and regulation of SAF. Only with quotas that are as globally applicable as possible can the relocation of CO_2 emissions to non-regulated regions be avoided. Uniform specifications for production, including feedstock requirements, will also ensure a level playing field and high sustainability standards.

2. Accounting uncertainty

Another regulatory consideration is certification, and the crediting of SAF towards corporate climate targets. Currently, for related carbon reduction to be accepted by an auditor and included in corporate reporting, fueling needs to take place at a local airport. Since sustainable aviation fuel is currently limited to specific airports, this poses a problem for regional and national reporting.

An international SAF certificate trading scheme, as for instance described by the World Economic Forum in collaboration with RMI and PwC Netherlands[IV], would be invaluable here, making it possible to decouple physical SAF quantities from carbon reduction crediting. Additionally, SAF-enabled Scope 3 emissions reductions would become creditable for companies.

Carbon accounting: Scope 3 disclosure

The Greenhouse Gas Protocol – a comprehensive global standardized framework for accounting and reporting greenhouse gas (GHG) emissions – categorizes these emissions into three ‘scopes’. Scope 1 covers direct emissions from owned or controlled sources. Scope 2 covers indirect emissions from the purchase and use of electricity, steam, heating and cooling. By using the energy, an organization is indirectly responsible for the release of these GHG emissions. Scope 3 includes all other indirect emissions that occur in the upstream and downstream activities of an organization. Scope 3 disclosure, then, is an assessment of GHG emissions from assets not owned or controlled by the reporting organization but that indirectly impact the organization through its value chain, for instance work travel.

This would have the advantage that SAF could be produced at the location with the best production conditions and used directly there, saving high-emission, expensive and time-consuming fuel transport. By selling SAF certificates, airlines or fuel producers could sell the Scope 3 reduction achieved via SAF to their corporate customers, generating additional income to close the price gap between SAF and conventional kerosene.

While several ideas are being discussed and pursued, there is not yet any agreement or official system in place, further hindering the international market ramp-up of SAF.

3. High investments and market uncertainty

Investor hesitancy is intensified by the scale of spending needed upfront to build up the infrastructure needed for SAF production, storage, and distribution.

This payback uncertainty for the initial high investment can be overcome in two different ways: through regulations and support schemes (for example, quotas as in Europe; tax benefits as in the US; or contracts for difference mechanisms, in which the state subsidizes the difference between fossil and renewable products); or through long-term offtake agreements[6] with companies that are willing to buy fixed quantities at fixed prices over a fixed period of time. Faced with a similar problem, the German hydrogen market provides one example of how to approach high investment costs via state support. Here, the H2 Global Foundation, via an intermediary – the Hydrogen Intermediary Company GmbH (HINT.CO) – has pledged to conclude long-term purchase contracts on the supply side, and short-term sales contracts on the demand side. Based on a mechanism analogous to the contracts for difference (CfD) approach, the difference between supply prices (production and transport) and demand prices will be compensated by grants from a public or philanthropic funding body. The combination of these long-term purchase agreements, with HINT.CO as a government-backed offtaker, provides the necessary investment security to unlock large-scale investments now, with a catalytic effect on the hydrogen economy[V].

6 SAF offtake agreements are contractual arrangements between a SAF producer and an airline or aviation company, defining the terms of purchase and delivery for the SAF including agreed volumes to be sold[IX]

“The initial high investment can be hedged in two different ways: Through regulations and support schemes, or through long-term offtake agreements.”

Dirk Niemeier, PwC Strategy& Germany,
Green Hydrogen and Alternative Fuels Leader

Beyond government measures, there are further options for influencing economic opportunities. Long-term offtake agreements may appeal to buyers on two counts: via the potential to address and reach new customer groups by marketing renewable products, while also helping companies to achieve their own climate targets. Car manufacturer Volvo purchased green steel produced in a joint project involving hydrogen in 2021, for instance, with a view to selling a ‘fossil-free steel’ car with green steel as an additional selling point[VI]. Transferring this practice to the SAF market, marketers could help airlines address new, environmentally-conscious target groups of passengers.

4. Availability and scalability of sustainable feedstocks

Another roadblock to SAF ramp-up is the limited availability and scalability of sustainable feedstocks, as already noted.

The public and private sectors both have a role to play in countering this. Dialog around international sustainability standards is important, certainly, even if the initial output is merely guidelines on which standard to apply to give investors and producers security.

Private companies, meanwhile, must stay close to the current regulatory landscape so they are aligned early on. A regulatory monitoring system would be useful to support this. A strategy for diversifying feedstock sources and supply would also be prudent. Sources such as particular vegetable oils or municipal solid waste could be further explored, along with the scope for global feedstock networks and partnerships – bearing in mind that certain regions, such as South America or Southeast Asia, may be more favorable for growing feedstock.

5. Scalability of SAF technology

Another challenge is the ability to scale production capacity along the entire value chain to the required commercial levels – up to five times the capacity of current facilities. The respective facilities do need to be in close physical proximity to each other (for efficiency and environmental reasons, as well as necessity in the case of PtL), however, associated logistics will need to be established.

To build confidence in the viability of large-scale production, establishing additional demonstration facilities for all required steps along the value chain will be crucial. This not only includes demonstration facilities for SAF refinery, but also for carbon capture technologies and so on. Exploring international opportunities will be important too, particularly in regions with strong potential for renewable power production, including South America, Australia or the Middle East. These could be attractive markets for establishing large-scale production facilities, while ensuring close proximity of the different production steps.

6. Low public awareness for SAF

The final barrier surrounds the current lack of public awareness and acceptance of SAF. Although SAF is an important contributor to reducing companies' Scope 3 emissions for 'unavoidable' flights, most corporate customers are unfamiliar with SAF and its environmental benefits. Often SAF is confused with carbon offsetting mechanisms, which increasingly face distrust due to ambiguous practices in the past. High current market prices are exacerbating this lack of buy-in.

There are several possible strategies to increase awareness of SAF and its benefits. First, comprehensive educational campaigns could be designed by ecosystem players to target aviation players, policy-makers, and the general public. This plan could encompass dedicated events and workshops – physical and digital – where representatives discuss the benefits as well as the drawbacks of SAF to create an overall understanding.

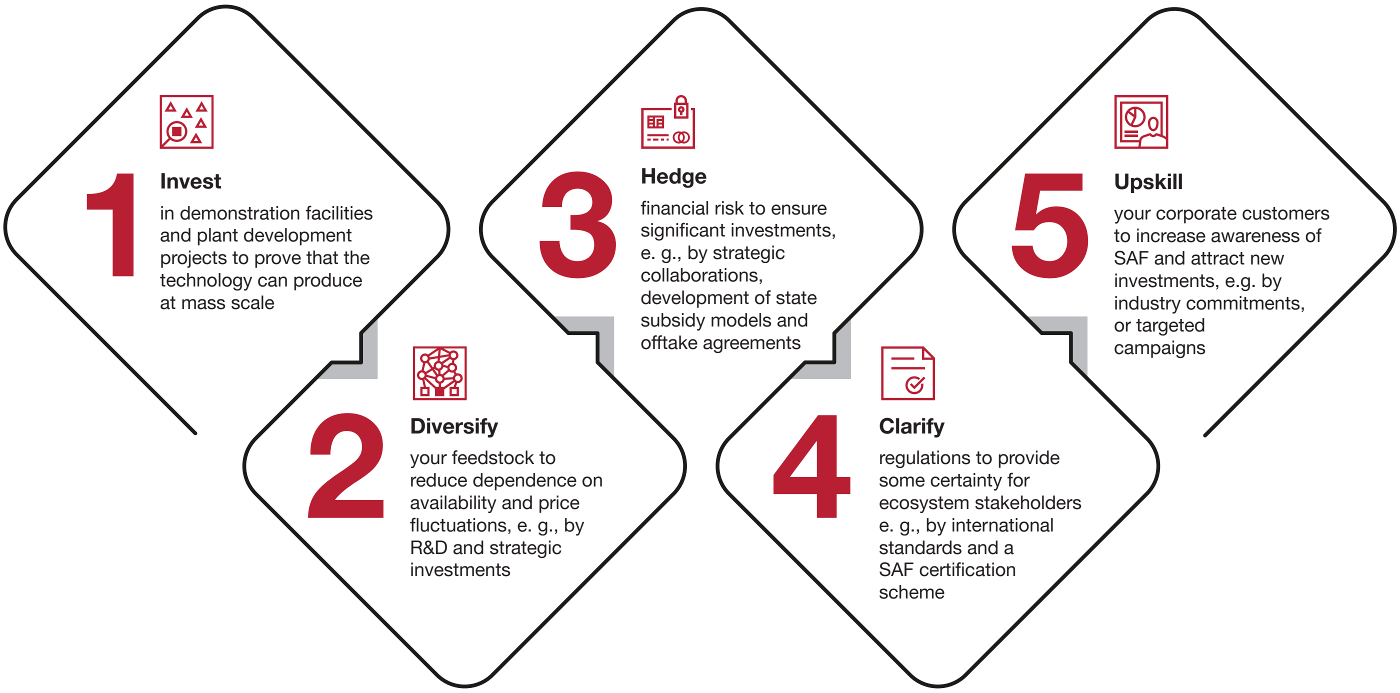
A second solution is the set-up of collaborations and partnerships. Global initiatives, such as the IATA and ICAO, or industry commitments like the 'First Movers Coalition' could harness their worldwide reach to promote SAF on a global scale. Demonstration projects of consortia and research collaborations would help confirm the viability and performance of such fuels and increase confidence in them. Role-model projects, such as the announcement of offtake agreements by airlines or governmental institutions, would further boost awareness for and trust in SAF technology.

A final opportunity surrounds classical marketing and online, social media, blog and podcast-based campaigns – to share information, success stories and current news about SAF, with especially engaging content potentially reaching a very broad audience.

Based on this assessment of the main SAF roadblocks, we have distilled five main activities now required to provide initial stability for all ecosystem stakeholders (*see Exhibit 11*). But first, let's explore the SAF ecosystem in more detail, and discern the different business archetypes whose active cooperation will make for a thriving market.

EXHIBIT 11

Steps to overcome roadblocks and enable the ramp-up of SAF



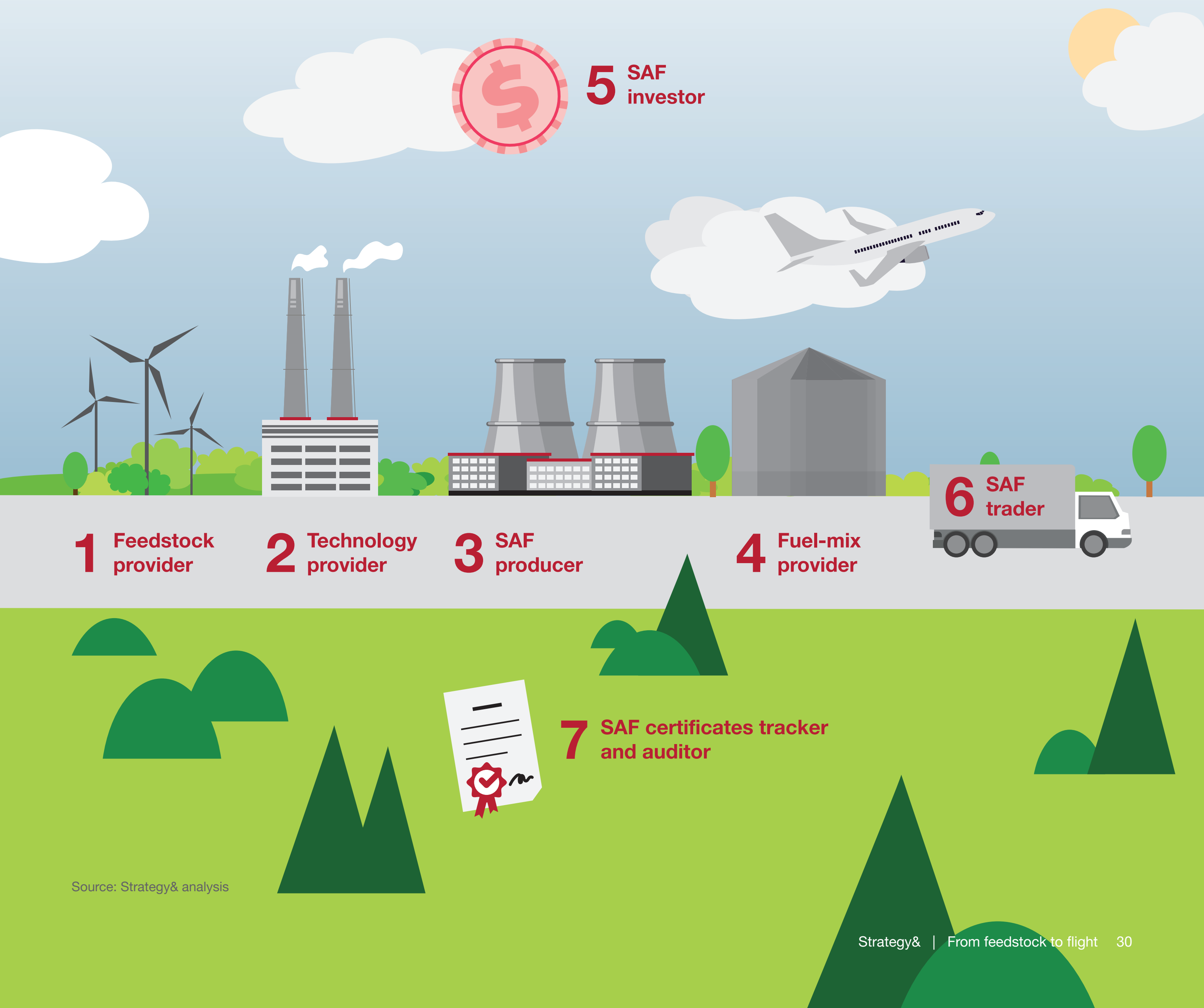
Source: Strategy& analysis

SECTION 4

SAF business archetypes

To drive the SAF market forward, all industry stakeholders will need to make a proactive and collective effort. This in turn requires the identification, establishment, and active engagement of the following sustainable and self-sustaining business archetypes (*see below*).

SAF business archetypes



Source: Strategy& analysis

We expect the following SAF commercial roles or business archetypes to evolve, in either pure-bred or combination form:

1. Feedstock provider

With a cost share of 50 to 60% of HEFA-based SAF, feedstock is the biggest contributor to the total cost of this subtype of fuel. Given the typically small scale of feedstock originators, the role of the feedstock organizer – collecting biowaste from different sources, pre-processing it, and ensuring steady supply for fuel producers – will become more pronounced, and profitable.

In the case of PtL-based SAF, affordable access to renewable electricity, hydrogen and renewable CO_2 in sufficient quantities will be critical. The first step here is the large-scale generation of renewable electricity, the main cost driver for PtL production. This needs to be available at the highest possible full load hours (the number of hours per year when a renewable energy asset produces electricity at its maximum capacity). Next comes hydrogen production, a key element for further synthesis. Here, it makes sense to produce the hydrogen locally – as close as possible to the PtL production plant – to avoid adding to the substantial cost of hydrogen transport and storage.

In the best-case scenario, electricity and hydrogen production will be geographically aligned with the carbon capture process. If all three input feedstocks are available as closely to one another as possible this will be particularly advantageous.

2. Technology provider

Another important business archetype along the SAF value chain is the technology provider. This entity can either grow out of traditional engineering companies producing the required equipment and plants used for SAF production processes, such as Fischer-Tropsch, or electrolyzers or be provided by innovative startups.

As it is not only the process, but also the equipment behind it, that must gear up for large-scale production, equipment manufacturers and integrators will need to anticipate the required technologies and prove their scalability potential early on. These improvements in production technologies are eventually expected to reduce both, production cost and production times significantly, increasing the competitiveness of the produced SAF compared to fossil kerosene.

3. SAF producer

The next and arguably most prominent role that needs to be established in the SAF value chain is the SAF producer. Currently, established oil and gas producers as well as startups – as exemplified in our guest posts above – are entering the SAF market. They must not only confirm the feasibility of SAF production technologies, but also demonstrate commercial scaling potential.

Potentially, this business archetype could bear the highest investments. Established players have an advantage here, in being able to renovate and expand their existing facilities to produce SAF, with a lower overall investment cost compared to setting up a new production site.

Beyond production itself, the producer's role could also include transportation of the fuel to the final point of destination (as with fossil oil products currently).

Given the potential for high cost, the role of investors, financial subsidies for startups, and the ability of established companies to leverage current profits in support of sustainable fuel production, is likely to be of critical importance.

4. Fuel-mix provider

Once pure SAF has been successfully produced and transported to the airport, another potential business archetype comes into focus: the mixed SAF fuel provider.

In process terms, the pure SAF needs to be mixed with fossil fuel (currently, up to 50% is certified). The resulting product can then be provided to fueling operators as ready-mixed fuel.

The SAF fuel provider takes care of the physical SAF flow at the airport and must also ensure that the SAF quotas are physically fulfilled.

5. SAF investor

The ramp-up of the SAF supply chain will inevitably require extensive capital expenditure, to finance production facilities and other developments. This creates an opportunity for investors including banks, venture capitalists, and other sources of capital.

6. SAF trader

Beyond the production and handling of the physical SAF and its feedstock, another business archetype involved in the commercial side of the SAF ecosystem is evolving: SAF traders. There is considerable potential for those that can act as an intermediary in the market. This would require the financial capability and bargaining power to buy larger amounts of SAF, for example in form of an offtake agreement; and the capacity to assume the price risk involved (the price of SAF is currently three to five times higher than that of fossil kerosene).

These volumes could then be resold to corporate clients looking to reduce their GHG emissions. In a more mature market, the SAF trader might also take on a 'commodity trader' type role – hedging future prices and/or taking positions, potentially achieving additional margin by speculating.

Thus, the SAF trader can play an important role in the ecosystem. First, in offtaking large volumes of SAF, the trader offers necessary investment security for SAF producers as they establish facilities. Second, where clients lack the bargaining power to secure their share of the limited SAF supply under their own steam, the traders offers commercially optimized access to SAF and reduce their corporate GHG emissions. By facilitating market liquidity, finally, SAF traders will help drive market ramp-up.

Beyond securing SAF quantities, the SAF trader will also need to take on SAF certificate trading, so clients can claim the accountable carbon reduction. A lack of current standard of SAF certificate trading is a potential challenge here though, and is something would-be traders will need to be aware of and continue to track. This also creates the scope for the following business archetype.

7.

SAF certificates tracker and auditor

To ensure SAF's credibility, and to make its use a certified part of meeting sustainability goals, certain sustainability criteria need to be fulfilled. It follows that institutions will need to be established that are able to audit the fulfillment of those criteria.

Meanwhile the flow of SAF certificates will need to be formally tracked to guard against double counting (claims by other parties to associated reduction of GHG emissions, when a company has already realized those sustainability credits).

Both of these endeavors – the set-up and conduction of auditing practices, as well as the establishment of technical support systems – are potential business opportunities.

The SAF offtaker

While a range of new SAF business archetypes is emerging, the role of SAF offtaker is no less vital. This is the party buying or consuming the sustainable aviation fuel – such as an airline or an airline customer – to reduce its GHG emissions. For these parties, SAF is a commodity rather than a business stream.

In its own right, the SAF offtaker plays an important role in the ecosystem by creating and securing the required level of demand for SAF, underpinning the market's development and, therefore, all ensuing business opportunities along the supply chain.

CONCLUSION

SAF is widely recognized as one of the main levers to reduce GHG emissions in aviation. However, while demand is steadily increasing driven by the voluntary market and the urge to comply with upcoming regulations, at the moment supply is insufficient to satisfy long-term demand. Our study shows that currently an interplay of different factors such as high investments under regulatory and market uncertainty, technological development, feedstock scarcity and missing public awareness is hindering the ramp-up of SAF.

Drawing on our findings, we propose a set of solutions across five steps that ecosystem stakeholders now need to address between them:

1 Invest
in demonstration facilities and plant development projects to prove that the technology can produce at mass scale

2 Diversify
feedstock to reduce dependence on availability and price fluctuations

3 Hedge
the financial risk to ensure significant investments

4 Clarify
regulations with a view to providing greater certainty for ecosystem stakeholders

5 Further upskill
corporate customers to increase awareness around the benefits of SAF, and attract new investment

The scale of the task ahead, cannot be solved by a single player. It requires a concerted industry effort in which each stakeholder plays its designated role. The described demand-gap is expected to sustain for the foreseeable future. This will allow producers of SAF to realize healthy profits when entering the market in due time and new business models to evolve. A common vision and international collaboration, underpinned by a healthy pragmatism, will be crucial to ensure that this energy transition happens – and is sustainable.

One thing is certain in all of this: climate change will not wait for human intervention to catch up. Rather, we must act collaboratively now if we are to unlock the potential of SAF within an acceptable and impactful timescale.

SOURCES

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II IATA, 2023, DfT (2023), Reuters (2023), Nikkei Asia (2023)
III Neste (2023)
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V H2Global Stiftung (2023)
VI Volvo (2023)
VII IEA (2021)
IX APEC Energy Working Group (2021)

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