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Ramping up Sustainable Aviation Fuels

There is enough sustainable feedstock available to power aviation in 2030 and beyond

WORLD ECONOMIC FORUM

Sustainable Aviation Fuel is the only near-term large-scale decarbonization option for the industry

There is no silver bullet! Different regions will transition to new technologies at different pace

There is enough sustainable feedstock available to power aviation in 2030, and beyond

- Power-to-Liquid / e-fuels use captured CO2 as a feedstock and are thus unrestricted. Today's technology is not yet fully mature.

SAF could become economically viable but requires supportive regulatory framework

-Power-to-Liquid has the biggest potential for cost decrease and will eventually become the most cost competitive alternative.

SAF pathways in focus have different opportunities and challenges depending on feedstock and technology maturity

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	HEFA	Alcohol-to-Jet[1]	Gasification/FT	Power-to-liquid
Opportunity description	Safe, proven, and scalable technology	Potential in the mid-term, however significant techno-economical uncertainty		Proof of concept 2025+, primarily where cheap high volume electricity is available
Technology maturity	Mature	Commercial pilot		In development
Feedstock	Waste and residue lipids, purposely grown oil energy plants[2] Transportable and with existing supply chains Potential to cover 5-10% of total jet fuel demand	Agricultural and forestry residues, municipal solid waste[4], purposely grown cellulosic energy crops[5] High availability of cheap feedstock, however fragmented collection		CO_2 and green electricity Unlimited potential via direct air capture Point source capture as bridging technology
% LCA GHG reduction vs. fossil jet	73-84%[3]	85-94%[6]		99%[7]

1. Ethanol route; 2. Oilseed bearing trees on low-ILUC degraded land or as rotational oil cover crops; 3. Excluding all edible oil crops; 4. Mainly used for gas./FT; 5. As rotational cover crops; 6. Excluding all edible sugars; 7. Up to 100% with a fully decarbonized supply chain

Source: CORSIA; RED II; De Jong et al. 2017; GLOBIUM 2015; ICCT 2017; ICCT 2019; E4tech 2020; Hayward et al. 2014; ENERGINET renewables catalogue; Van Dyk et al., 2019; NRL 2010; Umweltbundesamt 2016

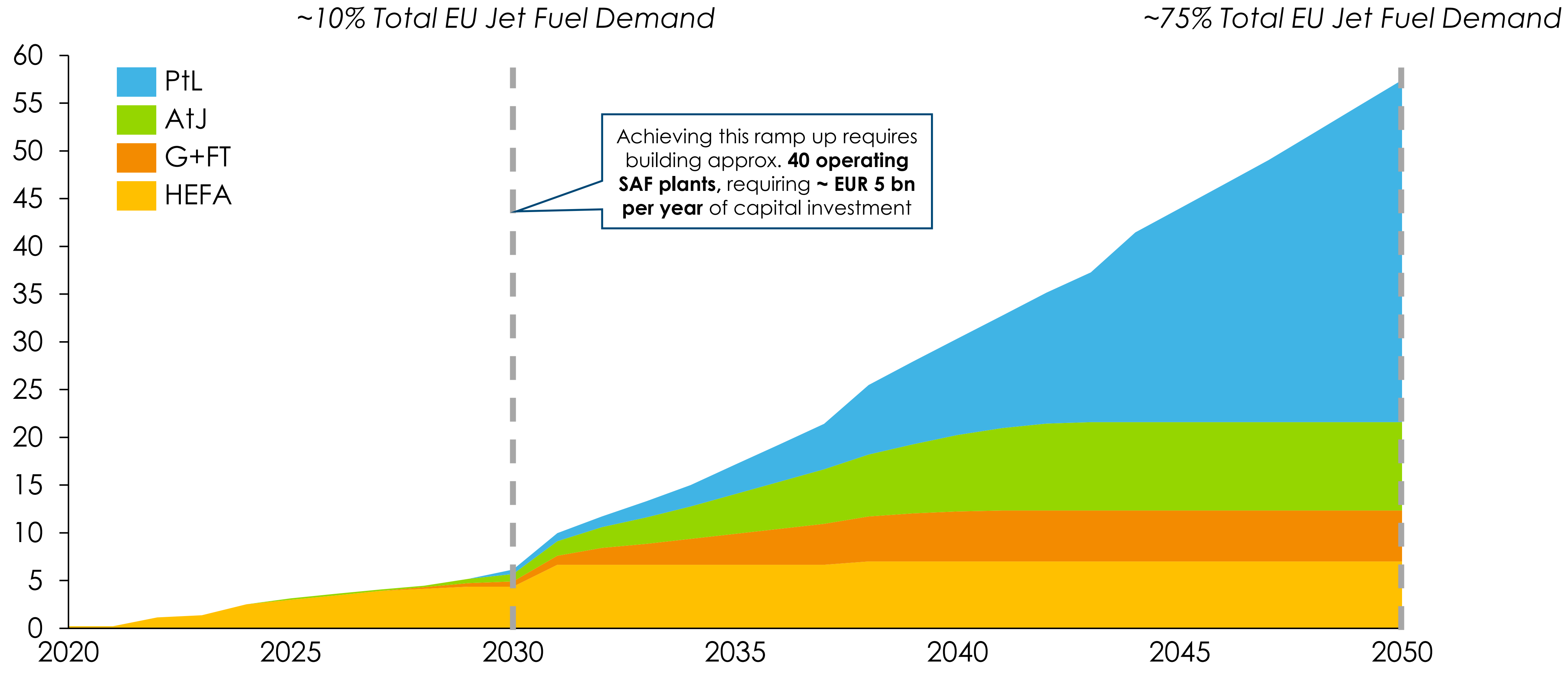
Scale-up of SAF production encounters multiple potential roadblocks – pathways have specific challenges

Pathway	Potential road blocks	Potential mitigation measure
Power-to-Liquid	**Extremely high electricity need:** Current process consumes a large amount of energy that has to be produced sustainably and faces increasing usage competition from other sectors	Refine or alter process to reduce required amount of electricity (e.g. via Power-and-Gas-to-Liquid) and support general green electricity turnaround
	High costs of sustainable H_2: Potentially insufficient scale of green hydrogen in other sectors for substantial cost decline	Carefully choose H_2 production locations providing lowest cost of renewable electricity and support deep decarbonization across other sectors to scale-up H_2 uptake
	Lack of sustainable CO_2 supply: Neither direct air capture carbon dioxide nor biomass based point source capture available at scale	Focus on CO_2 captured from biomass-use first (strategic location in high-density industrial clusters) and invest into direct air capture technology
	Technology complex at scale-up: Issues with scale-up of technology, especially Reverse-Water-Gas-Shift (RWGS) step	Validate technology feasibility in sync with H_2 and FT cost decreases and consider alternative process designs such as co-electrolyzer (SOEC) without the RWGS step

It is technically feasible to reach 10% SAF jet fuel uptake in Europe by 2030 with strong policy and financial support

Feasibility Assessment Results – Central Case Scenario: SAF Output by Technology Pathway

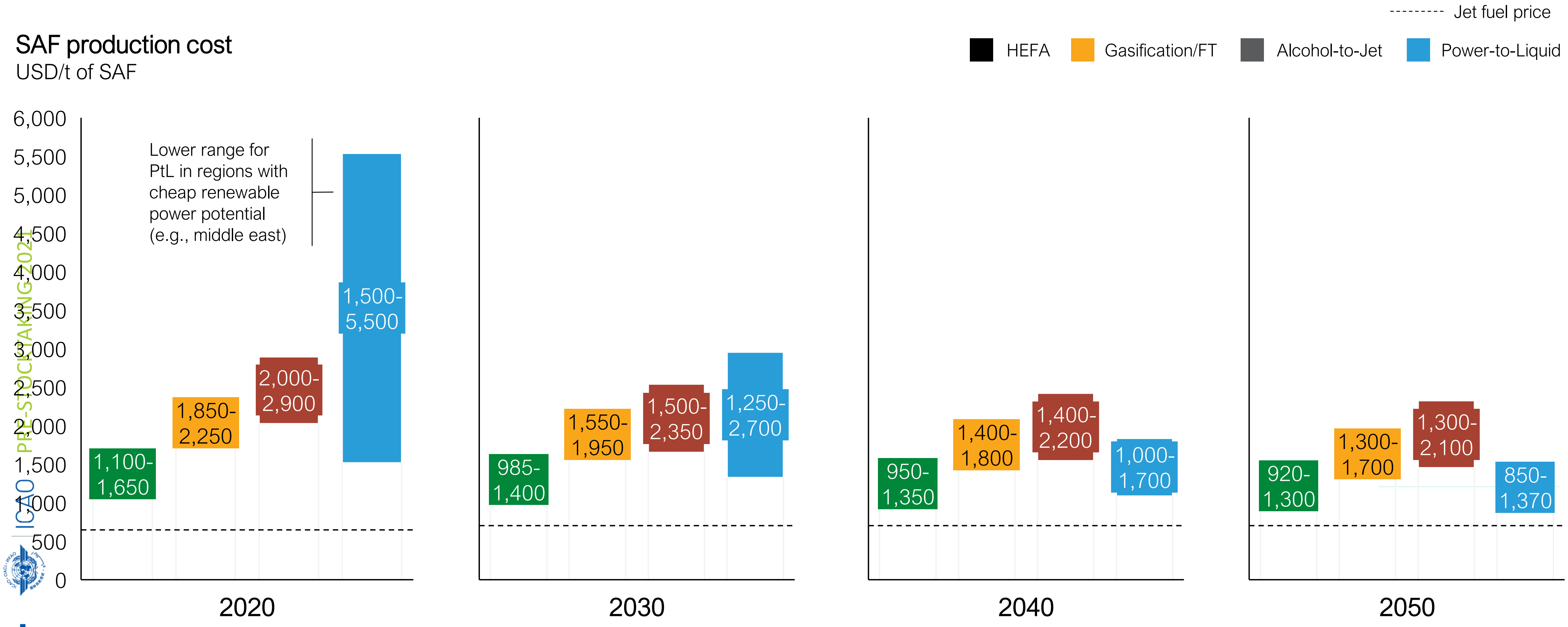
Mt./yr.



Note: Assume 40% of all sustainable biomass available in Europe is used for conversion to aviation biofuels – potential upside from imported biomass or finished SAF product from external regions (see results from scenario 3 below). EU jet fuel demand refers to EU28 including the UK.
Source: ETC Analysis.

SAF production costs vary significantly by pathway

Global SAF production cost shown for a range of selected feedstocks



Source: Expert interviews; McKinsey analysis

Announced Projects with SAF Production Capacity in Europe 2020-2025

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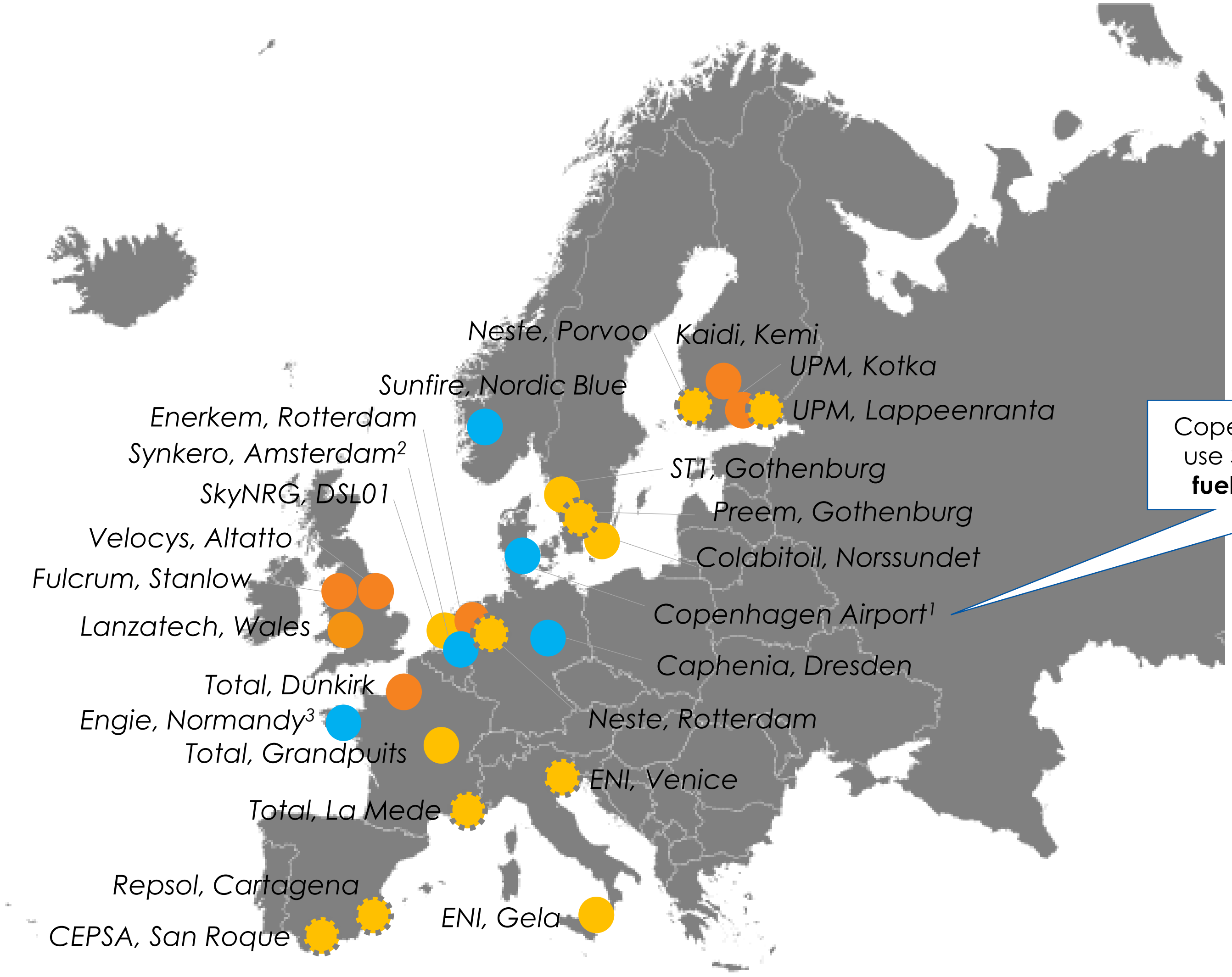
SAF Pathways

- HEFA (existing)
- HEFA (new)
- G+FT
- AtJ
- PtL



Copenhagen Airport plans to use SAFs from PtL for **30% jet fuel** consumption **by 2030**[1]

Risk of delays due to COVID crisis

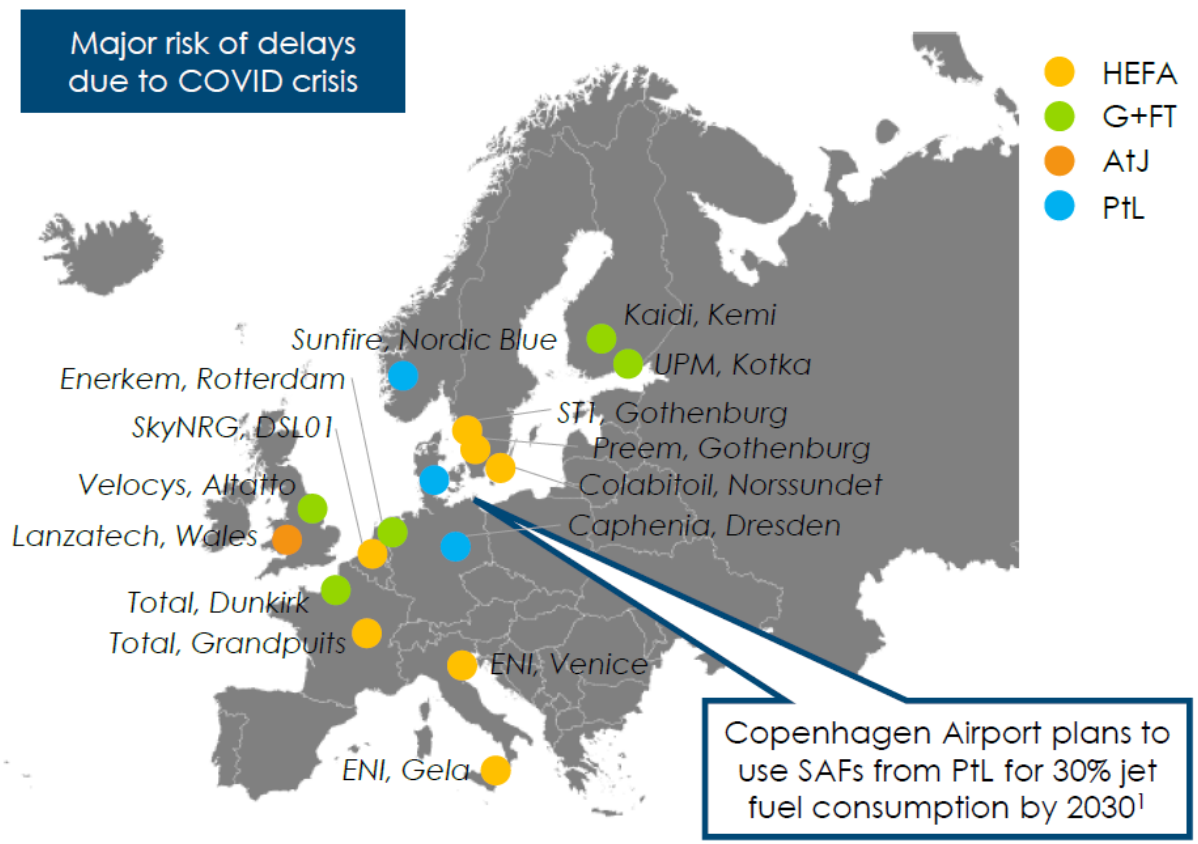
Note: * Pilot/demo plans. [1] This project is a partnership between Copenhagen Airports, A.P. Moller - Maersk, DSV Panalpina, DFDS, SAS and Ørsted to trial-scale production facility to produce sustainable fuels for road, maritime and air transport in the Copenhagen area. [2] Final investment decisions expected in 2021.

Source: ETC, McKinsey, IRENA (2017) Maersk, Neste, press releases.

Planned Capacity: total capacity could more than double in next 5 years to ~4 Mt/yr. if all projects completed on time

Companies have announced plants to open **15 new plants with SAF output potential in Europe** by 2025, but all need major policy support

Announced Projects with SAF Production Capacity 2020-2025



Supplier	Location	Tech.	Start Year	Total Fuel Capacity *(Mt./yr.)*
eni	Italy	HEFA	2021	0.8
Enerkem *	Netherlands	G+FT	2021	<0.1
COLABITOIL	Sweden	HEFA	2021	0.5
eni	Italy	HEFA	2021	0.2
st1	Sweden	HEFA	2022	0.2
KAIDI *	Finland	G+FT	2022	<0.1
SkyNRG	Netherlands	HEFA	2023	0.1
preem	Sweden	HEFA	2023	0.8
sunfire *	Norway	PtL	2023	<0.1
CAPHENIA *	Germany	PtL	2023	<0.1
TOTAL	France	G+FT	2024	0.2
TOTAL	France	HEFA	2024	0.3
NESTE	TBD[2]	HEFA	2025	1.0
VELOCYS	UK	G+FT	2025	0.1
LanzaTech	UK	AtJ	2025	0.4
UPM	Finland	UPM	2025	0.5

Note: * Pilot/demo plans. [1] This project is a partnership between Copenhagen Airports, A.P. Moller - Maersk, DSV Panalpina, DFDS, SAS and Ørsted to trial-scale production facility to produce sustainable fuels for road, maritime and air transport in the Copenhagen area. [2] Final investment decisions expected in 2021.
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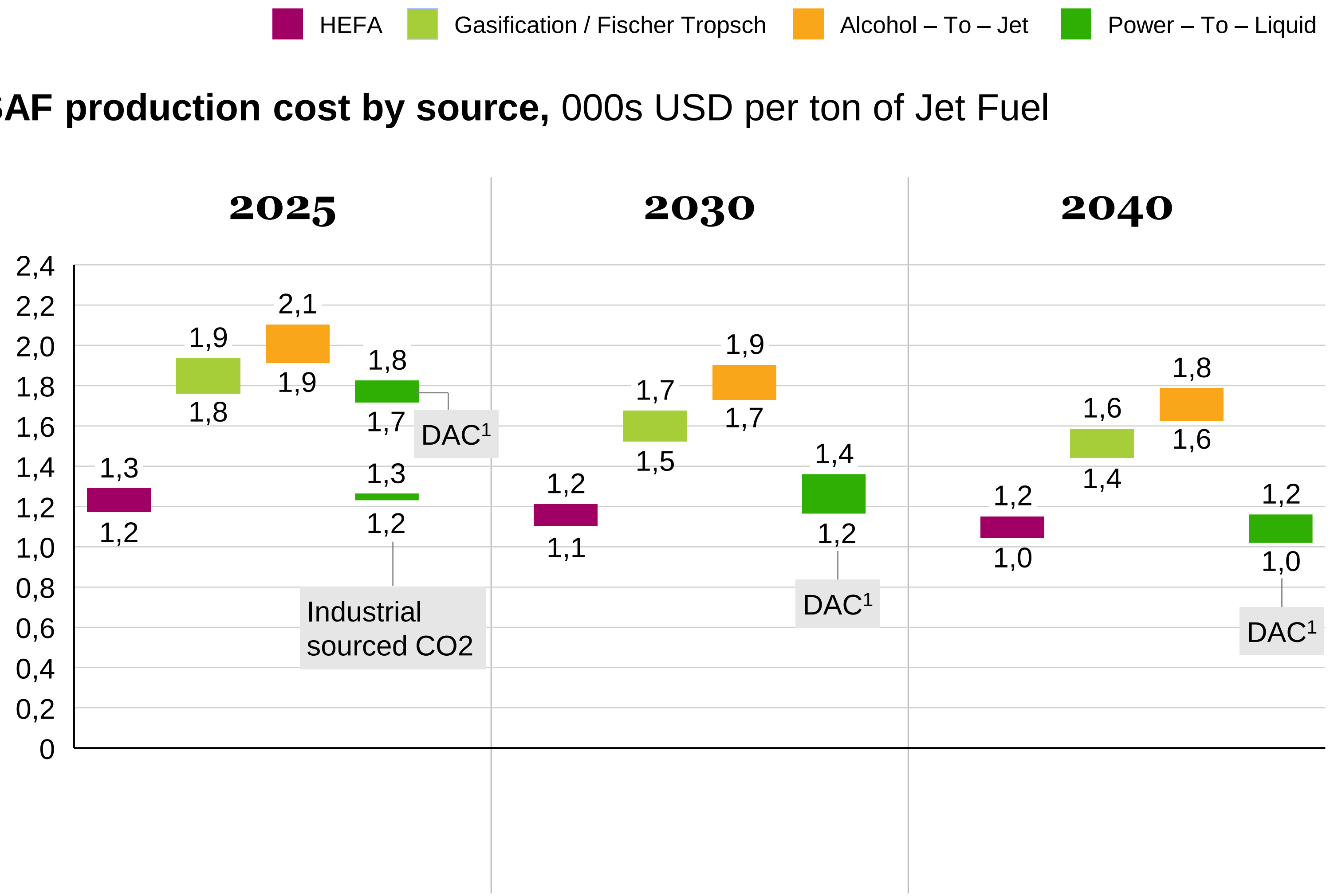
ENERGY TRANSITIONS COMMISSION

Chilean Synthetic Jet Fuel produced with DAC is projected to be cost competitive vs. SAF alternatives by 2030

Global SAF production cost by source, 000s USD per ton of Jet Fuel



Total Addressable Market

Pre-2030:

Synfuels form part of early-SAF mix (potentially using industrial sources) as airlines seek to establish **future, highly scalable decarbonization** options

Post-2030:

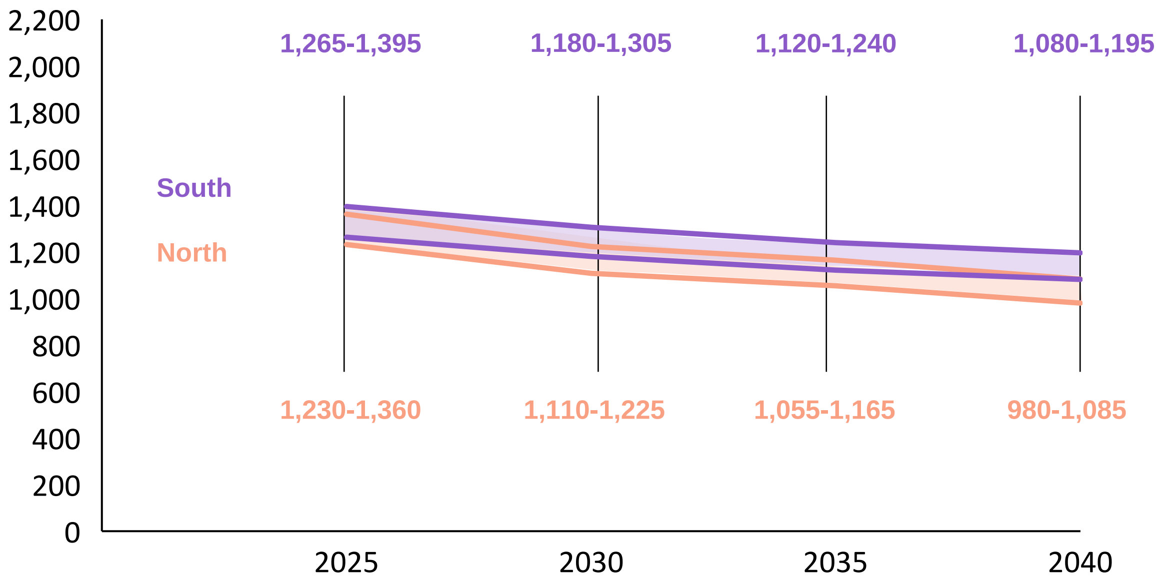
~2030 DAC Synthetic Jet Fuel made in Chile will **compete closely with HEFA economically** and benefit from greater scalability and perceived **environmental friendliness**

Source: Clean Skies for Tomorrow Report World Economic Forum report; McKinsey team analysis

By 2030, synfuel (jet) costs from production in Chile could get close to USD 1,000 per ton

Industrially Sourced CO2: Production cost curve for Jet Fuel / Diesel

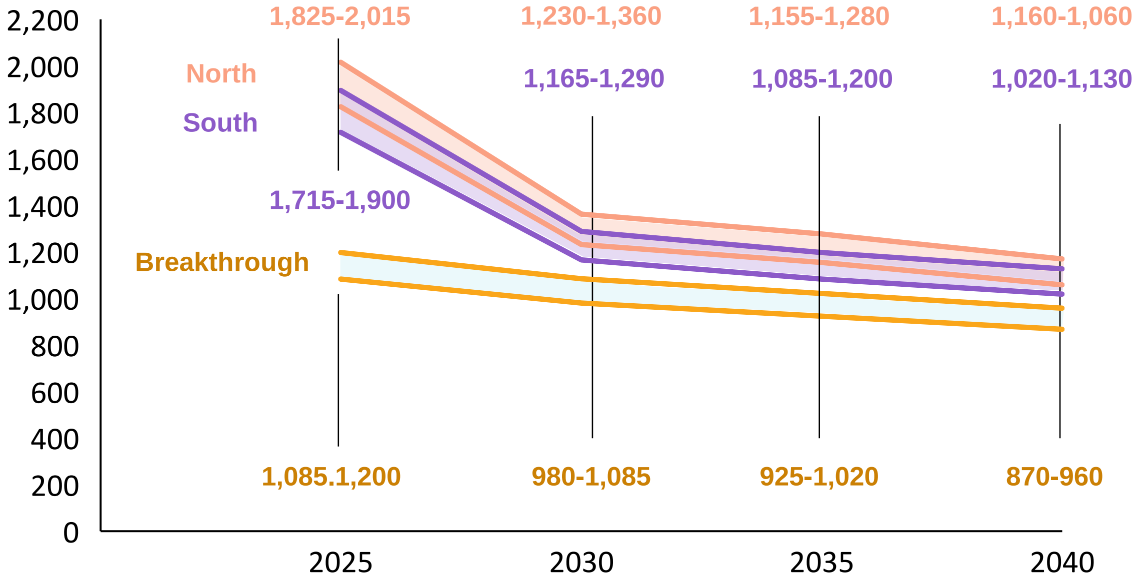
USD / Ton of Jet Fuel / Diesel



	2025	2030	2035	2040
North Industrial Source CO2 Cost *USD/T CO2*	60	60	60	60
South Industrial Source CO2 Cost *USD/T CO2*	105	105	105	105

DAC Sourced CO2: Production cost curve for Jet Fuel / Diesel

USD / Ton of Jet Fuel / Diesel



	2025	2030	2035	2040
Traditional DAC CO2 Costs *USD/T CO2*	250	100	92.5	85
Breakthrough DAC CO2 Costs *USD/T CO2*	30	30	30	30

Source: McKinsey

Thank You

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