Clean Skies for Tomorrow

WORLD ECONOMIC FORUM

In Collaboration with the Energy Transitions Commission

Guidelines for a Sustainable Aviation Fuel Blending Mandate in Europe

INSIGHT REPORT

JULY 2021

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Contents

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Executive summary

The World Economic Forum's *Clean Skies for Tomorrow* (CST) initiative is a coalition of leaders throughout the aviation value chain facilitating the transition to net-zero flying by mid-century. A public-private-partnership, CST is focused on advancing the deployment of sustainable aviation fuels and other clean propulsion technologies. CST also serves as a key aviation industry pillar within the Mission Possible Partnership, a broader alliance of leaders focused on decarbonizing the world's highest emitting industries.

In the context of the European Green Deal, European members of the CST community developed in 2020 a Joint Policy Proposal to accelerate the transition to net-zero CO_2 emissions in aviation in Europe, with a particular focus on increasing the uptake of SAF over the next decade to start reducing emissions from the sector and to develop the value chain and bring SAF costs down.

The aviation industry is beginning to orient itself towards the need for a sustainable aviation fuel blending mandate in Europe. This policy mechanism and accompanying measures will initially be defined at the European Union (EU) level in the ReFuelEU legislative proposal, which aims to boost sustainable aviation fuel supply and demand in the EU. However, the level of the mandate and the exact design of this policy mechanism remain to be determined. This new and more detailed report provides an industry-backed view of the feasible ramping up of SAF production in Europe (which could serve to underpin the level of the blending mandate), a set of recommendations on the design of a sustainable aviation fuel blending mandate, and important considerations about how to mitigate any competitive distortions that may arise, particularly for airlines and airports.[1]

This report aims to outline and address key considerations regarding the feasibility of an SAF blending mandate. It emphasizes the importance of supporting airlines as they face initially higher fuel costs – to bridge that cost differential and protect them against any risk of competitive distortion – and outlines how support to fuel providers in the initial stages of the SAF scale-up can help unlock economies of scale that will benefit the whole sector.

Across Europe, a host of projects have been announced that aim to bring SAF production capacity online in the next five years. In theory, if all the projects announced were to materialize within expected timelines and these plants optimized production for jet fuel, these projects alone could deliver a maximum of 3 million tonnes (Mt) per year of SAF output, which is about 5% of European jet fuel demand.[2] However, in the absence of a strong policy signal to maximize outputs for aviation, existing obligations in other sectors (including road transport fuel mandates) may lead fuel providers to make fuel optimization decisions that would limit European SAF production to 1.5-2 Mt/year by 2025, which would then cover between 2.5-3% of European jet fuel demand.[3] These numbers do not account for SAF imports, which will add an upside to the availability of SAF for European aviation.

> Public investment support for new sustainable aviation fuel plants could be €120 billion in total over the next 15 years.

Analysis conducted for this report finds that **SAF production can feasibly ramp up to 10% of total European jet fuel consumption by 2030 (about ~6.5 Mt/year)** provided that:

- A strong long-term policy framework is introduced promptly to support both airlines – protecting them against any competitive distortion – and fuel providers – to facilitate the financing of SAF plants;
- SAF pathways with lower technology readiness levels reach commercial-scale production, with some public support to de-risk first commercialization efforts;
- Appropriate policies drive higher production/collection of sustainable biomass, in particular wastes and residues, to meet growing demand and prevent any feedstock availability issues;
- SAF production capacity is optimized for jet fuel output.

These projections have been developed using the strict sustainability criteria with regards to feedstocks detailed in previous CST reports.[4] A significant proportion of this output can come from projects that are already planned but which will require unequivocal policy and financial support to be realized. The rest of the volume would come from newly developed projects, unlocked by a favourable long-term policy framework, most likely to come online from 2025 onwards given lead times for those industrial developments.

Achieving this level of SAF production will require **preferential access for aviation to sustainable sources of biomass**. European CST members strongly believe that aviation should be a priority use-case sector for biomass due to the lack of cost-effective alternative decarbonization options, whereas the power, residential heating or road transport sectors can, over time, continue to turn to increasingly cheaper renewable electricity-based technology options. In that context, **renewable fuels capacity should be optimized for SAF production, particularly after 2030**. Since SAF plants will always produce a fraction of output as road fuel, the growing number of SAF production facilities will continue to cater to the remaining needs of other mobility sectors as these sectors continue to decarbonize.[5]

While the introduction of the mandate is essential to the deployment of SAF, it will be insufficient to unlock investments in the SAF supply chain. Reaching the desired levels of SAF production in Europe will also require **significant public financial support to de-risk private investments in the SAF supply chain and to bridge the cost differential between SAF and conventional jet fuel for off-takers.**

Analysis for this report estimates that **public investment support for new SAF plants could be in the order of €120 billion in total over the next 15 years** to partially de-risk private investments in SAF production plants. This support could be provided in the form of development capital or loan guarantees. The bulk of that amount (approximately €110 billion) would go to supporting the commercialization of lignocellulosic production pathways and to power-to-liquid production pathways, which are currently at a lower technology readiness level than the hydroprocessed esters and fatty acids (HEFA) route. HEFA plants, which are currently the cheapest and most technologically ready option, would require less support as the introduction of the blending mandate should provide sufficient certainty of future demand to underpin the business case for investment.

“ A global SAF blending mandate solution would be optimal in driving the decarbonization of the whole industry while keeping a level playing field.

In parallel, **airlines – and to a lesser extent airports – will also need financial support mechanisms to bridge the cost differential between SAF and conventional jet fuel, and to mitigate the risks of competitive distortion and fuel tankering** that could be caused by the introduction of the SAF mandate in Europe. These would need to be maintained until a global scheme is in place and ensures a level playing field across the sector internationally. Initial assessments indicate that flights at risk of re-routing – intercontinental and feeder flights – represent about 10% of total traffic and that 5% of those might be impacted in the next 10 years on average. When the mandate is applied to all departing flights, revenue losses from re-routed passenger traffic would primarily be felt at major hub airports, where most of the international and transfer traffic is concentrated, and by airlines that primarily operate intercontinental flights. Higher blending levels, in the absence of a global playing field, would have a bigger impact on EU hub airports and could reduce connectivity both within and outside the EU. Tankering risks would be relatively low as long as the blending mandate is applied to all departing flights in Europe and European states adopt a harmonized policy framework.

European CST members also collaboratively developed a series of recommendations for the **optimal design of the SAF blending mandate**. Following extensive consideration, CST members recommend the following options to optimize the design of the SAF blending mandate:

- The SAF blending mandate could be **efficiently implemented via an obligation on fuel suppliers** in Europe, which is easier to operationalize and would limit competitive distortion risks if the policy framework applies the SAF differential to all departing flights.

- A global SAF blending mandate solution would be optimal in driving the decarbonization of the whole industry while keeping a level playing field. Yet, a uniform regional policy will play an important transitional role and would avoid extra competitive distortion and tankering risks from different national mandates. The EU should also continue to work at the International Civil Aviation Organization (ICAO) level to find a joint global solution to increase SAF uptake.

- The SAF blending mandate could be **implemented either via a volumetric target or via a greenhouse gas (GHG) intensity reduction target**. The former option would likely provide greater certainty of future SAF demand volumes and could therefore be more effective in de-risking investments in new SAF plants; but the target should be combined with minimum threshold requirements for SAF based on life cycle greenhouse gas emissions intensity, to be tightened over time.

- The SAF blending mandate should include **sub-targets for novel technological pathways** (lignocellulosic and power-to-liquid routes) with lower technical readiness levels to support their rapid deployment and accelerate their cost reduction.

Introduction

The aviation industry finds itself in the midst of an unprecedented crisis. Travel restrictions arising from the COVID-19 pandemic have caused an historical collapse in revenues for the industry, with a reported 70% year-on-year fall in revenue passenger kilometres in Europe in 2020.[6] Passenger traffic is not expected to return to pre-crisis levels until at least 2024.

Despite this challenge, the industry remains committed to reducing its climate impact and is actively collaborating to ensure it can play its part in meeting the objectives of the Paris Agreement. Through the *Clean Skies for Tomorrow* coalition (CST), leading companies from the aviation value chain are co-developing plans to accelerate the decarbonization of the aviation sector, with the objective of reaching net-zero emissions by mid-century.

Among the actions the aviation sector will need to deliver to achieve net-zero emissions in 2050 – including technological improvements in engines and airframes, and operational enhancements in air traffic management and carbon removals – sustainable aviation fuels (SAF) are indispensable, especially for long-haul flights. SAF are available for use today and can offer a 75-100% reduction in CO_2 emissions relative to fossil-based jet fuel.[7] They also have the significant practical and financial advantage of not requiring any major new equipment or infrastructure investments, as they can be directly blended with conventional jet fuel in existing aircraft.[8] Additionally, there is emerging evidence that the use of SAF has significant non-CO_2 benefits and greatly contributes to decreases in radiative forcing[9] and improvements in local air quality by reducing the formation of contrail-cirrus and sulphur dioxide emissions, respectively.[10]

Over the last year, there has been a groundswell of support for the acceleration of the use of sustainable aviation fuels to decarbonize the industry. However, today's commercial production of SAF is only approximately 0.05% of total European Union (EU) jet fuel consumption. The current pace of growth is nowhere near what is required to meet Europe's climate objectives. For the aviation sector to reach net-zero emissions by 2050, the production and use of SAF must ramp up rapidly in the immediate future.

In October 2020, the Clean Skies for Tomorrow Joint Policy Proposal developed by European CST members set out a series of aligned policy perspectives to support the large-scale commercial deployment of SAF as part of the European Green Deal. In this proposal, European CST members call for the implementation of the following key measures to simultaneously support the technological development and early deployment of SAF (priorities 1-3) and drive up SAF demand (priority 4):

1. *Support innovation to bring lignocellulosic/ biowaste and power-to-liquid pathways to market.*

2. *Support SAF provision through price floors guaranteed by governments during the early stages of deployment.*

3. *Support early deployment by de-risking investment in the first wave of production facilities.*

4. *Announce in 2021 an SAF blending mandate for European aviation to be enforced no later than 2025, with a blending level increasing progressively through to 2050.*

While government financial support for SAF producers is essential to increasing production volumes over the next 10 years, it will be insufficient in providing a strong business case for the development of SAF plants at an industrial scale in the absence of certainty on future demand levels. It is therefore crucially important that an SAF blending mandate be introduced in 2021 to provide greater certainty on future demand, unlock investments in the SAF provision value chain, and ensure the European aviation industry can be on a path to net-zero emissions by 2050.

As noted in the CST Joint Policy Proposal, SAF should eventually be deployed on all flights to decarbonize long-haul aviation. In the short term, a blending mandate applied to all flights departing from Europe would be easier to implement and would be the optimal solution for decarbonizing the sector. However, this could potentially lead to opposition from other parties outside Europe and hinder progress on global climate discussions within the International Civil Aviation Organization (ICAO). The application to intra-European flights only (including the United Kingdom and Switzerland) could limit those political risks but higher blending percentages would be required to grow the SAF supply chain to the same volumes and not slow down cost reductions. The cost differential arising from these higher blending percentages could in turn lead to a growing number of end-users opting for destinations outside the mandate area. Actively engaging with non-European countries in bilateral, multilateral and supranational discussions, particularly at the ICAO-level, to press for an effective international SAF blending mandate will be key to progressing SAF penetration in the medium term and could be instrumental in creating a consistent global approach.

This report serves as a sequel to the October 2020 CST Joint Policy Proposal and focuses on outstanding questions relating to the implementation of a European SAF blending mandate, which policy-makers are currently considering.[11]

The report is structured in four sections, focused on the following objectives:

1. Establish a profile for the feasible ramping up of SAF production in Europe from 2020 to 2050 to inform the level of the proposed SAF blending mandate over time;

2. Estimate the level of public financial support required to meet this volume of SAF production;

3. Assess the potential scale of competitive distortion effects from the introduction of the policy and consider options for their mitigation.

4. Propose solutions to currently unresolved questions relating to the design of the SAF blending mandate.

Part 1

SAF production ramp up feasibility & blending mandate implications

Assessing Europe's SAF production potential.

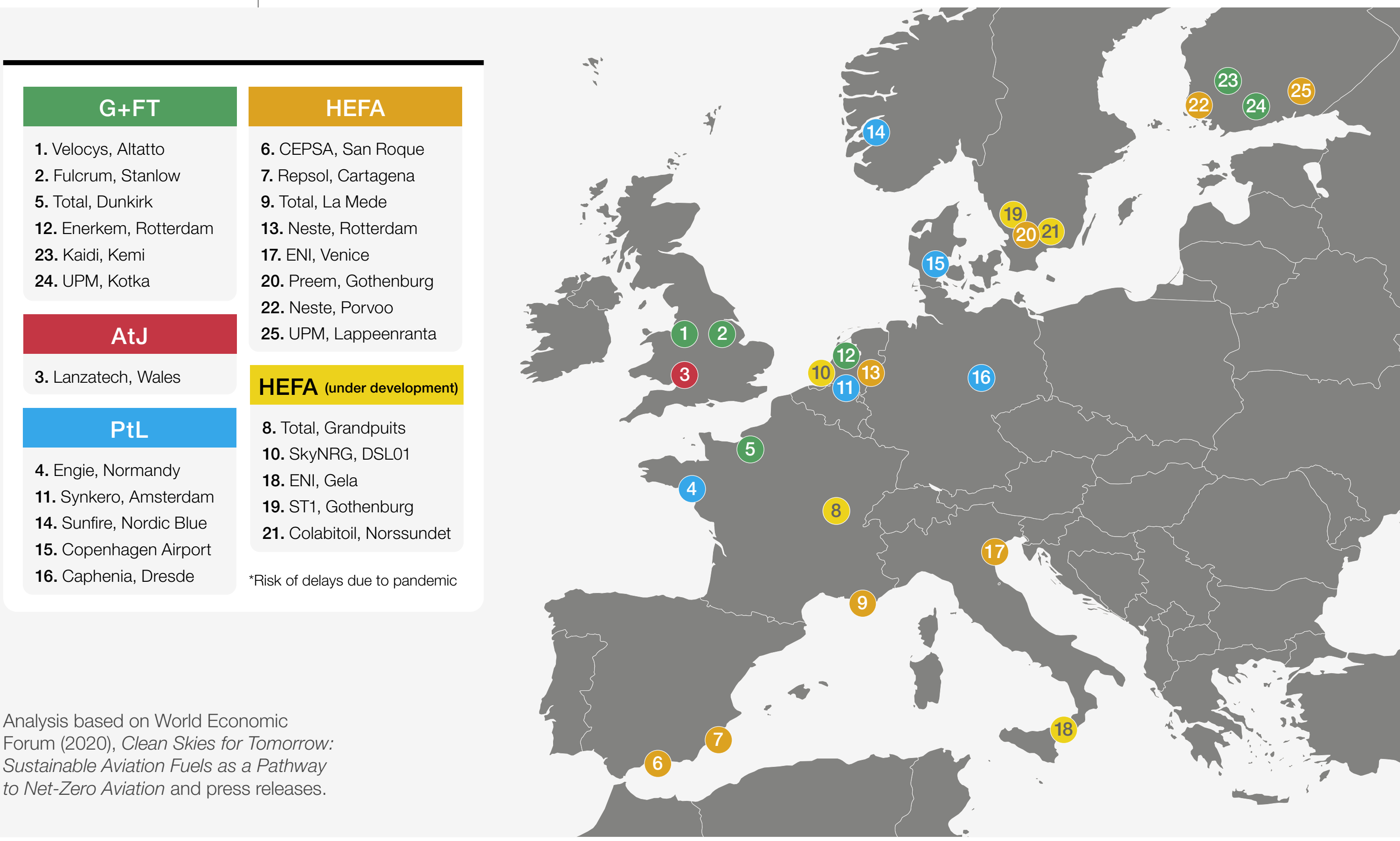
This section establishes the future SAF production potential in Europe considering sustainable feedstocks described in section 2 of the CST Joint Policy Proposal. In summary, this excludes the use of biomass feedstocks that compete directly with land for feed/food production; but it includes crops derived from degraded/marginal lands and cover crops meeting life-cycle emissions criteria (including from indirect land-use change). It includes residual and waste lipids, lignocellulosic and biowaste feedstocks, and power-to-liquid fuels. It also includes a transitional role for recycled carbon fuels to ramp up SAF capacity in the short to medium term[12, 13] but requires that SAF be derived only from renewable sources by mid-century. All states participating in the fuel mandate should apply the same eligibility criteria for feedstocks to avoid a complex patchwork of regulations across Europe.

1.1 How quickly can SAF production ramp up in Europe in the next 30 years?

The European Commission is currently assessing the potential speed and scale of the growth in SAF production from 2020 to 2050 as part of the ReFuelEU legislative process. The results of this process are crucially important as they will underpin the level of the proposed blending mandate in each year over this period.

The SAF mandate should be set at such a level each year that it supports the development of SAF production capacity in line with a net-zero trajectory, and in particular reaches a volume of production high enough to unlock learning effects and economies of scale before 2030. But the blending level should not expose the sector to excessive technological and financial risk, nor create any risk of insufficient supply in the face of growing demand that would drive prices up, as this would undermine the objectives of the policy. These tensions are particularly important to navigate before 2030 given the low commercial readiness of some of the key production pathways and the respective lead times to bring new production capacity on the market, although they are expected to go down after 2030. The feasible level of the blending mandate in 2025 and 2030 therefore depends on a robust assessment of future production capacity and on the effectiveness of the supporting policy framework.

FIGURE 1 **Announced projects in Europe with SAF production capacity, 2020–2025**



Analysis based on World Economic Forum (2020), *Clean Skies for Tomorrow: Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation* and press releases.

Across Europe, a host of projects to bring SAF production capacity online in the next five years has been launched (see Figure 1 and Figure 2). There are currently at least eight existing facilities and around 20 new plants or expansions at existing sites being planned (five of these are currently pilot and demonstration facilities), with the ability to jointly produce a theoretical maximum of approximately 3 million tonnes (Mt) of SAF per year, which is about 5% of European jet fuel demand.[14] However, in the absence of a strong policy signal to maximize outputs for aviation, existing obligations in other sectors (including a road transport fuel mandate) may lead fuel providers to make fuel optimization decisions that would limit SAF production between 1.5-2 Mt/year by 2025, which would then cover between 2.5% to 3% of European jet fuel demand.[15]

These projects will not materialize without: 1) an SAF blending mandate that provides certainty of demand for future output; 2) large-scale private capital investment; 3) major government financial support to de-risk this private investment.

FIGURE 2 **Capacity at sites with SAF production potential, all outputs**

	Supplier	Country	Site	Tech.	Start/Expansion	Total fuel capacity (Mt./yr.)
Existing facilities / Expansions	**Neste**	Finland	Porvoo	HEFA	–	0.4
	Neste	Netherlands	Rotterdam	HEFA	–	1.3
	UPM	Finland	Lappeenranta	HEFA	–	0.1
	Total Energies	France	La Mede	HEFA	–	0.5
	Cepsa	Spain	San Roque	HEFA	–	0.1
	Repsol**	Spain	Cartagena	HEFA	2023	0.2
	ENI**	Italy	Venice	HEFA	2024	0.4
	Preem**	Sweden	Gothenburg	HEFA	2025	1.0
New projects	**Enerkem***	Netherlands	Rotterdam	G+FT	2021	<0.1
	Colabitoil	Sweden	Norssundet	HEFA	2021	0.5
	ENI	Italy	Gela	HEFA	2021	0.5
	ST1	Sweden	Gothenburg	HEFA	2022	0.2
	Kaidi*	Finland	Kemi	G+FT	2022	<0.1
	SkyNRG	Netherlands	DSL01	HEFA	2023	0.1
	Sunfire*	Norway	Nordic Blue	PtL	2023	<0.1
	Caphenia*	Germany	Dresden	PtL	2023	<0.1
	TotalEnergies	France	Grandpuits	HEFA	2024	0.2
	SkyNRG / LanzaTech	TBD***	FLITE	AtJ	2024	0.0
	Preem	Sweden	Lysekil	HEFA	2024	0.7
	Neste	Netherlands	Rotterdam	HEFA	2025	1.0
	Velocys	UK	Altalto	G+FT	2025	0.1
	LanzaTech	UK	Wales	AtJ	2025	0.4
	UPM	Finland	Kotka	G+FT	2025	0.5
	Fulcrum	UK	Stanlow	G+FT	2025	0.1
	Synkero	Netherlands	Synkero†	PtL	2027	0.1
	Engie*	France	Normandy‡	PtL	TBD	TBD

HEFA G+FT PtL AtJ

Source: Analysis based on World Economic Forum (2020), "Clean Skies for Tomorrow: Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation" and press releases.

Note: List is not exhaustive. Timelines assume delay for projects announced pre-COVID-19.

*Pilot/demonstration facilities not counted towards future productive capacity estimates.

**Expansion or re-configuration of existing sites. Map does not include co-processing facilities – e.g. ConocoPhillips plant in Cork, Ireland & Galp Energeia in Sines, Portugal.

***Joint venture of the FLITE consortium, led by SkyNRG and Lanzatech, with funding support provided from the EU H2020 programme. The final location of the planned site is yet to be announced.

†Led by Synkero, a project development company, in collaboration with partners SkyNRG, the Port of Amsterdam, Royal Schiphol Group, and KLM. Production is set to commence at low levels after 2025 so is not included in the subsequent figures in the text.

‡Joint venture between Engie, Safran, ADP, Airbus, Sunfire, and Air France-KLM. The year of operation and expected output is yet to be announced.

SAF production can feasibly ramp up to 10% of total European jet fuel consumption by 2030.

The Energy Transition Commission (ETC) has conducted a techno-economic feasibility assessment of the potential ramp up of SAF production in Europe between 2020-2050, which it hopes can inform the proposed level of SAF blending in Europe.[16] This exercise was conducted in collaboration with CST coalition organizations, leveraging technical expertise spanning the aviation value chain, and builds on the foundational analysis of previous *Clean Skies for Tomorrow* reports.[17]

Analysis for this report finds that, if strong policy support is introduced immediately, SAF production can feasibly ramp up to 10% of total European jet fuel consumption by 2030. A quarter of this output can come from projects that are already planned, which will require both policy and financial support to be realized. Unlocked by a favourable long-term policy framework, the rest of the volume would come from newly developed projects from 2025 onwards given lead time for the legislative process to be concluded and for those industrial developments to then be realized. See Appendix A: Methodology for sustainable aviation fuel production ramp up feasibility assessments for results from different modelling scenarios.

Figure 3 shows the possible breakdown of potential SAF output from different sources in Europe between 2020 and 2050, taking into account expected technology developments and tight sustainability constraints, especially for biofuels. This represents the central case scenario of the CST modelling exercise, which is based on the following key assumptions:

1. New technologies (gasification + Fischer-Tropsch – G+FT, alcohol-to-jet – AtJ, power-to-liquids – PtL) overcome technical barriers for production at scale and reach commercial readiness within assumed project timelines before 2030.

2. Strict sustainability criteria are taken into account, supported by effective and transparent monitoring, verification and reporting mechanisms.[18]

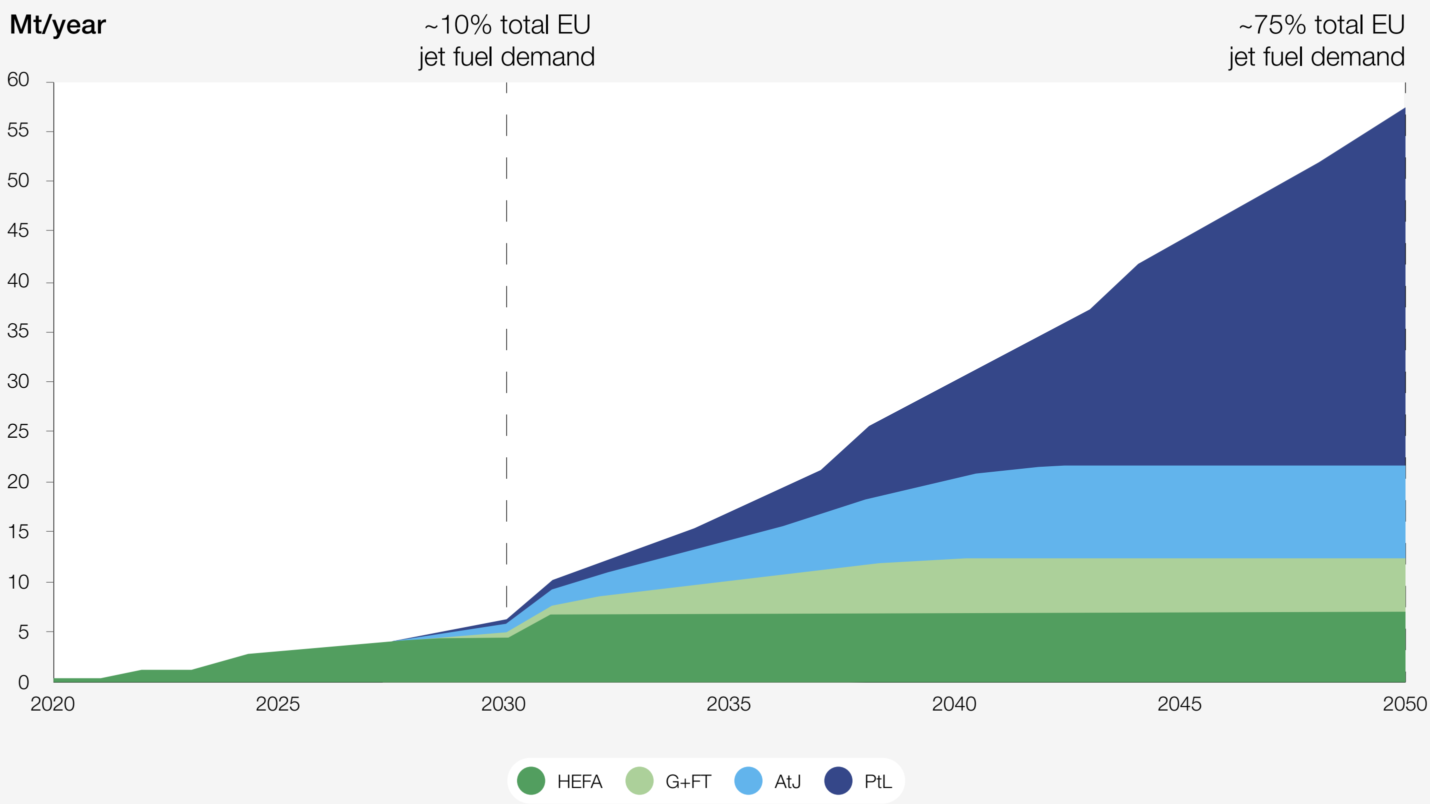
3. All planned projects to 2025 are completed and become operational on time.[19]

4. Once output to meet current existing obligations in other sectors (such as road transport) is met, all new and existing sustainable fuel plants with the capacity to produce SAF optimize output for jet fuel.

5. Sustainable biomass resources are focused for use in aviation – with 40% of total biomass that is sustainably available in Europe dedicated to jet fuel production. This is discussed further in Part 4: Design options for a European SAF blending mandate.

This central case scenario does not, however, consider the potential to use imported biomass and power-to-liquid fuels from other regions of the world. If potential imports of sustainable bio-feedstock or biofuels were available – in a context in which the European market is expected to grow faster than the rest of the world in the next 10 years due to more ambitious

FIGURE 3 **Feasibility assessment results – SAF output by technology pathway**



policy measures and other regions are able to generate a domestic surplus – this could add a significant potential upside to the availability of SAF for European aviation and serve as a buffer to compensate for eventual delays in the deployment of new technologies in Europe. Assuming the EU imports 15% of the global sustainable feedstock that can easily be transported over significant distances, SAF output in Europe could reach 20% by 2030.[20] This assumes that those imports would shrink and domestic production would replace them once the rest of the world's aviation sector increases its SAF use from 2035 onward. Strong safeguarding mechanisms to monitor, verify and report on the aforementioned sustainability criteria would be required to ensure feedstocks comply with those and that no fraud or mislabelling of products occurs.

As shown in Figure 3, the build-up of SAF production is expected to take place is three stages:[21]

– In the first instance, the argument is that the full potential of the hydroprocessed esters and fatty acids (HEFA) conversion process to produce SAF should be harnessed, while paying particular attention to the sustainability of feedstocks used. HEFA is currently the only production process commercially available at scale and the cheapest technology, offering considerable carbon savings (73-84% life-cycle CO_2 emissions savings vs fossil jet fuel) for the sector over the coming years. While domestic supply from waste and residue lipids is likely able to meet approximately 5% of total European jet fuel demand, a significant upside may be available via imports from other regions and oils derived from cover crops or crops from marginal/degraded lands.[22]

– From 2025 onward, new capacity will come online from the conversion of lignocellulosic biomass and biogenic waste sources to SAF via the G+FT and AtJ processes. While these technologies are yet to be available at scale commercially today, the biomass feedstock sources they use are relatively abundant and offer significant co-benefits for the agricultural, forestry and waste industries.[23]

– The largest volume of SAF in the long-term, especially from the mid-2030s onwards, will come from the PtL route, producing synthetic fuels (also called synfuels or e-fuels) derived from renewable electricity, water and CO_2 [24]) which will see the largest potential future reduction in production costs and will likely be more cost-competitive than other solutions by mid-century, falling an estimated 67% to reach $1,300 per tonne of jet fuel by 2050.[25]

It is important to note that there is a trade-off between the level of ambition of the blending mandate and the eligible feedstocks included in the scheme. If policy-makers were to exclude certain feedstock options considered in this analysis (in particular waste and residue lipids), the speed of the ramp up of SAF output would be much slower than suggested in these projections, especially in the next 10 years.

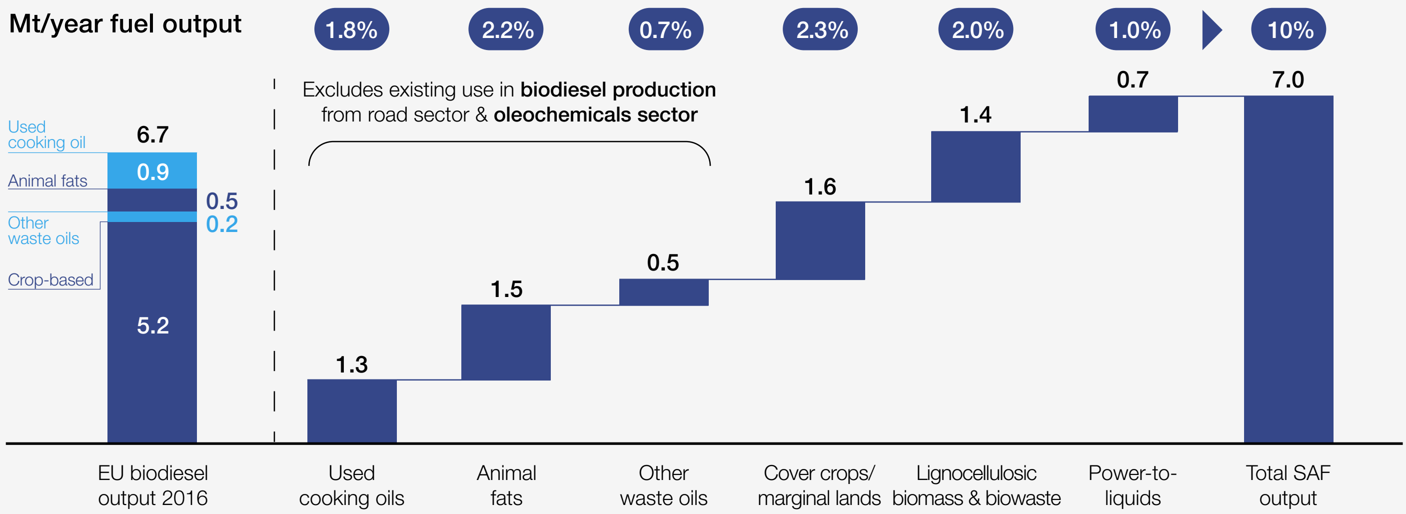
Once these technologies are fully commercialized, with established sustainable bio-feedstock supply chains and a large supply of variable renewable electricity for synfuel production, they will be able to deliver large volumes of SAF output and meet the needs of the European and global aviation industry. Additionally, technology improvements will allow SAF plants to gain in efficiency and deliver a higher share of jet fuel as a fraction of total fuel output, further boosting capacity. It is clear, though, that the full portfolio of SAF production routes will be required to decarbonize the aviation sector, as no single technology will be able to fully meet the large and growing demand for jet fuel in Europe.

1.2 What will it take to increase SAF production to meet 10% of European jet fuel consumption by 2030?

To meet this goal, a sustainable aviation fuel blending mandate ramp up in the range of 2-5% of European jet fuel consumption (~1-3 Mt/year) by 2025 is an appropriate trajectory. The level of the blending mandate for 2025 will determine the rate at which new and existing plants transition to optimize their production for SAF vs other use cases. A more aggressive target will accelerate this shift, while a more conservative target will cause a more gradual change over time. It is likely that output from currently planned new SAF plants in Europe could meet a large part of this target, with considerable upside potential from optimizing existing facilities for SAF production, as well as short-term imports of underused sustainable feedstocks from other regions. The introduction of a blending mandate at this level would provide the strong business case required to develop this capacity.

By 2030, a range of SAF production pathways will need to be jointly harnessed to maximize SAF output and emissions reduction. Figure 4 shows a breakdown of the different feedstocks and associated technological pathways that, combined, would enable Europe to reach 10% SAF uptake (~7 Mt/year) in its civil aviation operations by 2030. For comparison, the current annual production of biodiesel from domestic European feedstocks for the road sector is 6.7 Mt/year, which was largely developed in the last decade since the introduction of blending mandates in this sector.[26] This suggests that the speed of deployment is achievable; however, unlike in past experience, a sustainable aviation fuel blending mandate should not rely on crop-based biofuels from dedicated land with high impact on land-use change. As noted above, this target also requires the development novel technological production processes that require support to commercialize at scale.

FIGURE 4 **SAF production potential by feedstock in Europe in 2030**



Source: Analysis based on World Economic Forum (2020), *Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation* and ECOFYS (2019), *Technical Assistance in Realisation of the 2018 Report on Biofuels Sustainability*.

Note: Other waste oils includes tall oil, fish oil and technical corn oil, but does not include palm oil by-products palm oil mill effluent (POME) or palm fatty acid distillate (PFAD). Assumes HEFA plants able to achieve 70% SAF output in product slate by 2030.

As shown in Figure 4:

– HEFA produced from domestic sources of waste and residue lipid could jointly cater for almost 5% of total European jet fuel consumption. This excludes domestic EU feedstocks already used in other sectors – including the 1.5 Mt/year used in current biodiesel production for the road sector and demand from the oleochemicals industry.[27] Note that this figure will be lower if other sectors – such as road transport – claim an increasing share of these feedstocks.

– An additional 2.3% (~5 Mt/year) could be met via the HEFA route using oils derived from cover crops or crops grown on marginal/degraded lands. Biomass supply from these sources could theoretically provide up to 10% of total jet fuel supply by 2030;[28] but considerable support will be required to make this a feasible and attractive option for farmers, including financial incentives and training.

– The remaining 3% of jet fuel would have to come from currently less technically mature technological pathways.

A sustainable aviation fuel blending mandate should not rely on crop-based biofuels from dedicated land with high impact on land-use change.

– 2% could be derived from lignocellulosic biomass and biowaste sources via the G+FT and alcohol-to-jet pathways. In the next decade, these will likely remain 3-4 times more expensive than conventional kerosene, so securing demand for output via a blending mandate and providing plant-level financial support will both be essential.

– PtL synfuels, which are currently the most expensive SAF option, are expected to start to come online by 2030 to provide approximately 1% of jet fuel demand.[29] While this is currently the most expensive pathway, several projects are already underway to develop capacity before the end of the decade due to promising long-term cost curves. Various European governments have developed targeted support policies (such as Germany).

Other recent SAF ramp up projections published by different industry groups and experts support the ETC central case scenario:

– It is supported at the global level by broader projections from the Waypoint 2050 report published in September 2020, which find that global SAF uptake of 8-14% by 2030 is required for a decarbonization profile that reduces emissions by 50% by 2050 and achieves net-zero emissions by 2060/65 at a global level.[30]

– It follows a similar profile as the Destination 2050 future SAF profile but has an earlier ramp up of production given the assumption of stronger policy support. This report was developed jointly by a large group of European aviation stakeholders.

– The Sustainable Aviation (UK) estimates are relatively lower as they were devised as part of a broader decarbonization profile for the United Kingdom aviation industry that relies more heavily on market-based carbon removal measures to achieve net zero by 2050.[31]

– A recent International Council on Clean Transportation (ICCT) working paper[32] mentions a lower potential SAF production number for Europe of 5.5% by 2030, as it assumes more conservative technological deployment rates for non-HEFA pathways and does not envision a prioritization of bio-feedstock use for aviation above other sectors (see further discussion in Appendix A: Methodology for sustainable aviation fuel production ramp up feasibility assessments.

– The 26th Conference of the Parties (COP26) High-Level Champions advocate for global SAF use of 2% by 2025 and 10% by 2030 as an aspirational goal that would put the sector on an S-curve trajectory to reach net-zero emissions by 2050.[33]

FIGURE 5 **Comparison of SAF production ramp up forecasts – Europe**

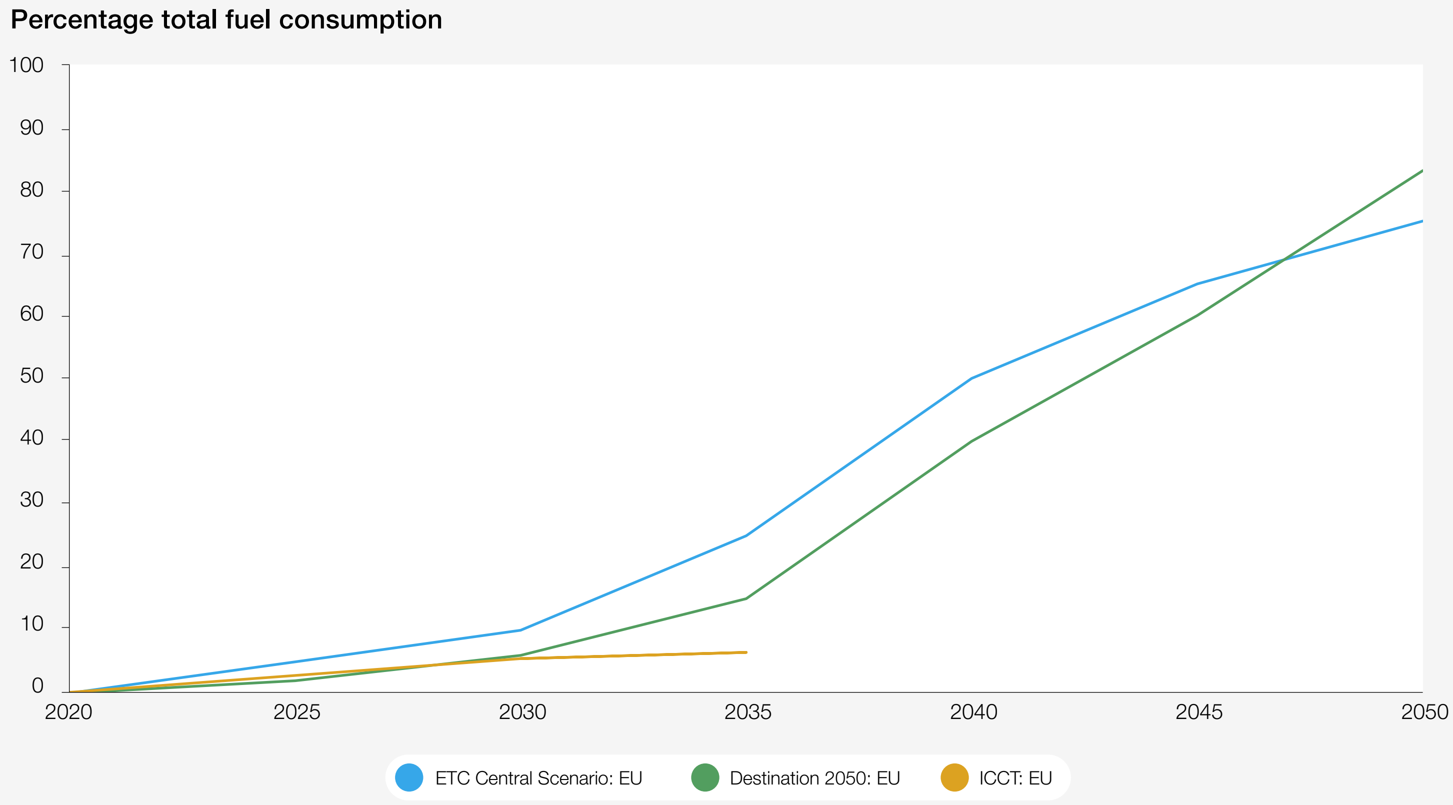
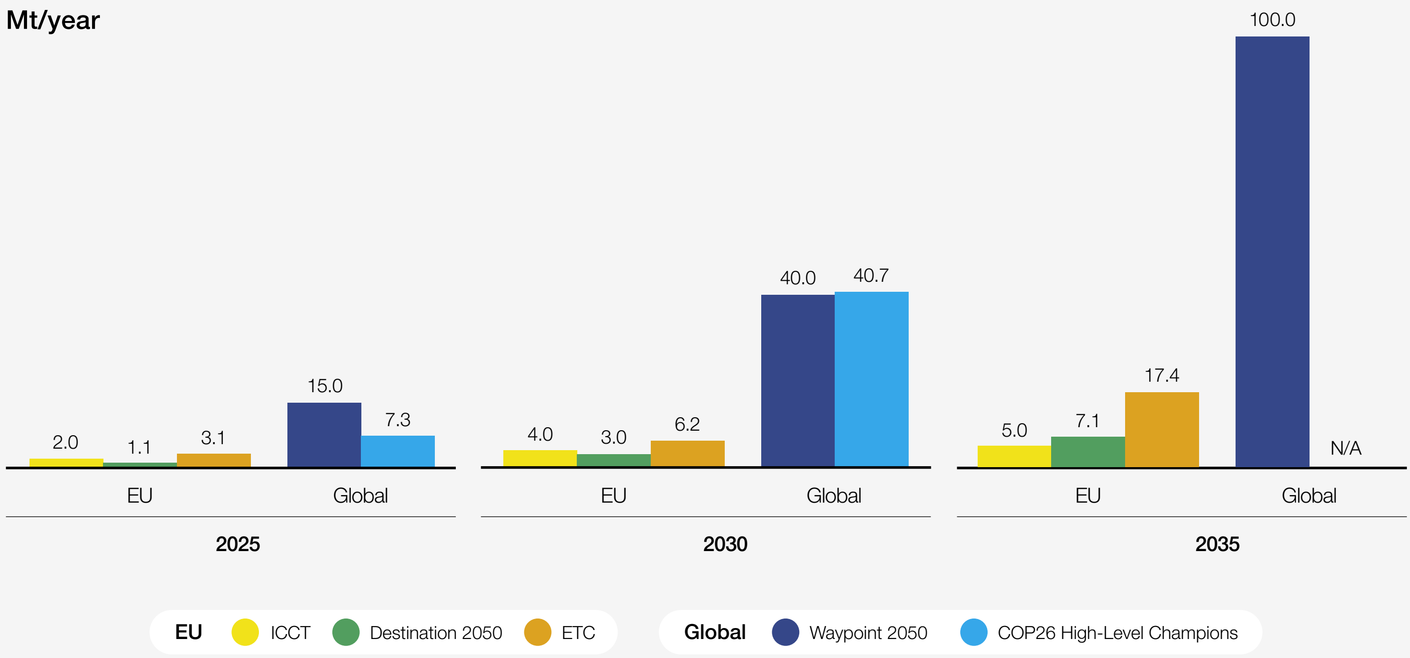


FIGURE 6 **Comparison of SAF production ramp up forecasts**[34]



Based on this analysis and comparison with other available estimates, the signatories of this report view the following SAF blending levels for the proposed European SAF blending mandate as optimal, assuming that the appropriate long-term policy framework is established and sufficient financing made available:

TABLE 1 **SAF blending levels for the proposed European SAF blending mandate**

Year	**SAF blending mandate level in Europe** % total jet fuel consumption
2025	2%–5%
2030	10%
2035	25%
2040	50%

As mentioned above, the choice of the 2025 target will crucially depend on (i) the speed at which the mandate is legislated – as failing to send strong policy signals in 2021 could reverberate in delays to ramp up production – and on (ii) the intended speed of the transition of waste-oil/lipid-based fuel production from optimization for road to optimization for aviation.

Part 2

Public support of SAF production

Reaching the desired levels of SAF production requires concerted public support across the value-chain.

While the introduction of the mandate is essential to the deployment of SAF, it will be insufficient to unlock investments in the SAF supply chain. Reaching the desired levels of SAF production will also require significant public financial support to de-risk private investments in the SAF supply chain, especially to support the commercialization of lignocellulosic and power-to-liquid production pathways, which are currently at a lower technology readiness level than the HEFA route. In parallel, the provision of public support to SAF off-takers will also be required, which is the focus of Part 3: Public support to off-takers to bridge the cost gap and address risks of competitive distortion.

2.1 How many new SAF plants are required for this ramp up in production from 2020 to 2050?

The necessary ramp up in SAF production in Europe will require the development of approximately 30 sustainable fuel plants by 2030 and 250 plants by 2050, depending on average capacity. Of these, 15 projects are already being planned in Europe.[35] The majority of new output before 2030 will likely come from HEFA plants, which are typically larger than the other technologies presented above primarily due to the centralization allowed by transportability of input feedstocks. However, even before 2030, large-scale G+FT, AtJ and PtL plants will need be developed. These types of plants then need to be built out at a rapid and consistent speed until 2050.

SAF plants have project lead times of 3-4 years from the point of inception to operation, once the technology is deployed commercially.[36] It is therefore imperative to unlock planning and approval for new sites as soon as possible to grow output significantly in the second half of the 2020s. This will require strong policy signals in 2021, which can provide some certainty on future markets until at least 2030.

2.2 How much investment is required to realize this production ramp up?

> The majority of capital investment will be required after 2030 to build out new capacity from G+FT, AtJ and PtL technologies.

Total capital expenditure (CAPEX) investments required for the SAF ramp up profile shown above is estimated to be approximately €15 billion per year on average from 2020-2050.[37] The largest proportion of this will be required to finance the development of large-scale SAF production from G+FT, AtJ, and PtL once these technologies are proved at scale.

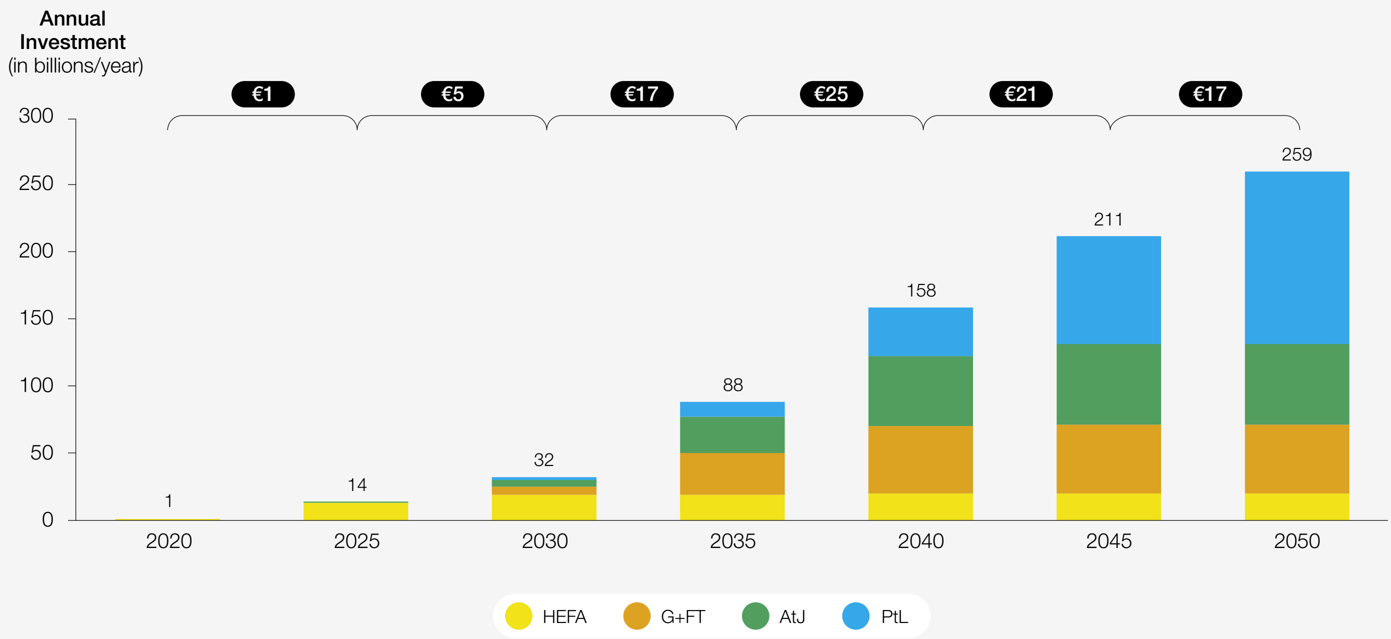
Before 2030, the ramp up of SAF output from HEFA plants is likely to require less than €7 billion in CAPEX investments in total. Just under 20 HEFA plants are required for this level of output by 2030. There are already six facilities in the EU that produce renewable diesel for road transport that could adjust their product slate to optimize for SAF output, if justified by prevailing market prices and policies (see discussion in Part 4: Design options for a European SAF blending mandate). There are also plans to build eight new HEFA plants in Europe before 2025[38] (see Figure 2); six additional plants would also be required beyond these projects. These plants will require the least public financial support, since these are currently the cheapest production route and the demand pull created by the introduction of the SAF blending mandate will create a strong business case for the construction of new plants. However, financial incentives and public support for farmers could nonetheless be required to develop the supply of oils from cover crops and degraded/marginal lands. At present, the cost, time and knowledge required to grow these remain a major barrier for most farmers.[39]

Before 2030, a relatively more limited level of capital investment will be required in the G+FT, AtJ and PtL pathways in order to bridge the gap between HEFA output and the level of demand arising from the blending mandate and to reach a critical scale of production that will unlock learning curve effects and economies of scale to facilitate a fast deployment of those technologies in the 2030s. In the period from 2025 to 2030, once these technologies are proved at scale, total CAPEX investments of approximately €25 billion will be required.

The majority of capital investment will be required after 2030 to build out new capacity from G+FT, AtJ and PtL technologies. From 2030 to 2040, approximately €200 billion in CAPEX will be needed for the construction of lignocellulosic and biowaste conversion facilities, and over €250 billion in power-to-liquid facilities, with the majority of this investment in the production of green hydrogen from renewable electricity, which accounts for roughly two-thirds of total CAPEX for PtL (including generation costs).

These figures could be lowered considerably by converting or reconfigure existing facilities, such as pulp and paper mills or refineries, and by leveraging co-processing at existing sites.[40] For alcohol-to-jet plants, almost half of the investment cost is required for ethanol production, which could instead partially rely on production from existing facilities. For G+FT plants, municipal and industrial solid waste feedstocks could potentially be sourced at negative costs in the future, reducing overall productions costs.

FIGURE 7 **Total number of SAF plants**



2.3 How much public financial support is required to support SAF production in the 2020s?

As established in the CST Joint Policy Proposal, significant public financial support will be required alongside the blending mandate to support this initial SAF production ramp up phase. The type of financial support for SAF deployment will differ by technology type and maturity. This support will likely be phased out progressively in the 2030s and 2040s as SAF becomes more cost competitive.

For SAF pathways at higher technological readiness levels (such as HEFA), public support should mostly be in the form of de-risking mechanisms to crowd-in private capital (for example, tax incentives, loan guarantees), as the blending mandate should provide sufficient certainty of future demand to underpin the business case for investment and the lower price of HEFA compared to other SAF production pathways would facilitate its access to market. Assuming governments have to cover 10% of total capital costs for the development of new HEFA plants, this build-out will require approx. €700 million from 2020 to 2030.

For the less mature pathways (such as lignocellulosic biofuels, power-to-liquids), R&D support will continue to be required to bring these to market at the necessary speed over the next decade. Specific public support for investments will then be required to develop first-of-a-kind and second-of-a-kind plants, as the technology risk associated with these sites will preclude full private financing. This report estimates that the provision of direct government financial support to new SAF plants from G+FT, AtJ and PtL pathways could amount to some €30 billion in the next 15 years, such as in the form of development capital or loan guarantees, to realize the trajectory outlined above.[41]

Additionally, during the early stages of deployment, SAF pathways with higher production costs but with the highest potential to scale and the most sustainable sources of feedstock will likely require government-supported price floors to guarantee sufficient revenue streams. Covering the full price premium between SAF produced from these routes and the cheapest available route (HEFA) is expected to cost a maximum of €15 billion in total from 2025 to 2035, assuming the production mix defined in the ramp up profile above. The introduction of sub-targets within the blending mandate (see discussion in section 4) could reduce the need for such price floors from the late 2020s onward.

Part 3

Public support of SAF off-takers

Bridging the cost gap and addressing risks of competitive distortion.

3.1 What additional costs would SAF off-takers face?

SAF costs can be 2-5 times more than conventional jet fuel or higher. The introduction of the blending mandate is expected to contribute to cost reductions over the years by driving growth in production volumes and related learning curve effects and economies of scale. Previous *Clean Skies for Tomorrow* reports show that the SAF costs from different production pathways could be brought down between 4 to 40% by 2030 depending on the technology readiness levels of the respective processes.[42] Despite this reduction in production costs, the growing SAF blending levels and the increasing proportion of SAF from higher cost routes are likely to continue imposing fuel costs pressures on airlines in the future. Public support to bridge that cost gap will, therefore, be required to ensure the blending mandate does not penalize the European aviation sector.[43]

3.2 What competitive distortions could a SAF blending mandate create?

The introduction of an SAF blending mandate in Europe is a novel and ambitious step in reducing the climate impact of aviation. However, since its geographic scope is limited to participating nations, whereas aviation is by nature a global industry, there are potential risks of causing competitive distortions in the industry. Competitive distortions are the demand effects felt by companies – in particular, airlines and airports – as a result of the uneven introduction of policies across the market. An SAF blending mandate will increase fuel costs for flights that refuel in Europe as it obliges the use of higher cost SAF instead of cheaper fossil-based jet fuel. This will likely cause an increase in ticket prices for end-consumers on affected flights. This could then, in turn, under certain circumstances, cause a reallocation of demand to non-affected flights. Beyond the potential economic impact on the European aviation sector, this would be an issue for the sector's climate goals, as re-routing passenger movements onto longer flights transiting via non-EU/United Kingdom airports would cause carbon leakage into other regions of the world.

The application of an SAF blending mandate at the level of the European Economic Area (EEA) would be a useful step in aligning policies throughout Europe and would avoid competitive distortions within the European area. However, Figure 8 shows that competitive distortions could arise for a subset of European traffic. Assuming the mandate is levied on fuel suppliers, this impact will be felt on all flights departing from European destinations but only certain routes will be subject to competitive distortions. Direct flights into and out of Europe will be unaffected as no alternative routes exist that are unaffected by the mandate. However, transfer flights are exposed to the risk of competitive distortions since passengers can choose to transfer via alternative destinations that are not subject to the mandate. A mandate levied on intra-EEA flights only would not trigger the same scale of competitive distortions.

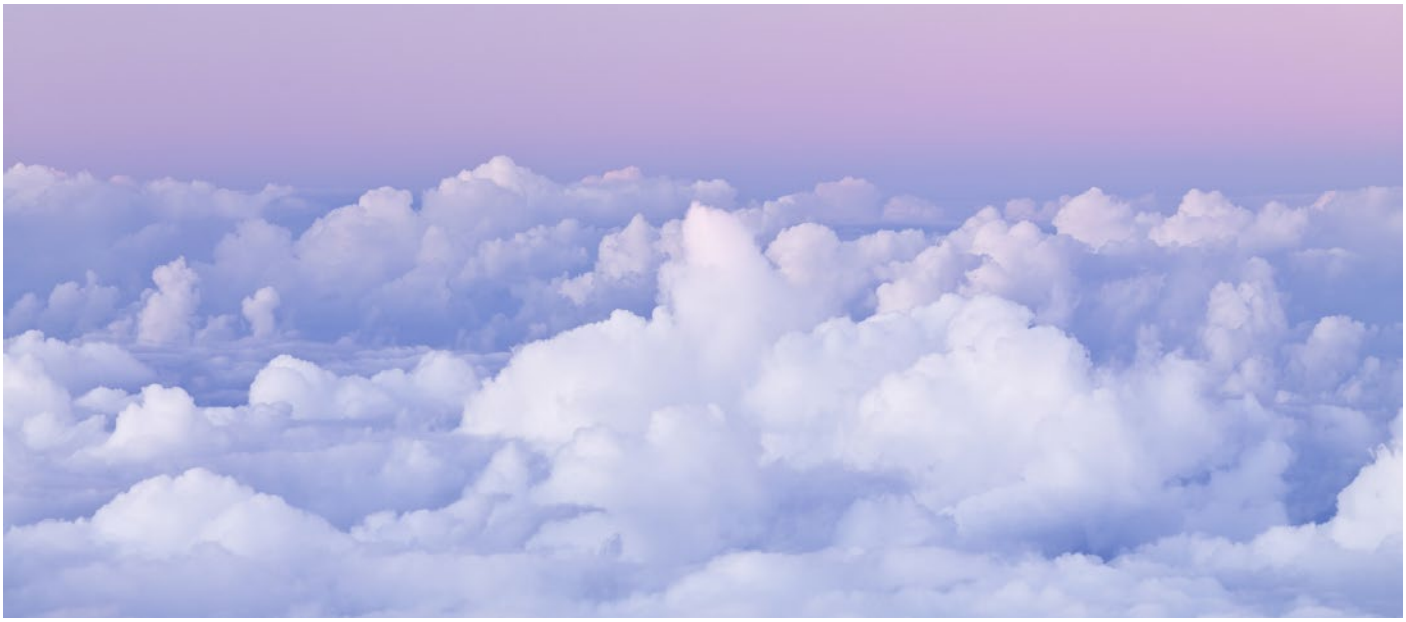
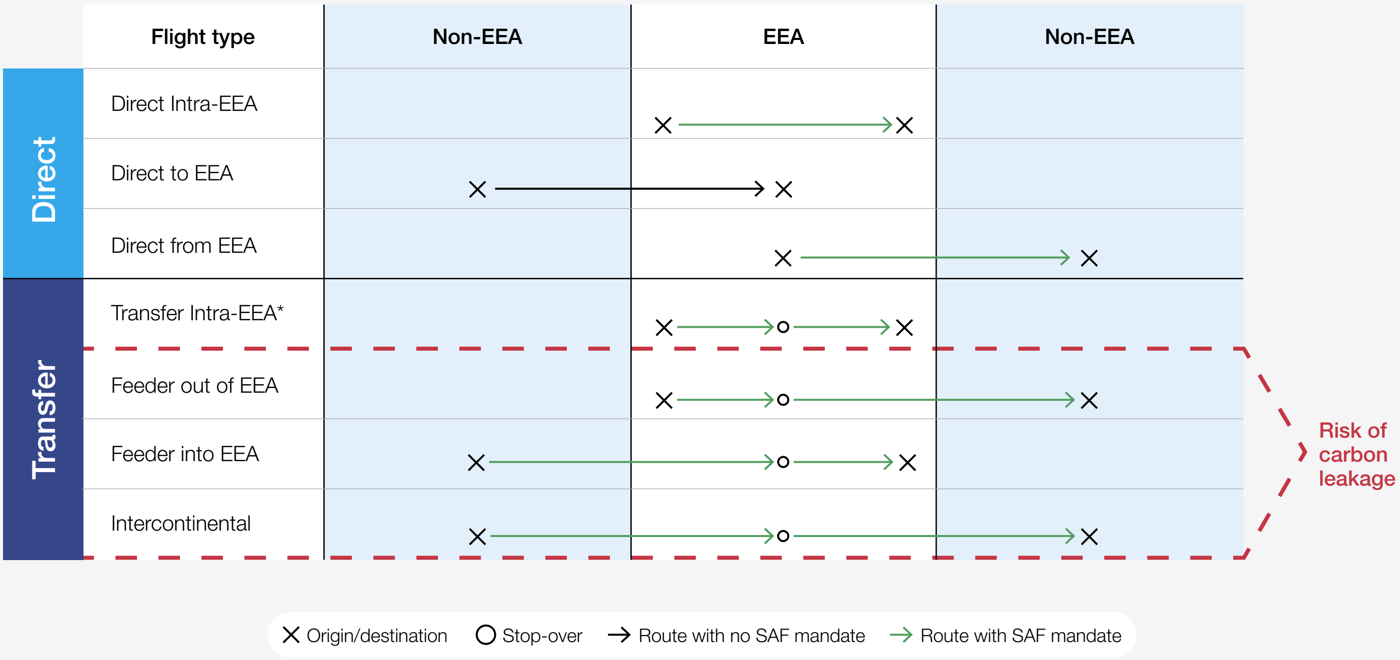


FIGURE 8 | **Competitive distortions could arise for a subset of European traffic**



Note: EU refers to EU-28 countriess including the UK. *At low blending levels there is unlikely to be an incentive for intra-EU transfer flights to re-route via non-EU airports.

Competitive distortions can apply across four different types of transfer flights. These flights are at risk of losing demand due to competitive distortions since passengers can choose to transfer via an unaffected non-European airport instead:[44]

1. **Intra-European transfer flights:** Flights departing from and arriving at a European airport, also transiting via a European airport. These are potentially exposed to competitive distortions but at low blending levels there is unlikely to be an incentive for re-routing via a non-European airport due to the additional costs from extending the journey distance. *Example: Lyon -> Paris -> Vienna*

2. **Feeder flights out of Europe:** Flights departing from a European airport (typically smaller), transferring via a European airport (typically larger or hub airport) to arrive at a non-European destination. *Example: Vienna -> Zurich -> New York*

3. **Feeder flights into Europe:** These are the inverse of the flights described above – they depart from a non-European airport, transit via a European airport to arrive at a smaller European destination. *Example: New York -> Zurich -> Vienna*

4. **Inter-continental transfer flights:** These are flights that depart from a non-European airport, transit via a European airport, and arrive at another non-European destination. *Example: New York -> Paris -> Delhi*

The potential scale of this competitive distortion is difficult to accurately estimate. The increase in ticket prices will depend on: a) whether the blending mandate is levied on all departing flights or only on intra-EEA flights; b) the level of the blending mandate; c) the price premium for SAF vs kerosene; and d) the degree to which this cost increase is passed onto departing flights in Europe for ultimate charging to consumers. The impact on demand will then also depend on: a) the price-elasticity of demand for different types of flights; b) the extent to which areas outside the policy jurisdiction introduce similar initiatives; and c) the availability and practicality of alternative routes that would circumvent areas affected by the mandate.

Moreover, a mandate will likely cause a series of responses from airlines (such as fleet switching and replacement, pricing strategy, adjusted operating margins) and consumers (for example, switching to bus/rail transport modes for shorter distances).

However, an indicative assessment of the volume of flights at risk from a SAF blending mandate indicate that this risk is manageable at lower blending levels, provided additional policy support is in place to mitigate the effects of lost passenger demand as these become more damaging. Initial analysis of passenger data shows that “at risk” flights – meaning feeder flights and intercontinental flights into and out of the EU/United Kingdom – would represent respectively 8% and 2% of total annual traffic in European Union and United Kingdom

“ This risk is manageable at lower blending levels, provided additional policy support is in place.

airports. Assuming that a SAF blending mandate follows the profile established in section 1, the ETC estimates that the total number of passengers lost due to ticket price increases from the mandate will likely be about 5% of total traffic on at-risk flights by 2035, meaning below 1% of total flights on average.[45] These indicative figures provide an order of magnitude of aggregated impact at the European level; however, revenue losses from re-routed passenger traffic would primarily and more intensively impact major hub airports where the majority of international and transfer traffic is concentrated (see Figure 9 and Figure 10), as well as airlines that primarily operate intercontinental flights. A pragmatic policy framework would alleviate the risks identified above based on a granular assessment of their potential impact.

In parallel, the continuous increase in consumer environmental awareness, exemplified by the recent launch of corporate sustainable buyers' alliances and "flight-shaming" campaigns might translate into a future attenuation in traffic loss risks and indicate rising commercial opportunities in green aviation for companies willing to take the lead in achieving net-zero operations.

FIGURE 9 **Transfer passengers from EU to non-EU countries connecting via the EU by airport**

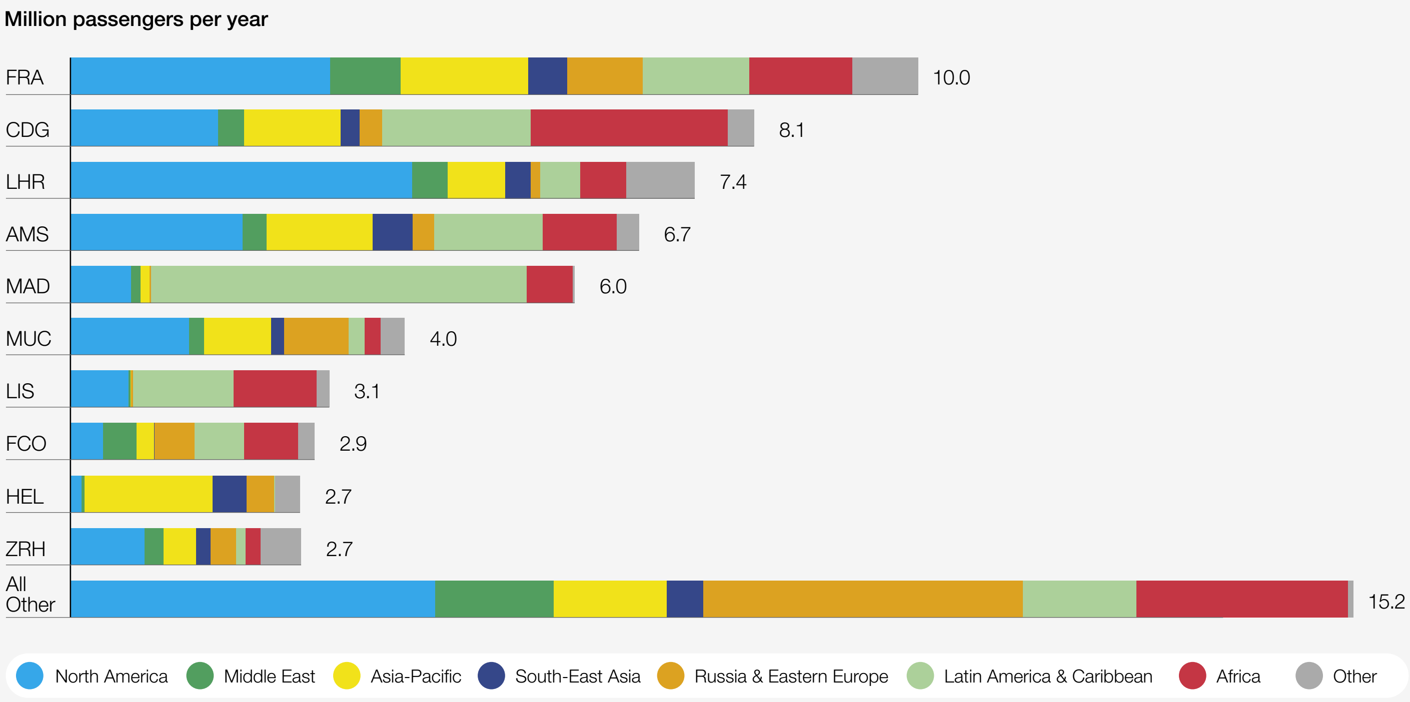
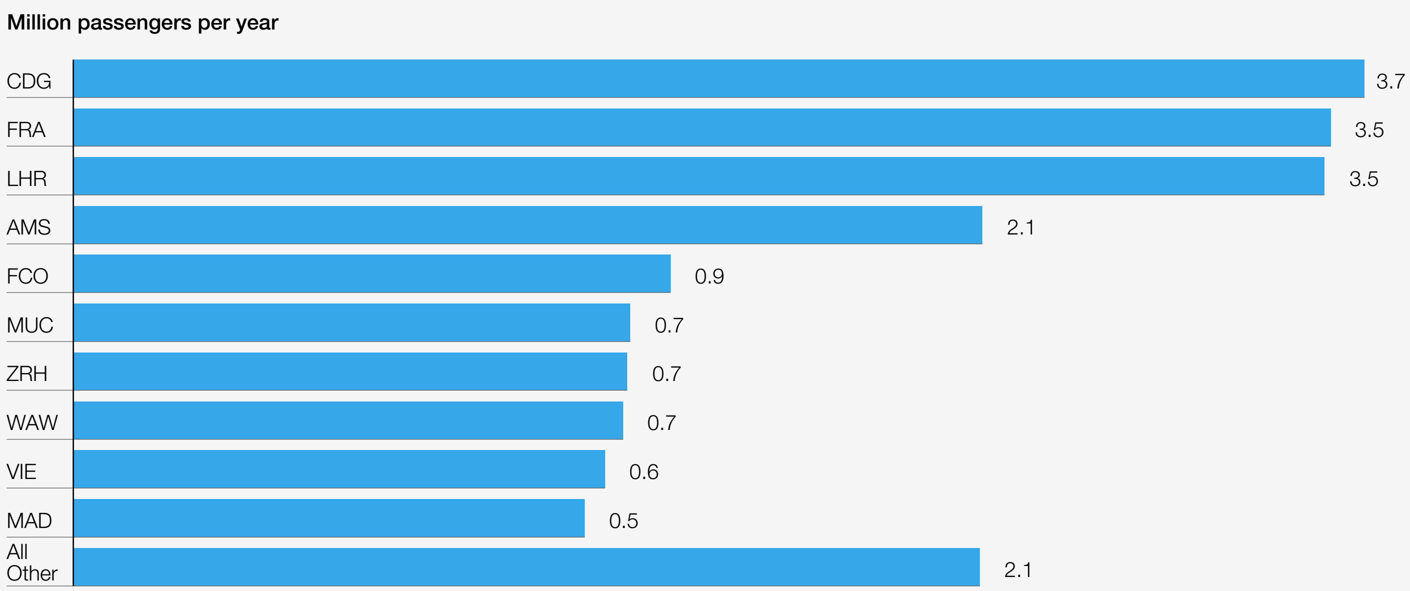


FIGURE 10 **Transfer passengers from non-EU to non-EU countries connecting via the EU**



3.3 What impact will a SAF blending mandate have on fuel tankering?

The introduction of a sustainable aviation fuel blending mandate could also increase the risk of fuel tankering activity by European airlines. Tankering is the practice of carrying extra jet fuel on board flights to avoid paying higher prices on arrival. Tankering is widespread in Europe and is driven by considerable differences in fuel prices between airports, caused by a range of factors. At present, full tankering occurs on approximately 15% of total flights in the European airspace and a further 15% of flights use partial tankering. Fuel tankering is estimated to be responsible for 0.9 Mt/year of extra emissions in the European airspace (approximately 0.5% of total emissions from European aviation).[46]

The introduction of an SAF blending mandate may introduce an extra incentive to tanker fuel on flights into and out of Europe, as this would allow airlines to avoid higher fuel costs from SAF blending in affected countries. Increased tankering behaviour risks causing higher greenhouse gas (GHG) emissions from the sector via carbon leakage through non-EU/United Kingdom flights.

However, if the mandate is applied throughout Europe, tankering levels are likely to be relatively limited at low blending levels. Tankering typically occurs on shorter flights as excess storage capacity is available on board. If the mandate applies throughout the continent, airports where fuel consumption could be diverted to avoid the mandate (such as in the Middle East and Eastern Europe) are likely to be too far for large-scale tankering to occur, especially as the majority of jet fuel uptake in Europe is concentrated in large international hub airports in the north-west of the continent. Going forward, it will be important to undertake a full impact assessment of the potential scale of carbon leakage caused by tankering.

3.4 What options are there to mitigate the effect of potential competitive distortions?

While the SAF blending mandate is unlikely to cause major passenger losses at low blending levels, it will increasingly lead to competitive distortions if the rest of the world does not follow the same decarbonization trajectory as SAF accounts for an increasingly larger share of jet fuel used in Europe. It is therefore important to consider options to mitigate this effect to preserve the competitiveness of European airports and airlines and avoid carbon leakage (including through tankering). There is a range of potential solutions for this problem that could be explored at the European level, among which:

1. *Using support mechanisms to bridge the cost differential between SAF and conventional jet fuel:* In the next 10 years, as the scale of the SAF supply chain grows, SAF prices will reduce significantly (see Figure 12 in the appendix) while the expansion of climate-related regulations worldwide will hopefully reduce competitive distortion risks. In the meantime, SAF off-takers would benefit from public financial support to bridge the cost differential between SAF and conventional jet fuel and to ensure a level playing field, particularly at higher blending levels. This could take the form of an EU-wide SAF fee levied on each ticket, with different rates defined to reflect the distance to the final destination and adjusted according to the raising blending target. Airlines could potentially use the income from such a fee to support the purchase of SAF. Another option could be a performance-based tax credit for airlines based on the level of SAF blending and the demonstrated life-cycle reduction in greenhouse gas emissions.[47]

2. *Modulating or repurposing part of the existing European aviation taxes based on SAF use:* In Europe, taxes on intra-EEA flights typically represent the largest share of additional charges for airlines beyond operating expenses and fuel costs (for example, for a typical flight from London to Rome, the air passenger tax is €15 per person, equivalent to 25% of fuel costs and additional charges for the flight). The aggregation of all current flight taxes in Europe represents about €10 billion per year. These taxes could potentially be modulated based on SAF use or partially repurposed to compensate for the cost differential between conventional jet fuel and SAF – if 20% were used for this purpose, it could cover half the extra fuel cost triggered by a 5% mandate. However, this type of support would at this stage be defined at national levels as there is no harmonized taxation system across Europe.[48]

3. *Encouraging neighbouring regions to also implement SAF blending:* Another approach to avoid carbon leakage from a European SAF blending mandate could be to extend SAF blending to non-European airports that stand to benefit from competitive distortions via mutual agreement. This could address both competitive distortions on flights and any risk of tankering. This would require engaging bilaterally and multilaterally with the governments of relevant nations (including inter alia, the United Arab Emirates, Qatar, Turkey and Russia) to make the case for greater cross-regional coordination on aviation decarbonization – highlighting both climate and economic benefits.

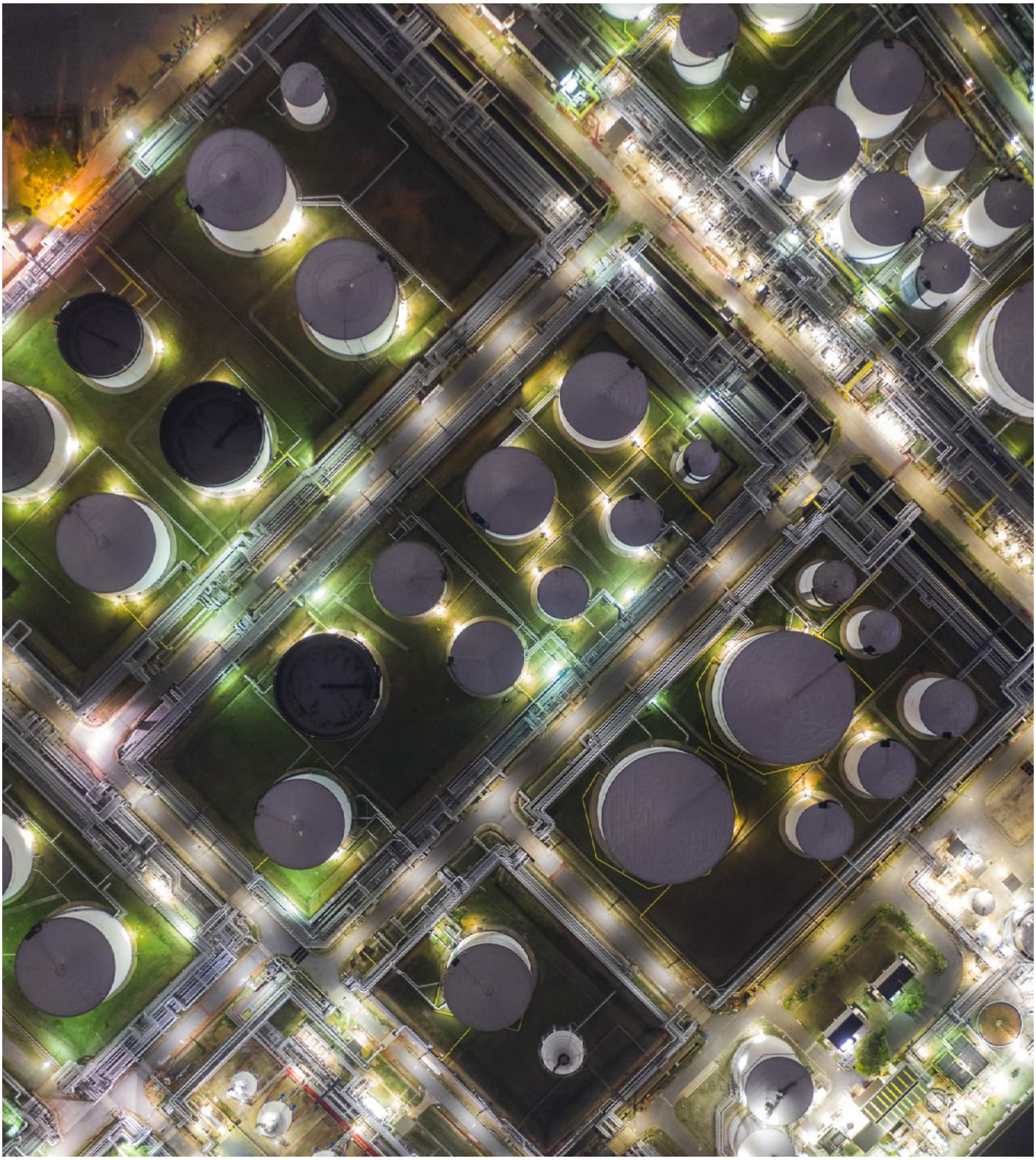
4. *Developing a global approach at the ICAO level:* The ideal medium-term set-up for an SAF blending mandate would be an ambitious global mandate established and enforced by ICAO, supported by a shared "book and claim" mechanism. Investment in SAF production capacity around the world will be greatly supported with a global SAF commitment of 10% by 2030 at the upcoming ICAO General Assembly in 2022. This issue also underpins the importance of continued European participation in international diplomatic efforts to reach net-zero emissions from global aviation by mid-century, in particular within the ICAO.

" Tankering is the practice of carrying extra jet fuel on board flights to avoid paying higher prices on arrival.

Part 4

Design options for a European SAF blending mandate

Defining clear targets for 2025 and 2030.



Europe's aviation industry is moving closer to consensus on the need to introduce an sustainable aviation fuel blending mandate to be announced as soon as possible with clear targets for 2025 and 2030 to support and facilitate immediate investments in the SAF value chain. Following extensive discussion and consultation, this report and the European CST community signatory members aligned on the following options for the final design of the SAF blending mandate.

4.1 What is the best possible SAF blending mandate design?

A The SAF blending mandate should be levied directly on fuel suppliers in Europe

Policy-makers must decide who should be the obliged party – meaning the party on whom the mandate is levied. The European Commission is considering three options: fuel suppliers, airlines or a combination thereof.[49] Fuel suppliers are the most feasible option for implementation based on practical and regulatory implications. However, it is essential to ensure a level playing field given increased ticket costs for end-consumers.

The fuel supply industry has the advantage of being highly concentrated and vertically integrated, characterized by a set of consolidated firms typically operating across multiple geographies. This facilitates compliance and avoids the need for exemptions to protect smaller local players. In addition, the establishment of a "book and claim" system can facilitate the implementation of a mandate by resolving localized supply constraints, enabling additional volumes between regulatory and voluntary SAF purchases, and ensuring accountability with regards to GHG protocols.

Under the EU Fuel Quality Directive, fuel suppliers are required to collect information on the source and sustainability of biomass feedstocks.[50] There are also procedures in place for the monitoring, verification and reporting of fuel standards to member state governments. Therefore, levying the SAF blending mandate on fuel suppliers would limit the administrative burden of the policy. By contrast, for airlines, existing policy schemes do not oblige non-EEA airlines to report information on SAF supplied in the EEA to European member states, meaning a new monitoring, verification and reporting system would need to be set up if the mandate were to be levied on airlines.

Establishing the mandate on fuel suppliers will also enable Europe to eventually achieve a greater scale of emissions reductions. If a blending mandate were applied to airlines, instead of or in addition to fuel suppliers, the scope would likely need to be restricted to intra-EU flights only to avoid potentially contravening the terms of existing international legal arrangements.[51] By levying the mandate on fuel suppliers, this issue is avoided.

B The SAF blending mandate could be implemented either via a volumetric target or via a greenhouse gas (GHG) intensity reduction target.

The proposed mandate can be applied either via an emissions reduction target or a volumetric fuels target. The former option would set an objective for GHG emissions reductions from the aviation sector for a given period (such as a 50% reduction in emissions by 2030). To monitor results, it would need to overcome the challenge to specify the GHG savings along the supply chain precisely for each type of fuel used to achieve this target. The latter option instead specifies a volumetric target for the sector (such as a certain percentage of total fuel use) and defines a threshold level of GHG emissions savings for eligible fuels.

The volumetric target system would provide a clearer demand signal for new technologies, encouraging investment in the SAF supply chain more effectively than a GHG emissions reduction target, which would leave greater uncertainty on the future scale of the SAF market. The strength of the demand signal is particularly important given the low technical maturity of certain required production pathways. Additionally, the volumetric option allows the use of sub-targets for certain pathways (see section below) and limits the need for complex assessments of the different technologies' life-cycle emissions beyond the threshold requirement. However, a volumetric target could present lower incentives for improvements in the GHG performance of different SAF production routes. The SAF mandate should be coupled with effective compliance enforcement mechanisms, designed such that the cost of non-compliance is higher than the cost of complying with the mandate.

A volumetric target should be combined with tight GHG savings targets for the fuels allowed into the scheme – as established in the EU Renewable Energy Directive. Policy-makers should then progressively tighten that threshold over time to drive the aviation industry toward the best-in-class forms of SAF. Such a mechanism would ensure, for instance, that high-performing recycled carbon fuels can play a role in the decarbonization of aviation in the next decade but be progressively phased out thereafter. As long as tight sustainability criteria are applied and effectively enforced, there would be no need to apply a maximum cap on any type of feedstock within the mandate.

C The SAF blending mandate should include sub-targets for novel technological pathways with lower technical readiness levels.

In the absence of a sub-target for specific production pathways, different feedstock and technology combinations will compete purely on costs. Sub-targets are an effective solution for promoting pathways with greater long-term decarbonization potential but currently higher production costs. The European Commission is considering a potential sub-target for power-to-liquid fuels in their ongoing SAF Impact Assessment. Some national governments are also exploring this option, with Germany recently proposing a 2% sub-target for PtL by 2030 in aviation.[52] This is a necessary measure to ensure the rapid commercial deployment of the technology despite its relatively higher cost versus the HEFA pathway in the short term. The same should be put into effect for lignocellulosic and biowaste-based SAF, especially in the next 10-15 years. This early deployment is essential to meeting 2030 targets and to building the foundations to scale up that value chain in the 2030s to meet increasing needs as the aviation sector heads toward net-zero emissions.

4.2 How can Europe manage the inter-sectoral allocation of bioresources?

At present, most bioresources in Europe are used for residential and industrial heating and power generation, and as biofuels in the transport sector. Approximately 10% of all bioenergy is used to produce biofuels, which road transport almost entirely consumes.[53]

In the transition to a net-zero-carbon economy, the demand for bioresources is expected to increase significantly in both current and new use-segments. A bio-based solution often enables the reuse of existing infrastructure and equipment, whereas electrification, which is often less expensive over the life cycle of the asset, requires upfront investments. However, aggregate demand for bioresources across all sectors will likely be much higher than available sustainable supply.[54] This requires a prioritization of these resources across the economy based on the cost and availability of alternative decarbonization technologies.

Aviation is a clear priority use-case for scarce bioresources in the next 15-20 years given the lack of feasible low-carbon alternatives, in particular the low level of technology readiness for power-to-liquid fuels. Conversely, the sectors that currently consume most bioresources, including power and road transport, should not be considered as priority use-cases as less expensive and more land-efficient decarbonization solutions are already available in those sectors.

The road sector, for example, has a viable alternative decarbonization pathway through electrification. Battery electric vehicles (BEV) are already a cost-effective option for light-duty vehicles and are projected to constitute at least 35% of new vehicles sales in Europe by 2030 – with several manufacturers already announcing phase-out dates for internal combustion engine (ICE) vehicle production.[55] In the heavy-duty road transport segment, battery electric vehicles (BEVs) are expected to become cost competitive for long-haul trucking in the 2020s in Europe.[56] This will reduce the need for the use of biofuels in road transport in future years, particularly after 2030, a reality that has not yet been translated in biofuel mandates put in place in the past decade.

Moreover, SAF is produced via a conversion process that jointly produces other hydrocarbon products. All SAF production technologies considered in this report yield a product slate containing a range of other products, such as biodiesel, naphtha or chemicals – products that are commercially relevant in automotive, petrochemical and other sectors. Every sustainable fuel plant must therefore determine optimum output for these different products. Plants will only choose to optimize the product slate for jet fuel if this is financially attractive. Policy therefore needs to ensure that this option is more profitable than the alternatives by establishing a sufficiently high value for SAF to cover the cost premium for producing SAF vs other outputs.[57] This could be achieved via a tradable credit system established to support the mandate, such as via the introduction of price floors or through contracts-for-difference schemes.

Even if outputs are optimized for aviation, new biofuel and synfuel plants will nonetheless continue to produce outputs other than SAF, given technical limits to product slates, and will therefore partially continue to cater to the needs of other sectors.[58] ETC estimates that fuel plants optimized for SAF production will still generate co-production of some 5 Mt/year of road fuel by 2030 in the central case ramp up scenario, enough to satisfy almost one-third of currently planned mandate levels for the sector.

> “ Even if outputs are optimized for aviation, new biofuel and synfuel plants will nonetheless continue to produce outputs other than SAF.

Overall, policy-makers are advised to adhere to the following key principles to effectively manage the inter-sectoral allocation of bioresources in coming years:

1. Bioresources should be used for priority use-case sectors with the highest cost alternative decarbonization solutions, including aviation.

2. Existing and new bioresources should be gradually transitioned into use in these priority sectors, which will be supported by the strengthening of demand signals in these sectors, including via an SAF blending mandate in aviation.

3. Existing fuel mandates in other transport sectors (such as road/rail) should be respected so as to not disrupt the market and then progressively phased out, with aviation being positioned as a priority market for investment.

4. In the meantime, policy mechanisms must ensure that the price premium for SAF at the point of sale is above the cost premium for producing SAF vs other potential outputs (via price floors or contracts for difference).

Signatories

This paper was co-developed in partnership with the members of the *Clean Skies for Tomorrow* coalition's European policy workstream. Although not all parties necessarily agree with each statement, the following participants have formally endorsed the general thrust of the viewpoints expressed in this report.

Airbus Group

Boeing

bp

Copenhagen Airport

Deutsche Post DHL Group

Groupe ADP

Heathrow Airport

International Airlines Group

KLM Royal Dutch Airlines

Kuehne+Nagel

LanzaJet

LanzaTech

Neste

Norsk e-Fuel

Rolls-Royce

Royal Dutch Shell

Royal Schiphol Group

SkyNRG

Sunfire

TotalEnergies

Velocys

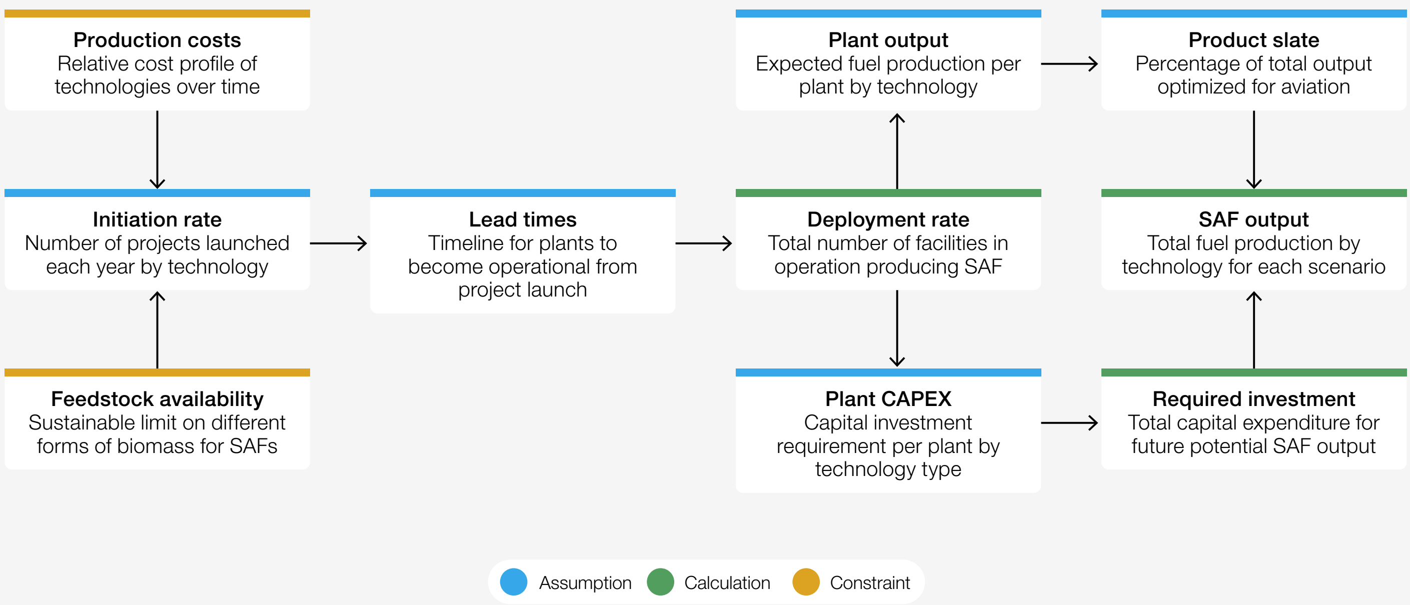
Appendices

Appendix A: Methodology for sustainable aviation fuel production ramp up feasibility assessments

The Energy Transition Commission (ETC) modelled a range of scenarios to estimate the potential ramp up sustainable aviation fuel (SAF) production in Europe from 2020-2050. The flowchart below outlines the methodology of this feasibility assessment.

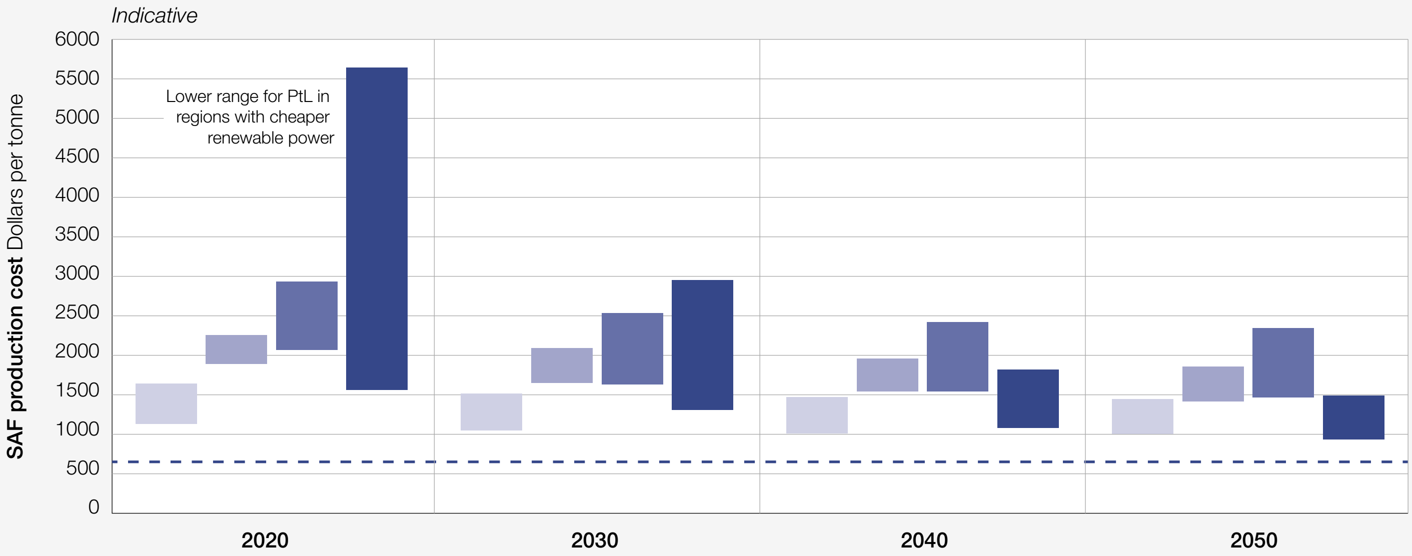
At a high-level, the potential future SAF output is determined by the initiation rate of new SAF plants combined with a series of plant-level assumptions for each technology pathway, which have been co-developed with leading industry specialists from the *Clean Skies for Tomorrow* (CST) community. The initiation rate (i.e., the rate at which new projects are launched) is determined by two key external constraints: 1) the production costs of the different potential SAF technological pathways, and 2) the availability of sustainable biomass feedstock.[60]

FIGURE 11 **Outline of approach**



The production cost of different SAF technologies determines the period in which it is financially viable to open a new plant using this pathway, assuming strong policy support. This is based on the profile of future production costs outlined below. As shown in the chart, the hydroprocessed esters and fatty acids (HEFA) route is the cheapest option at present, but other advanced biomass routes using lignocellulosic and biowaste feedstock are expected to become more cost-competitive by the 2030s. Power-to-liquid fuels display the largest potential reductions in production costs from economies of scale and learning curve effects and are expected to become a cost-competitive solution at the latest by the 2040s.

FIGURE 12 **Global SAF production cost for selected feedstocks**

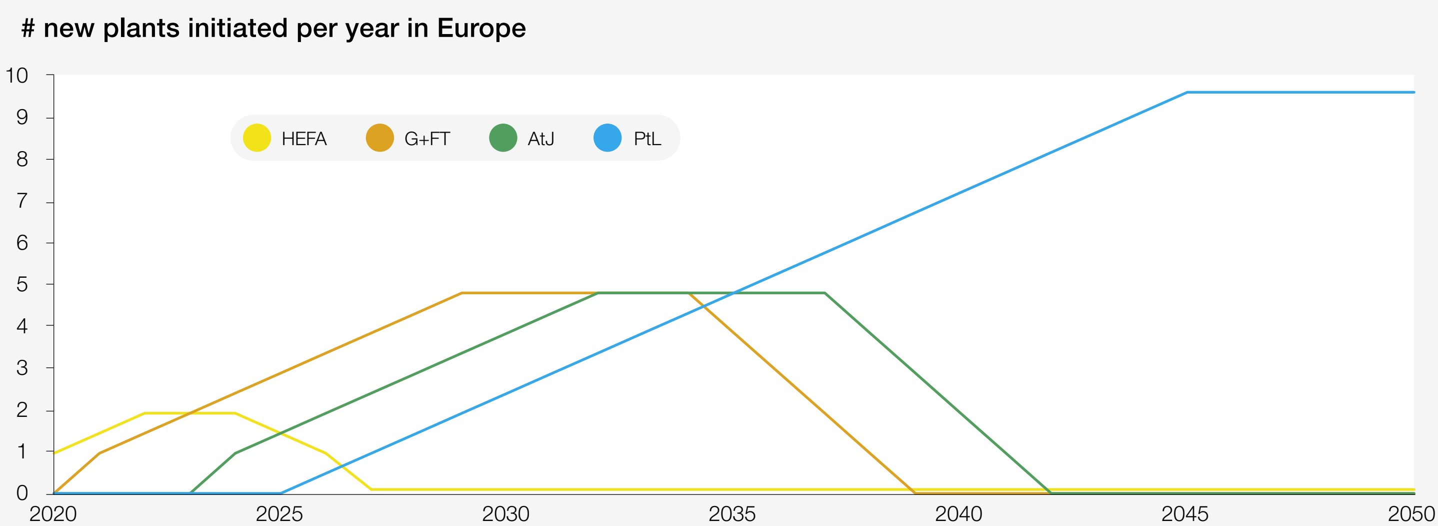


Source: World Economic Forum (2020), *Clean Skies for Tomorrow: Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation.*

The total number of plants of any given technological pathway is capped by the availability of sustainable biomass used as feedstocks in the production process. In the ramp up of SAF production, there cannot be more SAF plants than is permitted by the availability of biomass as determined by a strict set of sustainability criteria. For example, this assumes a maximum of 20 HEFA plants in operation by 2050, as this is the most that can be opened based on assumed availability of waste oils and cover crops/crops from marginal or degraded land in the region.[61]

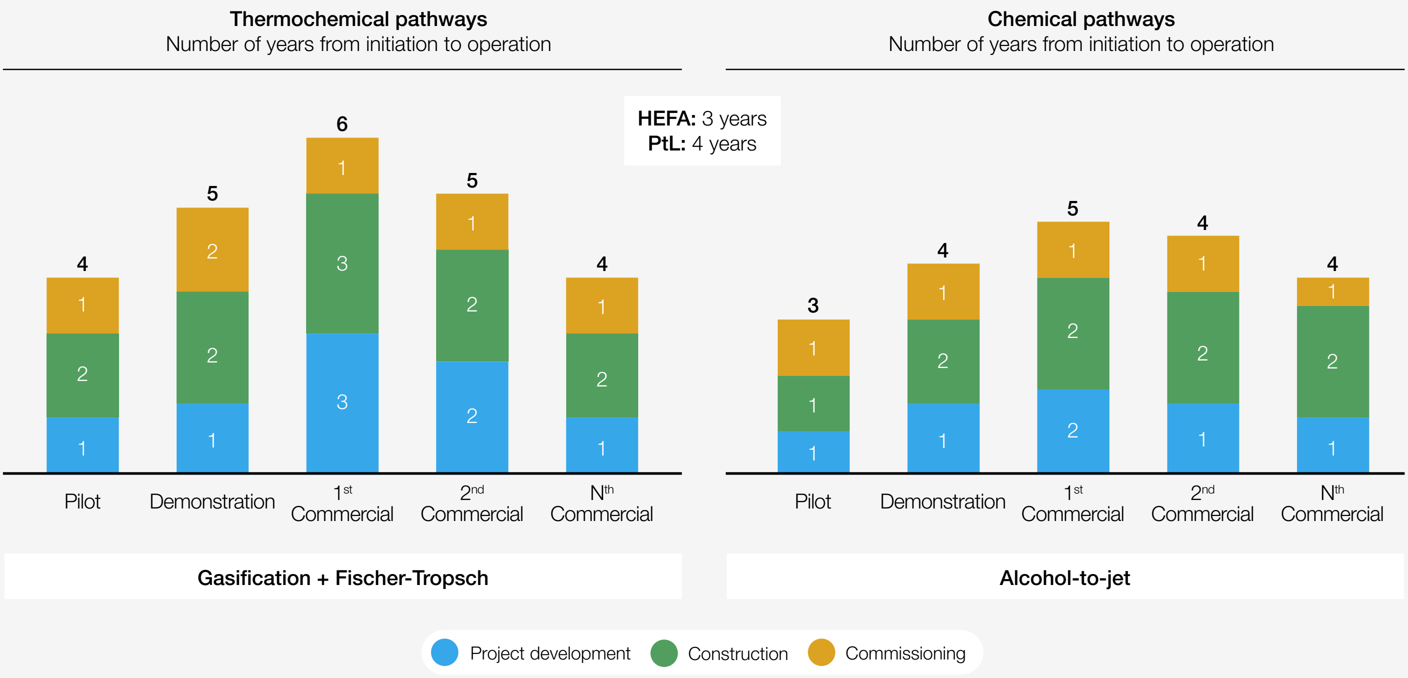
These two constraints thus jointly shape the profile of the deployment rate for new SAF plants for each technology over time. As shown below, HEFA plants are assumed to be initiated first due to lower production costs relative to other pathways. However, before the end of the decade the number of new plants initiated per year drops, as feedstock becomes limited and other pathways become less expensive. Similarly, SAF plants using lignocellulosic and biowaste material as feedstocks are initiated in large numbers from the late 2020s to mid-2030s, as they are the most cost-competitive solution in this period (excluding HEFA output, which cannot expand significantly further).[62] By the late-2030s, as shown below, power-to-liquids plants are initiated in large numbers due to their expected lower production costs. This will nonetheless demand a large volume of renewable electricity and increasing large volumes of sustainable carbon as inputs, which continues to restrict the potential scaling of SAF output via this pathway.

FIGURE 13 **Inflation rate by technology (central case scenario)**



This initiation rate is then matched with assumed lead times for each technology pathway to create a feasible profile of the deployment rate for new plants in Europe, meaning the number of SAF facilities in operation in each year. Assumed lead times differ according to the technology type and the type of facility (see Figure 14). Pilot and demonstration facilities have shorter lead times due to their small scale, whereas first-of-a-kind plants have the longest lead times due to higher technical challenges from opening large-scale commercial facilities. Once these are opened, subsequent commercial plants are assumed to go from initiation to operation more rapidly.

FIGURE 14 **Thermochemical and chemical pathways**



The profile of deployment of new plants is then matched with the expected annual output from each plant by technology type. The assumptions for total hydrocarbon output per plant are listed in Figure 15 by technology, where the central case figures are used in the ETC central case ramp up scenario.

These figures are based on expert interviews with fuel suppliers and currently announced plans for new sites. The central case figure for HEFA plants is based on the average of plant size of existing and announced plants in Europe from 2020-2025, excluding co-processing facilities.

FIGURE 15 **Range of potential SAF output by technology pathway**

Mt/year fuel output

Technology	Output per plant		
	Lower bound	**Central case**	**Upper bound**
HEFA	0.2	0.5	1.0
Gasification + Fischer-Tropsch	0.1	0.15	0.2
Alcohol-to-jet	0.1	0.2	0.3
Power-to-liquids	0.05	0.4	0.8

Finally, total output per plant is multiplied by the expected share of output that can be used as jet fuel, which again differs by technology. The product slate (mix of types of hydrocarbon output) can be adjusted to optimize for different types of products but can never be 100% SAF; there will inherently always be a residual share of output in the form of road fuels and light-ends (light hydrocarbon gases and liquids, such as liquified petroleum gas (LPG) or naphtha).

However, in the long term, technology improvements could raise the optimal share of SAF output to higher levels for certain technologies. Prior to 2030, it is assumed that the share of SAF output at news plants remains at currently feasible levels.[63] After 2030, it is assumed that plants can achieve a higher percentage of SAF output due to technology improvements and repurposing. However, shifting to higher output share for jet fuel still requires: 1) the adoption of latest conversion technologies across all sites; 2) additional capital investment to upgrade plant facilities; and 3) regulatory/policy changes to ensure financial incentives are in place to optimize for SAF output.

The final estimates of potential SAF output by scenario are thus derived by combining the modelled initiation rate for each technology pathway with the subsequent assumptions on plant operations and SAF output. Separately, required capital investment is estimated by matching the number of plants that must be deployed by year with the projected future capital costs by plant type over time.

The purpose of this exercise is to illustrate the feasible rate of future SAF output in Europe, given the current understanding of feedstock availability, technical barriers and projected costs. It should be clear that this assessment will not be realized unless there is strong supply- and demand-side policy support implemented in the coming years.

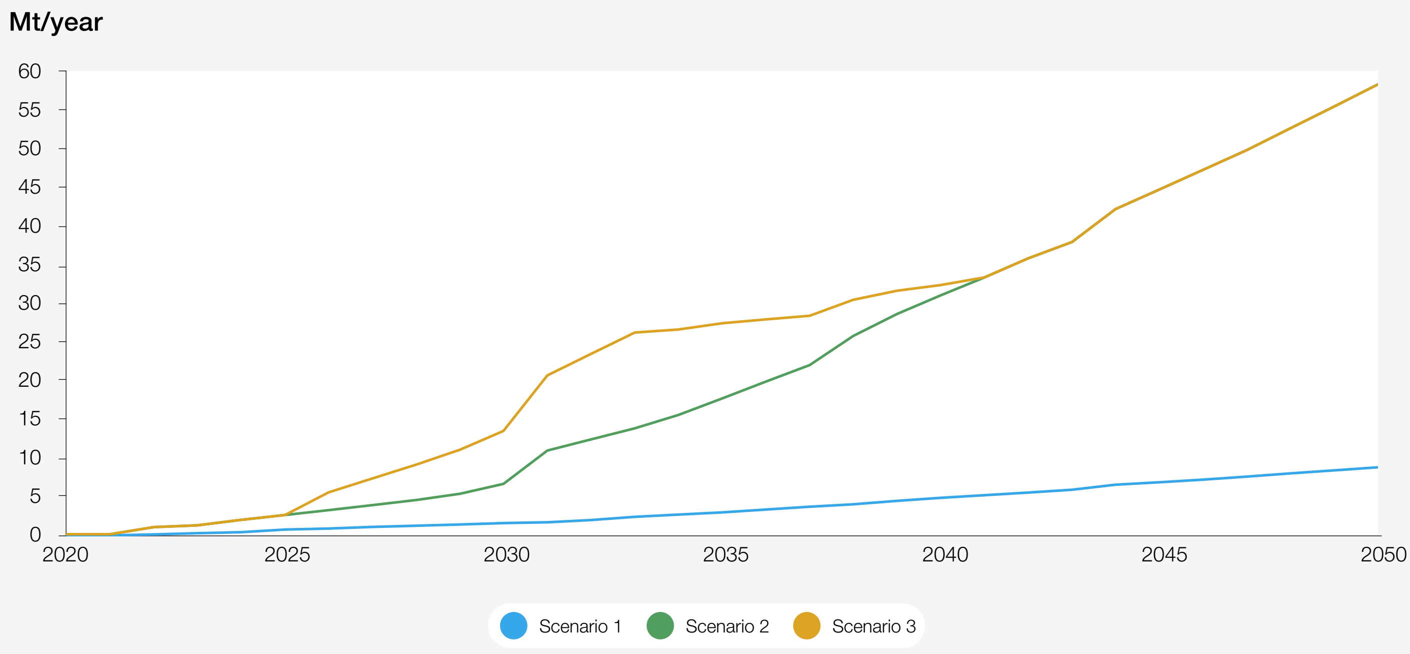
Appendix B: Three sustainable aviation fuel ramp-up feasibility scenarios

The future level of sustainable aviation fuel (SAF) production in Europe depends on three key factors: a) the rate of deployment of new plants; b) the level of biomass importation from overseas; and c) the optimization of output for jet fuel vs other uses. This report considers three scenarios to understand the potential future range of SAF output based on these uncertainties.

- **Scenario 1:** Low deployment rate + non-jet optimized output
  - In this scenario investments broadly follow business-as-usual trends, such that only half of currently planned SAF plants become operational by 2030.
  - It is assumed that all plants maximize product slate for non-jet fuel output, due to weak financial incentives to switch to jet fuel optimization.
  - This scenario most closely reflects the likely future development of SAF production if policy support is limited, giving an approximate lower bound trajectory.
- **Scenario 2:** High deployment rate + jet optimized output
  - In this scenario, there is a rapid and sustained increase in investments in new SAF plants due to strong policy support.
  - New facilities are deployed at the maximal rate allowed by domestic (European) feedstock availability and technical constraints.
  - It is assumed that all SAF plants maximize their product slates for jet fuel output, as it is profitable to do so.
- **Scenario 3:** High deployment rate + jet optimized output + biomass imports
  - This scenario is identical to scenario 2, described above, but allows for imports of transportable biomass from external regions (outside Europe) to Europe.
  - This reflects the possibility that Europe is the leading global market for SAF over the coming years if Europe introduces ambitious policy measures that other regions of the world do not match.
  - It assumes Europe imports a maximum of 15% of global sustainable and transportable biomass (waste oils and wood pellets) for SAF production from 2025-2040.

Figure 16 shows the results by scenario: 1) In the low deployment and jet-optimization scenario without strong policy support (scenario 1), SAF supply remains highly limited in Europe, and 2) imports of sustainable biomass from other regions could provide significant upwards flexibility to output levels if Europe develops SAF demand earlier than the rest of the world.

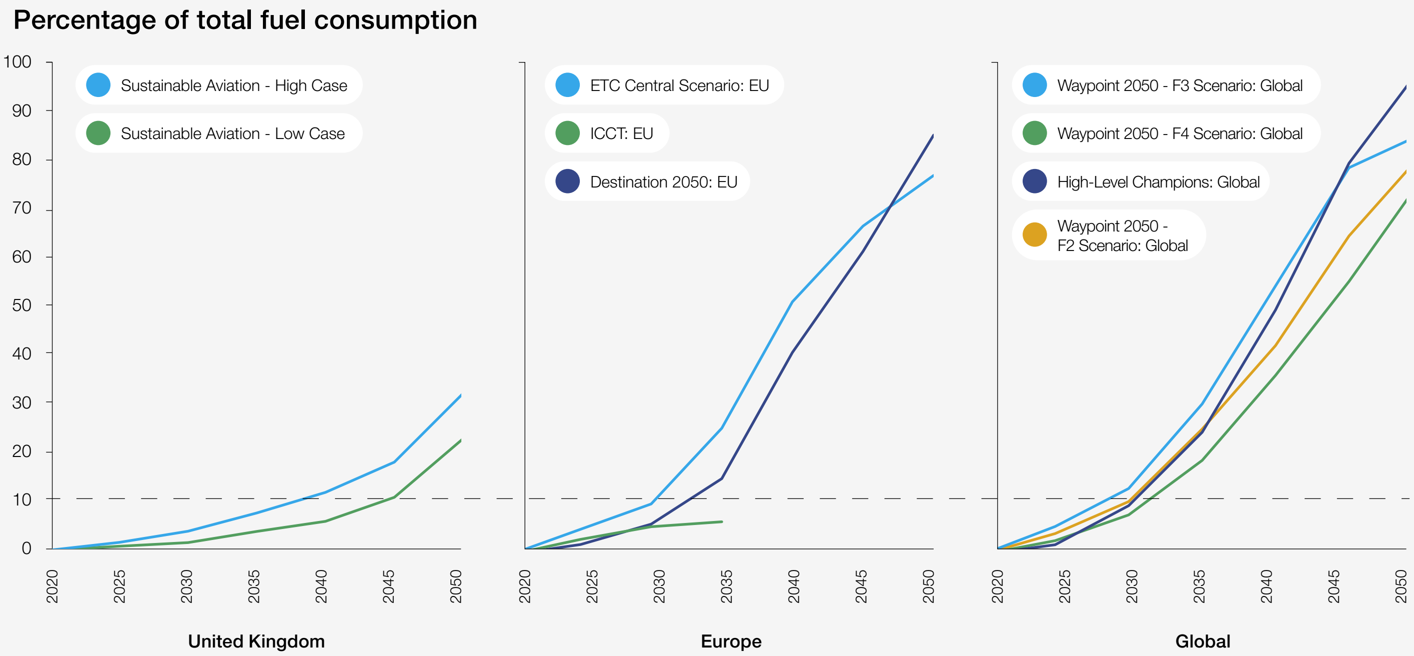
FIGURE 16 | **SAF production in Europe with biomass imports, by scenario**



Appendix C: Comparison of sustainable aviation fuel ramp up projections

The Energy Transition Commission (ETC) feasibility assessment for the potential ramp up of SAF production in Europe was conducted independently of other forecasts. Figure 17 compares estimates from recently published forecasts that also consider future SAF use in aviation across different geographies. As shown by the chart, there are a range of projected values for SAF use as a percentage of total jet-fuel consumption over time at national, regional and global levels.

FIGURE 17 | **Comparison of SAF production ramp up forecasts, by geography**[64]



There are broadly two types of SAF ramp up forecasts and backcasts that have been conducted to date, loosely classifiable as top-down and bottom-up. Top-down projections (Waypoint 2050, Destination 2050, COP26 High-Level Champions S-Curves[65]) typically target net-zero emissions from aviation by 2050 and back-solve to estimate the level of SAF production required to achieve this, given the contribution of other decarbonization levels over time. Waypoint 2050 differs from other top-down forecasts as it targets a reduction of total emissions from the sector of 50% by 2050 relative to 2005 levels, with net-zero achieved by 2060. Destination 2050 uses a hybrid approach for 2030 figures.

Bottom-up forecasts, on the other hand, build up potential SAF use levels based on feasible rates of deployment for SAF production capacity. In this approach, the use of SAF across the sector depends on the number of facilities producing SAF output opened over time, itself contingent on a range of data and assumptions regarding feedstock availability, technological development, policy support, and financial investment. The Sustainable Aviation UK report and the ICCT and ETC EU reports followed this approach.

As mentioned above, the differences in forecasts at the EU level between this ETC report and the recent International Council on Clean Transportation (ICCT) report[66] can be explained by two main reasons:

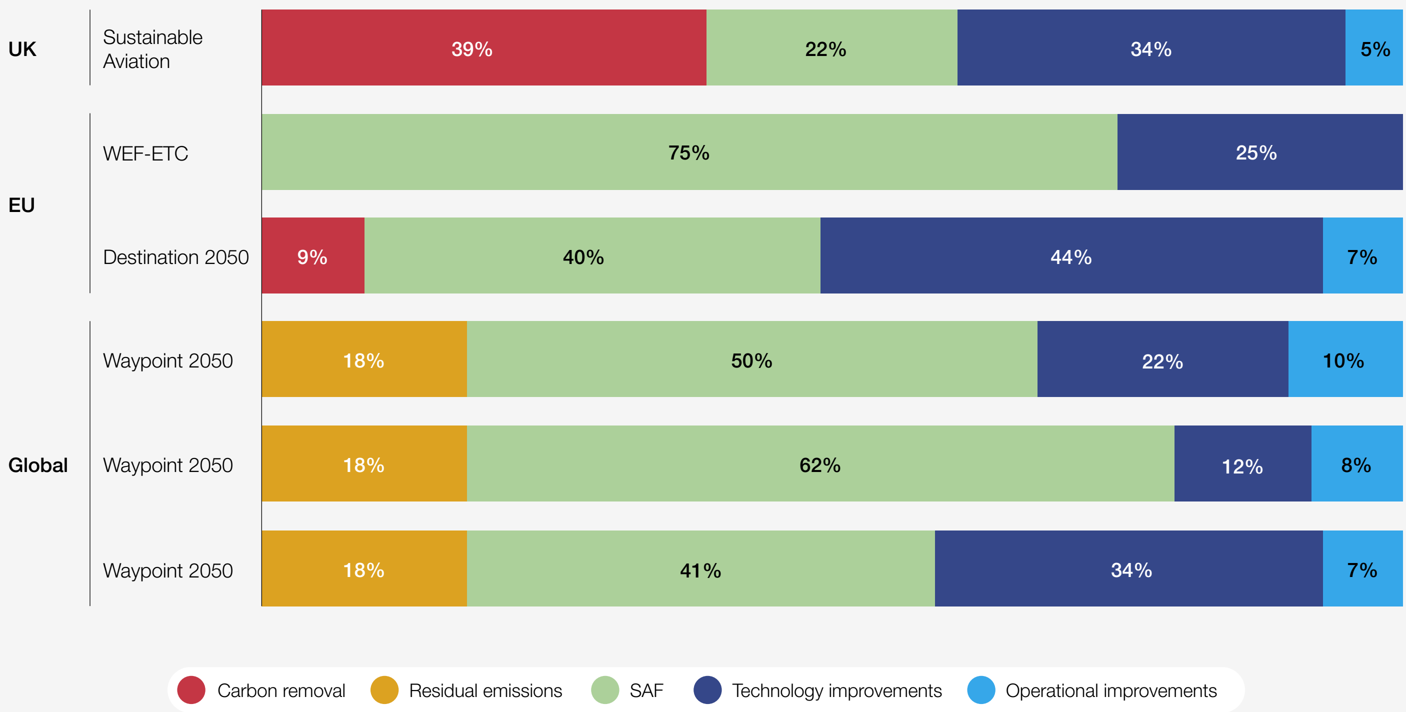
- ICCT assumes a more conservative rate of deployment for new advanced technologies due to lower assumed investment and policy support in the sector.
- ICCT has more conservative assumptions on the availability of sustainable biomass in Europe and the maintaining of the existing use of this potential feedstock in the power, heat, road and other sectors, whereas the ETC considers that this biomass should be transitioned for use in aviation in line with the transition to a low-carbon economy.[67]

Therefore, the variation in anticipated levels of SAF production over time between different publications can be largely explained by the distinct approaches taken for different modelling exercises. Additionally, publications have different assumptions on other future variables that affect the volume of future jet fuel consumption from the sector. This includes:

1. Forecast passenger growth rates;
2. The rate of technical improvements to fuel efficiency;
3. The rate of improvements to operational efficiency and air traffic management;
4. The scope and rate of deployment of new electric and hydrogen aviation technologies;
5. The role for carbon removal and offsetting measures; and,
6. The effect of market-based measures on demand.

Figure 18 provides an overview of the effect of these assumptions on emissions in different recent publications in relation to these factors.

FIGURE 18 **Overview of the effect of these assumptions on emissions**



Contributors

World Economic Forum

Kevin Soubly
Project Lead, Clean Skies for Tomorrow

Lauren Uppink Calderwood
Head of Aviation, Travel and Tourism Industries

Christoph Wolff
Clean Skies for Tomorrow

Energy Transitions Commission

Faustine Delasalle
Director

Lloyd Pinnell
Aviation Lead

Carlos Eduardo Agnes
Consultant

Editing and Design

Danielle Carpenter
Editor

Laurence Denmark
Designer

This paper was co-developed through the *Clean Skies for Tomorrow* coalition's European policy workstream and was made possible through the invaluable contributions of all participants.

Contact

For questions about *Clean Skies for Tomorrow* and the World Economic Forum's Shaping the Future of Mobility Platform, contact Kevin Soubly kevin.soubly@weforum.org.

Endnotes

1. This report represents a collective view of the European group of the *Clean Skies for Tomorrow* (CST) Coalition. European CST members and signatories to the report endorse the general thrust of the arguments but should not be taken as agreeing with all statements.
2. ETC analysis for *Clean Skies for Tomorrow* (2021).
3. Blending percentages in this report rely on the basis of EU28 jet fuel demand figures (including the United Kingdom) on all departing flights. However, to avoid extra-competitive distortions and tankering risks from the introduction of the policy, the SAF blending mandate should be applied across all EEA members, including the United Kingdom and Switzerland.
4. World Economic Forum (2020), *Clean Skies for Tomorrow: Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation*, available at https://www.weforum.org/reports/clean-skies-for-tomorrow-sustainable-aviation-fuels-as-a-pathway-to-net-zero-aviation [accessed 21 June 2021].

   World Economic Forum (2020), *Joint Policy Proposal to Accelerate the Deployment of Sustainable Aviation Fuels in Europe - A Clean Skies for Tomorrow Publication*, available at https://www.weforum.org/reports/joint-policy-proposal-to-accelerate-the-deployment-of-sustainable-aviation-fuels-in-europe-a-clean-skies-for-tomorrow-publication [accessed 21 June 2021].
5. Such a feedstock strategy should be embedded within European policy frameworks such as the Renewable Energy Directive (RED) to mitigate potentially adverse effects related to feedstock scarcity in other sectors.
6. International Air Traffic Association (IATA) (2020), European Air Transport COVID-19 Impacts and Recovery to be Worse than other Regions, available at iata.org/en/pressroom/pr/2020-12-10-01/ [accessed 21 June 2021].
7. World Economic Forum (2020), *Clean Skies for Tomorrow: Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation*, available at https://www.weforum.org/reports/clean-skies-for-tomorrow-sustainable-aviation-fuels-as-a-pathway-to-net-zero-aviation [accessed 21 June 2021].
8. SAF is currently certified for 50% blending with conventional jet fuel but major original equipment manufacturers (Rolls-Royce, Boeing and Airbus) are all actively developing new engines capable of supporting 100% blending, expected to be available in the next few years. In March 2021, the first test flight using 100% SAF was conducted with an Airbus A350 plane (https://www.airbus.com/newsroom/stories/A350-fuelled-by-100-percent-SAF-just-took-off.html).
9. Voigt, C., Kleine, J., Sauer, D. et al. (2021), Cleaner burning aviation fuels can reduce contrail cloudiness. *Commun Earth Environ* 2, 114 (2021), available at https://doi.org/10.1038/s43247-021-00174- y [accessed 21 June 2021].
10. Lee, D. S., Fahey, D. W., Skowron, A., Allen, M. R., Burkhardt, U., Chen, Q., & Gettelman, A. (2020), The Contribution of Global Aviation to Anthropogenic Climate Forcing for 2000 to 2018. *Atmospheric Environment*, 117834, available at https://www.sciencedirect.com/science/article/pii/S1352231020305689 [accessed 21 June 2021].
11. This report represents a collective view of the European group of the *Clean Skies for Tomorrow* (CST) Coalition. European CST members and signatories to the report endorse the general thrust of the arguments but should not be taken as agreeing with all statements.
12. Including the use of "blue" hydrogen, recycled CO_2 from industrial and waste sources, and residual non-biogenic fractions of municipal and industrial solid waste.
13. Recycled carbon fuels (RCFs) from industrial emissions in Europe could possibly produce around 11 million metric tonnes per annum (MTA) of ethanol. Conversion via the AtJ pathway could yield around 6 million MTA of drop-in SAF for the EU. Today, these fuels use waste carbon generated from carbon-intensive processes; but production processes could adapt as heavy industry transitions to lower-carbon solutions.
14. ETC analysis for *Clean Skies for Tomorrow* (2021).
15. Blending percentages in this report rely on the basis of EU28 jet fuel demand figures (including the United Kingdom) on all departing flights. However, to avoid extra-competitive distortions and tankering risks from the introduction of the policy, the SAF blending mandate should be applied across all EEA members, including the United Kingdom and Switzerland.
16. Analysis for this report assumes the scope of the mandate will be for the EU27 countries and the United Kingdom but recommends that as many European countries as possible meet this level of ambition to avoid competitive distortions and tankering risks (including EFTA members).
17. See Appendix A for a description of the methodology for this feasibility assessment.
18. Note that this analysis only considers the use of biomass that meets a strict set of sustainability criteria. No crops that compete for land with food production are considered eligible. All forms of lignocellulosic biomass respect tight social and environmental safeguards. See previous CST reports Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation and Joint Policy Proposal to Accelerate the Deployment of Sustainable Aviation Fuels in Europe for more information on SAF sourcing guidelines.
19. Assuming a 2-year delay period from original announced opening dates for the COVID-19 pandemic.
20. This includes waste oils and woody biomass pellets that can be transported for conversion into SAF in Europe but does not consider bulkier forms of biomass that are not cost-competitive to transport.
21. See previous CST reports Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation and Joint Policy Proposal to Accelerate the Deployment of Sustainable Aviation Fuels in Europe for more information on SAF production technologies and associated feedstocks.

22. World Economic Forum (2020), *Clean Skies for Tomorrow: Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation*, available at https://www.weforum.org/reports/clean-skies-for-tomorrow-sustainable-aviation-fuels-as-a-pathway-to-net-zero-aviation [accessed 21 June 2021] estimates that 1) cover crops can be used to supply 6% of total EU jet fuel consumption, assuming 25% of all arable land under rotational crop is available and that 20% of available land is planted with Camelina yielding 1.7 tonne/hectare; and 2) oil crops grown on degraded or marginal land can be used to supply 10% of total EU jet fuel consumption, assuming these are planted on 1% of all degraded land as seen by Bai, Z.G., Dent, D.L., Olsson, L. & Schaepman, M.E. (2008). Proxy global assessment of land degradation, *Soil Use and Management*, September 2008, 24, 223–234, available at https://onlinelibrary.wiley.com/doi/full/10.1111/j.1475-2743.2008.00169.x [accessed 21 June 2021].

23. Sustainable biomass from cellulosic cover crops, agricultural residues, forestry residues, wood processing waste and biogenic municipal solid waste are estimated to be sufficient to cover 100% of total jet fuel demand globally via conversion to SAF, before accounting for other potential alternative sectoral uses for this material (e.g. power, heat, bioplastics).

24. In an intermediate step, these can rely on recycled carbon sources as a transitional solution, but to obtain GHG emissions neutrality, synfuels for aviation must be derived only from CO_2 from direct air capture or bioenergy with carbon capture and storage (BECCS). Recycled carbon fuels are liquid and gaseous fuels produced from the conversion of exhaust or waste streams of fossil fuel-based industrial applications or of non-biogenic/plastic municipal or industrial waste. Recycled carbon fuels (RCFs) from industrial emissions in Europe could potentially produce around 11 million MTA of ethanol and conversion via the AtJ pathway could yield around 6 million MTA of drop-in SAF for the EU. Today, these fuels use waste carbon generated from carbon-intensive processes; but production processes could adapt as heavy industry transitions to lower-carbon solutions.

25. Figure 20 in World Economic Forum (2020), *Clean Skies for Tomorrow: Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation*, available at https://www.weforum.org/reports/clean-skies-for-tomorrow-sustainable-aviation-fuels-as-a-pathway-to-net-zero-aviation [accessed 21 June 2021].

26. ECOFYS (2019), *Technical Assistance in Realisation of the 2018 Report on Biofuels Sustainability*, Final Report Commissioned by DG ENERGY.

27. Used cooking oils as animal feed is excluded in this report as this has been restricted in the EU since 2002 as a reaction to the BSE148 crisis and the subsequent implementation of animal by-products regulation EC 1774/2002. However, this does not include other potential use cases for waste oils such as heat and power, food products or animal/pet food production, rubber emulsifiers, metalworking fluids, printing inks and adhesives, and energy-recovery applications.

28. Subject to demonstration that these crops do not contribute to additional cropland demand and novel supply chains can be set up in a timely manner.

29. This feasibility assessment considers potential power-to-liquid synfuels production in, or relying on energy provided from, neighbouring regions to Europe (such as North Africa) to be domestic European output.

30. Refers to results from modelling scenarios F2-F4 in Air Transport Action Group (2020), *Waypoint 2050: Balancing Growth in Connectivity with a Comprehensive Global Air Transport Response to the Climate Emergency*.

31. Sustainable Aviation (2019), *Decarbonisation Roadmap: A Path to Net-Zero – A Plan to Decarbonise UK Aviation*.

32. O'Malley, J. & Pavlenko, N. (2021), *Estimating the Sustainable Aviation Fuel Feedstock Availability to Meet Growing European Union Aviation Sector Demand*, International Council on Clean Transportation (ICCT), available at https://theicct.org/publications/sustainable-aviation-fuel-feedstock-eu-mar2021 [accessed 21 June 2021].

33. Marrakech Partnership for Global Climate Action (2020), Climate Action Pathway – Transport, available at https://unfccc.int/sites/default/files/resource/Action_table_Transport_.pdf [accessed 21 June 2021].

34. Graph modeling based on five scenarios:
    - O'Malley, J. & Pavlenko, N. (2021), *Estimating the Sustainable Aviation Fuel Feedstock Availability to Meet Growing European Union Aviation Sector Demand*, International Council on Clean Transportation (ICCT), available at https://theicct.org/publications/sustainable-aviation-fuel-feedstock-eu-mar2021 [accessed 21 June 2021].
    - NLR – Royal Netherlands Aerospace Centre & SEO Amsterdam Economics (2021), *Destination 2050: A Route to Net Zero European Aviation*, Airlines for Europe (A4E), CANSO (Civil Air Navigation Services Organisation), ERA (European Regions Airline Association), Airports Council International-EUROPE (ACI) & Aerospace & Defence Industries Association of Europe (ASD).
    - Air Transport Action Group (2020), *Waypoint 2050: Balancing Growth in Connectivity with a Comprehensive Global Air Transport Response to the Climate Emergency*.
    - Sustainable Aviation (2020), *Sustainable Aviation Fuels Road-Map: Fuelling the Future UK Aviation*.

35. Excluding pilot and demonstration facilities. See estimates by feedstock in Appendix A.

36. Timelines are likely to be longer for first-of-a-kind plants (between 5-6 years depending on the technology).

37. CAPEX requirements are estimated by matching total upfront capital investment requirements per plant and by technology type, with the number of plants that must open in each year for the SAF ramp up profile established above. In practice, this will be annualized over the associated financing term length.

38. Note that two of these HEFA plants are expansions of existing sites.

39. United States Department of Agriculture Sustainable Agriculture Research and Education (SARE) programme (2020), *Annual Report – National Cover Crop Survey*, available at https://www.sare.org/wp-content/uploads/2019-2020-National-Cover-Crop-Survey.pdf [accessed 21 June 2021].

40. See for further detail: De Jong, S. (2018), *Green Horizons: On the Production Costs, Climate Impact and Future Supply of Renewable Jet Fuels*.

41. Assuming public financial support accounts for 25% total CAPEX for new SAF plants from 2020 to 2040 for HEFA, G+FT, AtJ, and PtL facilities.

42. Appendix A, Figure A.2, in World Economic Forum (2020), *Clean Skies for Tomorrow: Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation*, available at https://www.weforum.org/reports/clean-skies-for-tomorrow-sustainable-aviation-fuels-as-a-pathway-to-net-zero-aviation [accessed 21 June 2021].

43. The scale of this potential support was not quantified.

44. In this section, Europe refers to EEA countries + the United Kingdom and Switzerland.

45. Assumes 50% cost pass-through of fuel cost increases from the SAF price premium vs kerosene is passed onto consumers. Assumes price elasticity of demand of -0.92 for intra-European Union + United Kingdom (short-haul) flights and -0.63 for extra-European Union + United Kingdom (long-haul) flights.

    Air Transportation Analytics and Clarity (2018), *The Carbon Leakage and Competitiveness Impacts of Carbon Abatement Policy in Aviation, Report to the Department of Transport*.

46. EUROCONTROL (2019), *Fuel tankering in European skies: economic benefits and environmental impact*, available at https://www.eurocontrol.int/publication/fuel-tankering-european-skies-economic-benefits-and-environmental-impact [accessed 21 June 2021].

47. Inspired by Sustainable Aviation Fuel Act, H.R. 741, 117th US Congress (2021-2022), available at https://www.congress.gov/bill/117th-congress/house-bill/741/text [accessed 21 June 2021].

48. Such repurposing of taxes should avoid reducing funding for other aviation policies such as security.

49. European Commission (2020), *Sustainable Aviation Fuels Roundtable – Background Paper*.

50. Under the Renewable Energy Directive (RED), voluntary certification schemes report information on biomass feedstocks to member state governments and fuel suppliers to ensure compliance with sustainability criteria.

51. Including ICAO Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), the Chicago Convention, and the EU bilateral treaties on aviation.

52. German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit BMVI) (2021*), PtL Roadmap: Nachhaltige strombasierte Kraftstoffe für den Luftverkehr in Deutschland*, available at https://www.bmvi.de/SharedDocs/DE/Anlage/LF/ptl-roadmap.pdf?__blob=publicationFile [accessed 21 June 2021].

53. Biodiesels account for ~80% of biofuel production in Europe. This primarily relies on domestic crop-based feedstocks (with rapeseed oils accounting for 38% of final output), though 44% is also sourced from imported biomass. Only a small share relies on waste-based oils (~15%). ECOFYS (2019), *Technical Assistance in Realisation of the 2018 Report on Biofuels Sustainability*, Final Report Commissioned by DG ENERGY.

54. Energy Transition Commission (ETC) (2020), *Making Mission Possible.*

    Energy Transition Commission (ETC) (forthcoming 2021) report on bioenergy.

55. BloombergNEF (2020), *Electric Vehicle Outlook 2020*.

56. McKinsey Centre for Future Mobility (2017), What's sparking electric-vehicle adoption in the truck industry?

57. At present, the most inexpensive solution is to optimize output for biodiesel production, which is also incentivized for use in road transport via the EU renewable energy directive (RED-II). As a result, the vast majority of existing biofuels are used in this sector, despite the 1.2x multiplier applied to aviation and shipping.

58. Such a feedstock strategy should be embedded within European policy frameworks such as the Renewable Energy Directive (RED) to mitigate potentially adverse effects related to feedstock scarcity in other sectors.

59. This report represents a collective view of the European group of the *Clean Skies for Tomorrow* (CST) Coalition. European CST members and signatories to the report endorse the general thrust of the arguments but should not be taken as agreeing with all statements.

60. For further information on biomass availability by source and sustainability criteria applied to these estimates, see: World Economic Forum (2020), *Clean Skies for Tomorrow: Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation*, available at https://www.weforum.org/reports/clean-skies-for-tomorrow-sustainable-aviation-fuels-as-a-pathway-to-net-zero-aviation [accessed 21 June 2021].

61. The availability of these feedstocks can increase due to both population growth and technological progress, and imports from other regions of the world that are not currently using them.

62. Assumes that a maximum of 10 G+FT and AtJ plants per year can be opened annually in this period due to capacity constraints from personnel and equipment.

63. For a full breakdown of product slate assumptions by technology, see: World Economic Forum (2020), *Clean Skies for Tomorrow: Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation*, available at https://www.weforum.org/reports/clean-skies-for-tomorrow-sustainable-aviation-fuels-as-a-pathway-to-net-zero-aviation [accessed 21 June 2021].

64. Sources:

- Sustainable Aviation (2020), *Sustainable Aviation Fuels Road-Map: Fuelling the Future UK Aviation*.
- O'Malley, J. & Pavlenko, N. (2021), *Estimating the Sustainable Aviation Fuel Feedstock Availability to Meet Growing European Union Aviation Sector Demand*, International Council on Clean Transportation (ICCT), available at https://theicct.org/publications/sustainable-aviation-fuel-feedstock-eu-mar2021 [accessed 21 June 2021].
- NLR – Royal Netherlands Aerospace Centre & SEO Amsterdam Economics (2021), *Destination 2050: A Route to Net Zero European Aviation*, Airlines for Europe (A4E), CANSO (Civil Air Navigation Services Organisation), ERA (European Regions Airline Association), Airports Council International-EUROPE (ACI) & Aerospace & Defence Industries Association of Europe (ASD).
- Air Transport Action Group (2020), *Waypoint 2050: Balancing Growth in Connectivity with a Comprehensive Global Air Transport Response to the Climate Emergency*.
- Marrakech Partnership for Global Climate Action (2020), Climate Action Pathway – Transport, available at https://unfccc.int/sites/default/files/resource/Action_table_Transport_.pdf [accessed 21 June 2021].

65. S-Curves from:

- Air Transport Action Group (2020), *Waypoint 2050: Balancing Growth in Connectivity with a Comprehensive Global Air Transport Response to the Climate Emergency*.
- NLR – Royal Netherlands Aerospace Centre & SEO Amsterdam Economics (2021), Destination 2050: A Route to Net Zero European Aviation, Airlines for Europe (A4E), CANSO (Civil Air Navigation Services Organisation), ERA (European Regions Airline Association), Airports Council International-EUROPE (ACI) & Aerospace & Defence Industries Association of Europe (ASD).
- Marrakech Partnership for Global Climate Action (2020), Climate Action Pathway – Transport, available at https://unfccc.int/sites/default/files/resource/Action_table_Transport_.pdf [accessed 21 June 2021].

66. O'Malley, J. & Pavlenko, N. (2021), ,Estimating the Sustainable Aviation Fuel Feedstock Availability to Meet Growing European Union Aviation Sector Demand, International Council on Clean Transportation (ICCT), available at https://theicct.org/publications/sustainable-aviation-fuel-feedstock-eu-mar2021 [accessed 21 June 2021].

67. O'Malley, J. & Pavlenko, N. (2021), ,Estimating the Sustainable Aviation Fuel Feedstock Availability to Meet Growing European Union Aviation Sector Demand, International Council on Clean Transportation (ICCT), available at https://theicct.org/publications/sustainable-aviation-fuel-feedstock-eu-mar2021 [accessed 21 June 2021]. ICCT estimates of sustainable biomass availability also exclude the United Kingdom as the focus of the study is exclusively on the EU27.

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World Economic Forum
91–93 route de la Capite
CH-1223 Cologny/Geneva
Switzerland

Tel.: +41 (0) 22 869 1212
Fax: +41 (0) 22 786 2744
contact@weforum.org
www.weforum.org