S&P Global
Commodity Insights

Global SAF and e-SAF development

APEC Symposium on Bioenergy
Chua Wei Jun, Biofuels Analyst

3rd December 2024

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KEY STATS

6.5-8%
Annual revenue growth on average through h2023

~$14B
Annual revenue growth on average through h2023

>35K
People

45
Economies with direct presence

~$350M
Run-rate revenue synergies

~$600M
Run-rate expense synergies

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Powering the Markets of the Future

Our Purpose
Accelerate Progress

Our Values

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We cultivate breakthrough thinking to uncover new sources of value

Partnership
We form connections for impact

Integrity
We do what's right

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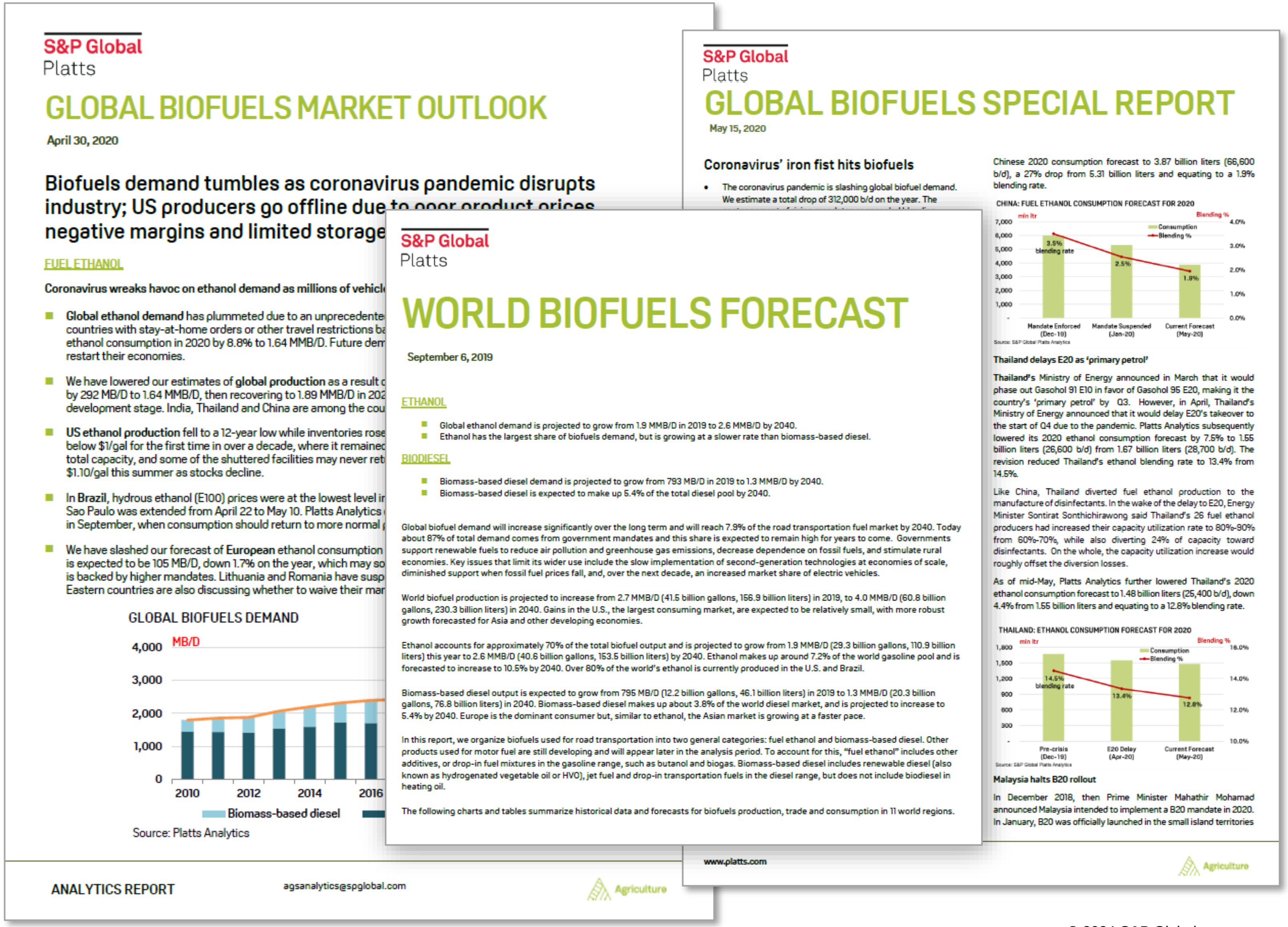
Biofuels Analytics:
Global production/ consumption, prices, manufacturing economics, trade flows

- Monthly forecasts, 2 years ahead
- Annual forecasts, up to 2050
- **Feedstock price forecasts** for key feedstocks
- **Product price forecasts** for ethanol, FAME, renewable diesel and SAF
- Global **supply-demand** estimates
- **Trade flows** and economies mandates
- **Global capacity database** for ethanol, FAME, renewable diesel and SAF
- **Deal trackers** for feedstocks, SAF and marine bio-bunkers
- **SAF market outlook report** (quarterly)



Policies and Initiatives

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SAF is dependent on policy support, but the global regulatory landscape is very fragmented

Mandate | Incentives | Airlines

		2030	2050	Type	Details
Regional	Europe	6% →	70%	Mandate	• **ReFuelEU Aviation sets target of 70% vol by 2050 in the EU.** RFNBO sub-target of 35% by the same date. The UK approved a SAF mandate of 22% by 2040.
Regional	The US	10%* → *Based on 3-billion-gallon target	100%	Incentives	• **The US Government seeking 3 billion gallons of domestic SAF production by 2030, increasing to 35 billion by 2050** under its 'SAF Grand Challenge'. 35 billion gallons is the estimate of total aviation jet fuel use in 2050.
Regional	Asia Pacific	Economies-level policy developments		Mandate	• **China:** 50 kt by 2025 (target) • **Indonesia**: 1% in 2027 • **Thailand**: 1% in 2026, 5% by 2036 • **Singapore**: 1% by 2026, 3-5% by 2030 • **India**: 1% by 2027, 2% by 2028 • **Japan**: 10% by 2030 (target) • **Korea**: 1% by 2027
Regional	Latin America / Other	Economies-level policy developments		Mandate	• **Brazil** aims at 1% emissions reduction mandate for aviation by 2027, 10% by 2037. • **Chile** launched a SAF roadmap to achieve 50% blend rate in 2050.
Regional		Airlines driving growth in Middle East		Airlines	• **Rest of world**: No stated mandates but higher share expected in Middle East due to connectivity role with other key regions.
Global	IATA	5% →	65%	Airlines	• **IATA's Net Zero strategy for 2050**: 65% SAF, 19% offsets and carbon capture, 13% new technology; 3% infrastructure and operational efficiencies
Global	ICAO	Carbon neutral growth		Incentives	• **ICAO (UN) does not have a global SAF mandate**, but supports CORSIA, a market-based mechanism to address carbon emissions from international air travel

Data compiled September 20, 2024.

Source: S&P Global Commodity Insights.

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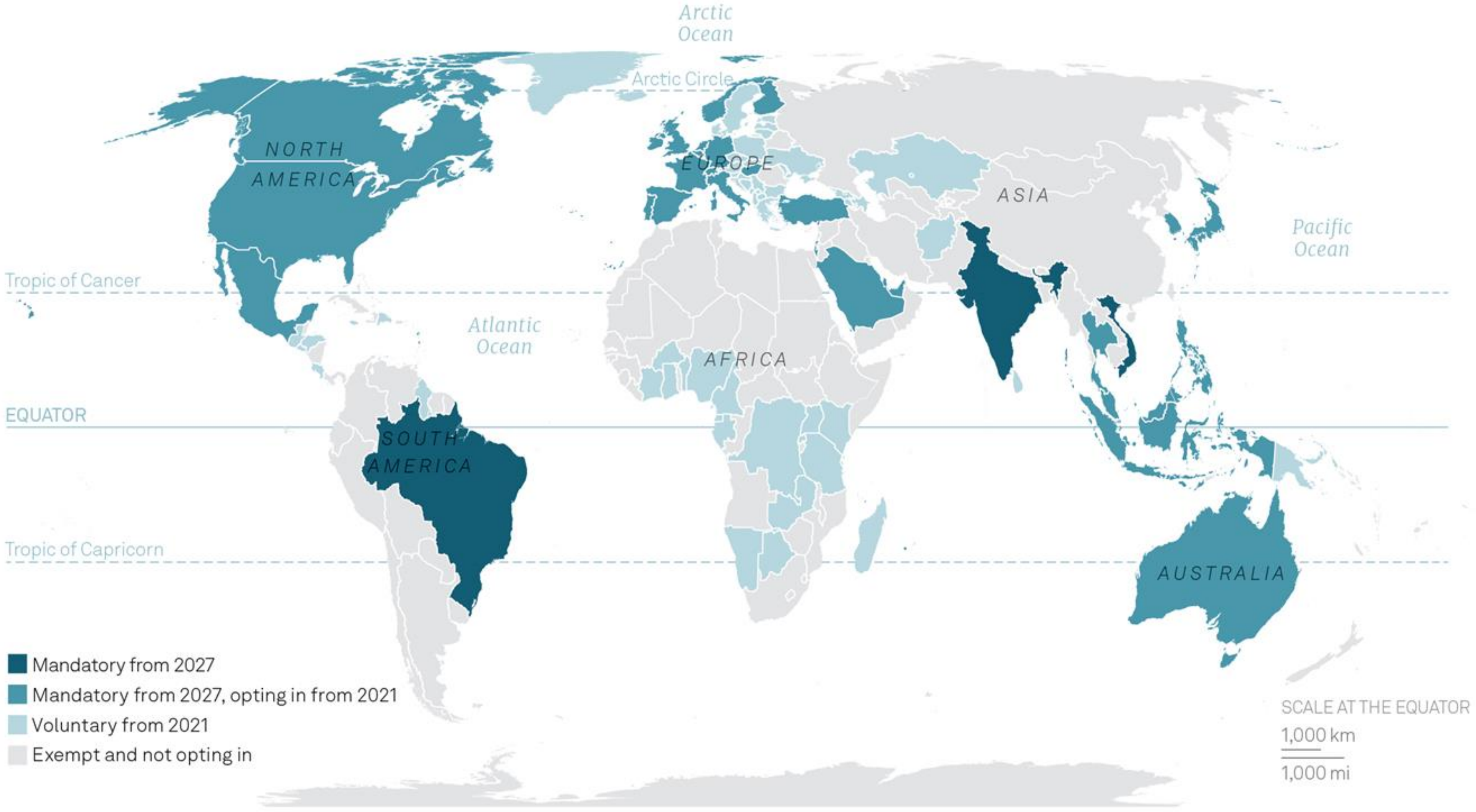
CORSIA - developed by ICAO, is designed to deal with international aviation emissions which are not governed by UN climate framework

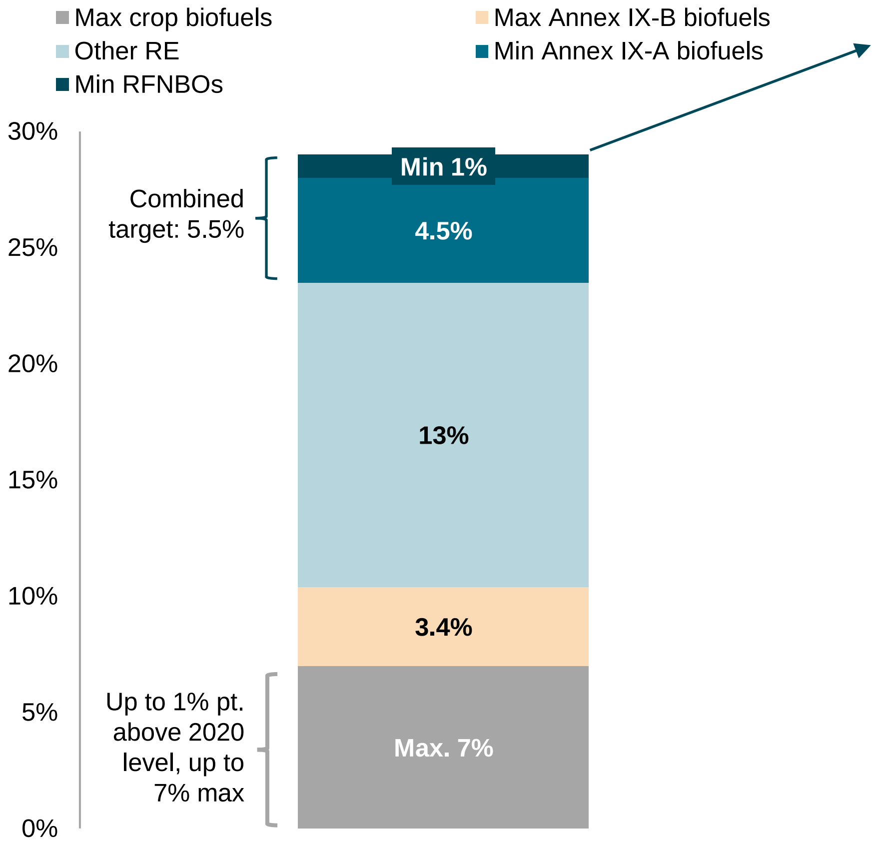


Source: ICAO, ICCT, S&P Global Commodity Insights

ICAO; International Civil Aviation Authority. CORSIA; Carbon Offsetting and Reduction Scheme for International Aviation

Use of RFNBOs in road, aviation and shipping can all contribute to the minimum 1% energy target in 2030 under RED III

RED III 2030 targets for transportation



Data compiled Oct. 2, 2024.

*Double counting means that each unit of RFNBO energy counts for twice its energy content.

Source: S&P Global Commodity Insights.

Renewable fuels of non-biological origin (RFNBOs)

- RFNBOs must contribute a minimum of 1% to transport energy by 2030 but can double count* towards this target**.** Member States may also set a higher target than the 1%.
- To be eligible for support, RFNBOs must achieve a lifecycle GHG emissions saving of >70%.

Compliance options include:

- Use of green H_2 as an intermediate product in the production of conventional transport fuels and biofuels
- Use of e-SAF in aviation, with an additional multiplier of 1.5x
- Use of RFNBOs in shipping, with an additional multiplier of 1.5x (e.g. green H_2, e-methanol)
- Direct green hydrogen use in road transport (e.g. in fuel cell electric or hydrogen vehicles)
- Use of e-fuels in road transport (e.g. e-diesel, e-gasoline)

ReFuelEU sets long-term targets for SAF use in the EU, including a sub-target for synthetic aviation fuels

Background

- ReFuelEU Aviation was adopted by the EU in September 2023 and aims to reduce the GHG emissions from the aviation sector by increasing demand for SAF.

Targets and coverage

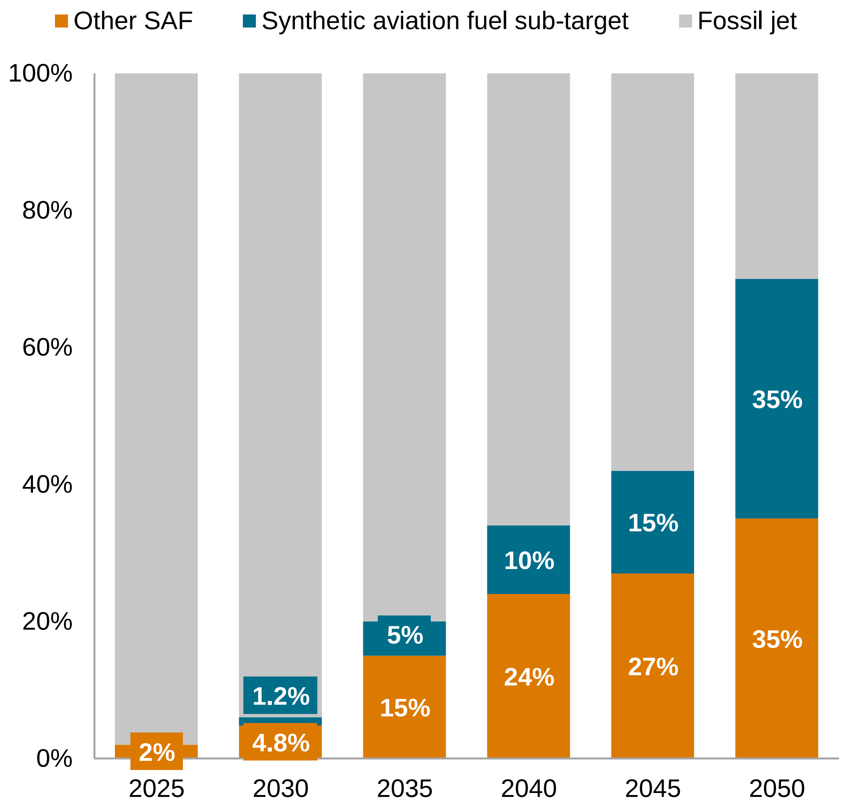
- Commencing in 2025, aviation fuel suppliers must increase the minimum volume of SAF supplied in total aviation fuel, starting at 2% and growing to 70% by 2050. This includes a synthetic aviation fuel sub-target, increasing from 1.2% in 2030 to 35% in 2050.
- ReFuelEU applies to aviation fuel suppliers supplying jet fuel at EU airports, EU airports with over 800,000 in passenger traffic, and aircraft operators at EU airports.
- Aircraft operators must uplift over 90% of their yearly aviation fuel required at EU airports to avoid anti-competitive fuel tinkering at locations with lower fuel prices.

Implementation

- ReFuelEU sets a penalty for non-compliance at not less than twice the yearly average price differential of conventional fuel and applicable SAF type, multiplied by the shortfall quantity. Member States must develop a specific methodology for the penalty calculation by 2024 end.
- During a flexibility period from Jan 2025 to Dec 2034, fuel suppliers may meet targets by supplying the min. SAF share as an average of total fuel supplied at EU airports for that period.
- As of October 2024, the European Commission is assessing whether a book-and-claim system should be implemented to help facilitate the supply and uptake of SAF.

ReFuelEU Aviation SAF targets

% of EU jet fuel mix by volume



Data compiled Oct. 2, 2024.

Source: S&P Global Commodity Insights.

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SAF Fundamentals

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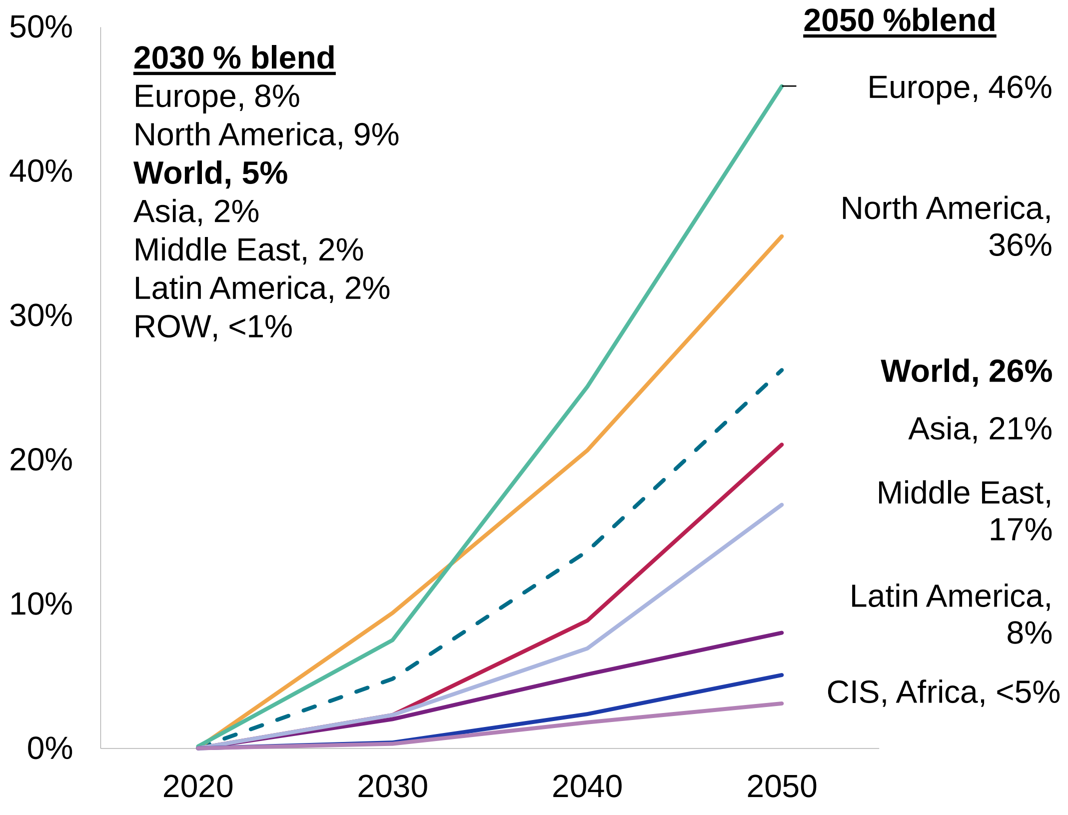
As the aviation sector has no scalable alternative to decarbonize, SAF demand is expected to see significant growth in demand compared to other biofuels

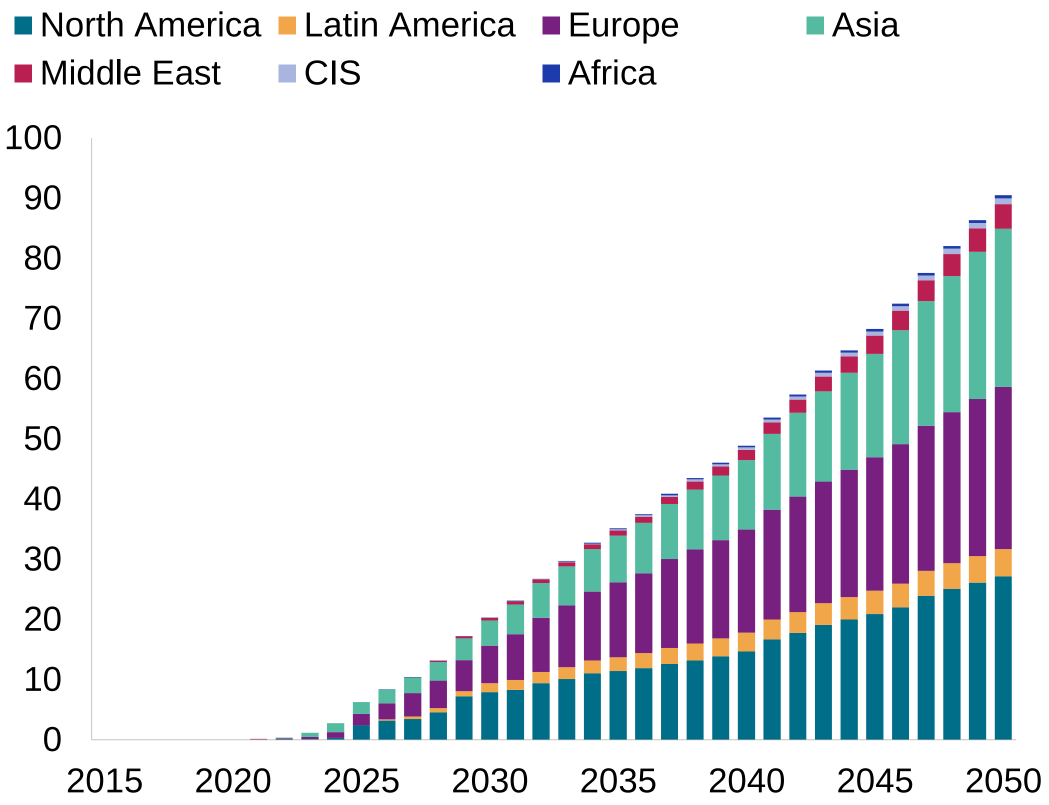
Global SAF blendrate by region

(SAF blend rate in jet fuel, vol%)



Global SAF demand by region

(Million metric tons)



Data compiled July 31, 2024.
Source: S&P Global Commodity Insights.

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Feedstocks and technologies used to produce SAF

Sustainable aviation fuels feedstocks and pathways

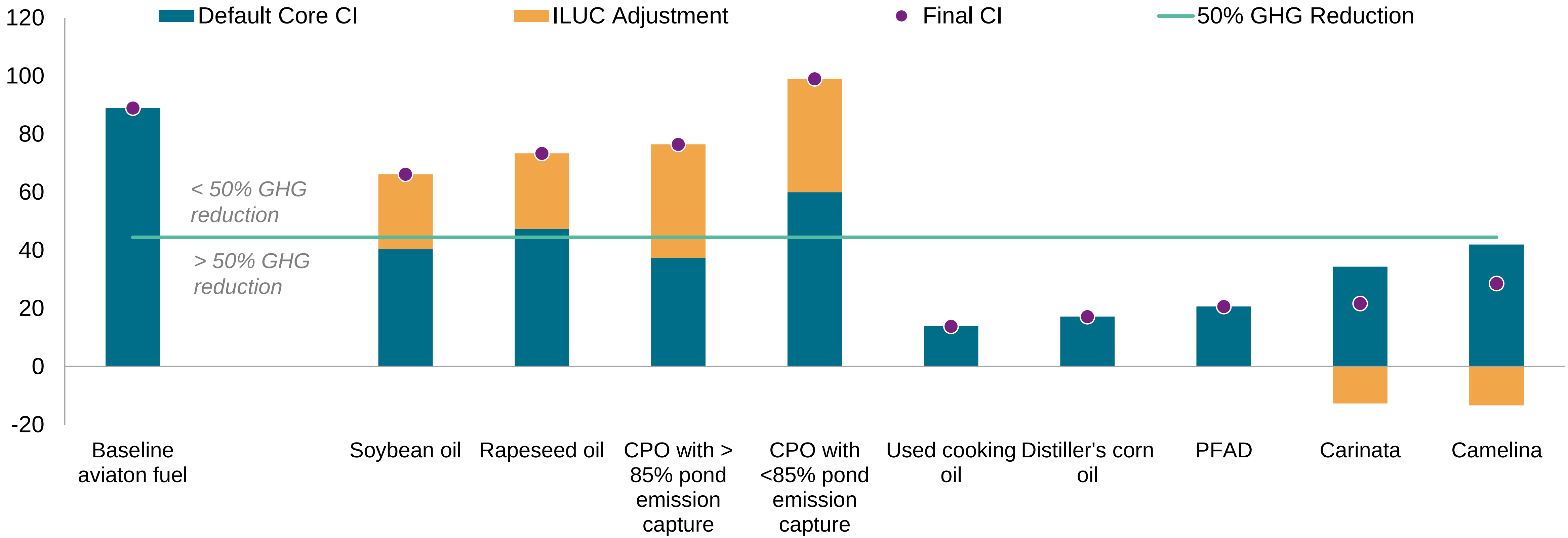
Generation	Category	Feedstocks	Pathway	CI reduction
1st Gen – Crop	Edible oil crops	Palm oil, Soybean oil, Sunflower oil, Rapeseed/Canola oil	HEFA-SPK	20-45% CI reduction
	Edible sugars	Sugarcane, maize/corn, sugar beet	ATJ-SPK	
2nd Gen – Advanced / waste	Waste lipids	Tall oil, Palm Oil Mill Effluent (POME), Palm Fatty Acid Distillate (PFAD), Used Cooking Oil (UCO), Animal Fat (Tallow)	HEFA-SPK	45-90% CI reduction
	Energy crops	Oil trees: Jatropha, Pongamia, Oil cover crops: Camelina, Carinata, Pennycress. Cellulosic cover crops: Switchgrass, Miscanthus, Reed	Oil: HEFA Cellulosic: ATJ	
	Ag residues	Straw, sugarcane bagasse, corn stover, cereal residues	ATJ-SPK	
	Forestry residues	Roundwood, sawdust, woodchip, sawmill slabs, logging leftovers, stemwood residues	FT-SPK	
	Biogenic compounds	Municipal waste streams (biogenic portion), algae, sewage sludge	HEFA-SPK	
3rd Gen – RFNBO / eFuels	Non-biomass	CO_2 from DAC, Green H_2	PTL-SPK	90-99% CI reduction
	Recycled carbon fuels	Fossil share of reusable plastic waste Industrial waste gas :CO_2 from CCS, Other (such as flue gas from steel production)	FT-SPK	

HEFA: Hydroprocessed Ester Fatty Acids, ATJ: Alcohol-to-Jet, FT: Fischer Tropsch, PTL: Power-to-liquid, SPK: Synthetic Paraffinic Kerosene, RFNBO: Renewable Fuels of Non-Biological Origin

Source: S&P Global Commodity Insights.

SAF producers will need to focus on waste oil and fats, and novel oil seeds (energy crops)

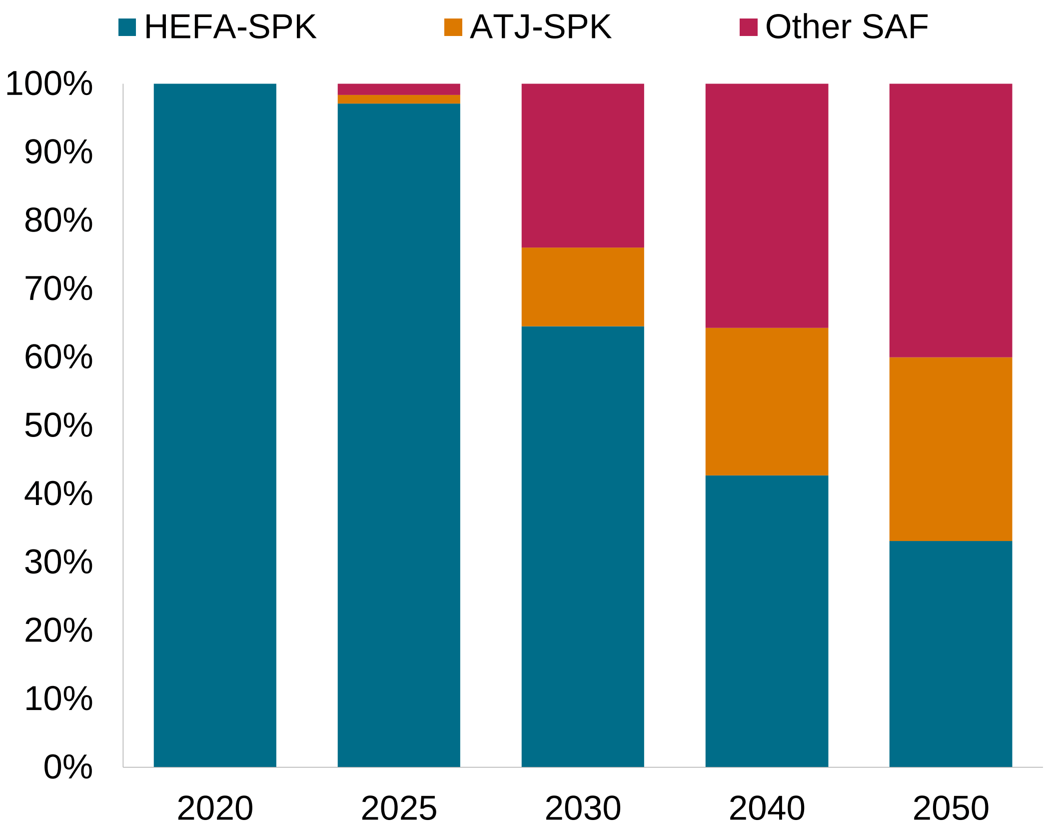
ICAO CORSIA’s default LCA assessment for HEFA aviation fuels
(gCO2e/MJ)



Note: Negative ILUC adjustments are still tentative, and may be adjusted up to 0 at a later point past the pilot phase
ICAO: International Civil Aviation Organization, CORSIA: Carbon Offsetting and Reduction Scheme for International Aviation
Source: S&P Global Commodity Insights, ICAO CORSIA.

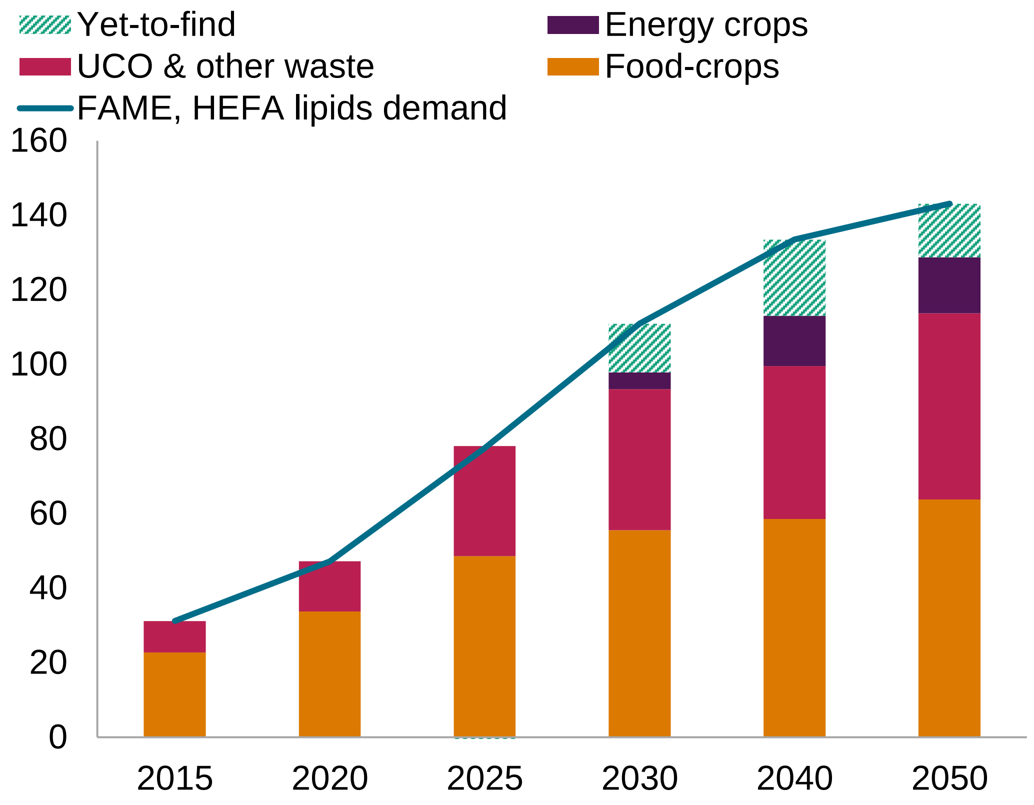
Alternative pathways and feedstocks will be required to help meet decarbonization targets

Global SAF supply by pathway



Global lipid feedstock demand for biofuels

(million metric tons)



Data compiled November 6, 2024.

Source: S&P Global Commodity Insights.

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e-SAF Technology

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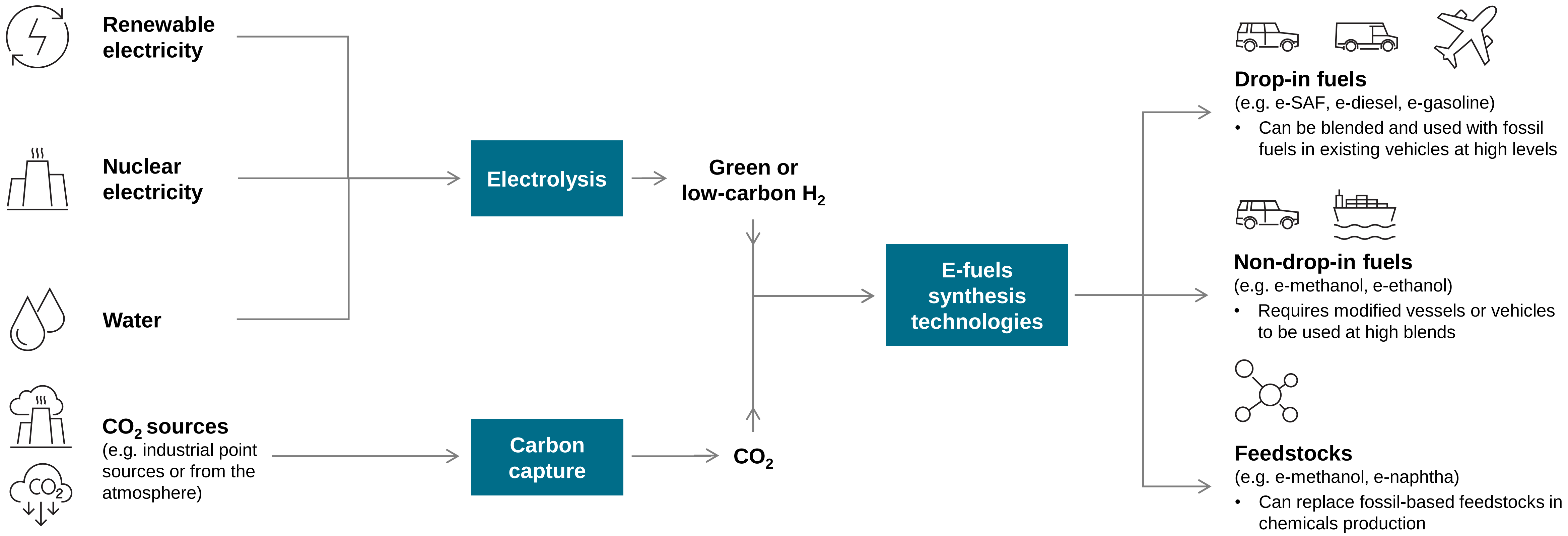
E-fuels are a category of synthetic fuels produced from low-carbon hydrogen via electrolysis and captured CO_2

E-fuel production technologies can produce a range of liquid or gaseous drop-in and non-drop-in fuels to decarbonize various transport modes and sectors.



Source: S&P Global Commodity Insights.

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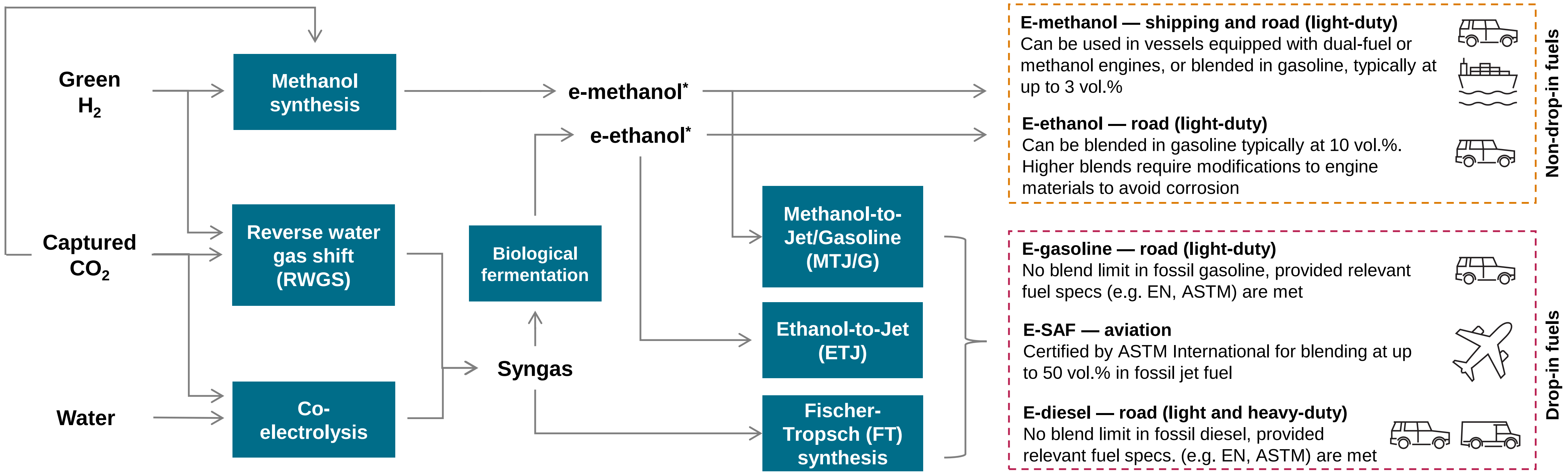
Different synthesis technologies exist to produce e-SAF and other e-fuel products

E-fuels production involves multiple chemical or biochemical synthesis processes, typically using alcohols (such as methanol or ethanol) or syngas (a mixture of H_2 and CO) as intermediates. E-fuels products can be categorized into:

- **Non-drop-in fuels:** can only be blended and used with fossil fuels at low levels. Blending non-drop-in fuels at higher levels requires significant modifications to vehicles and fuelling infrastructure to accommodate differences in fuel properties.
- **Drop-in fuels:** molecularly and chemically similar to fossil fuels, allowing them to be blended at high levels and used in existing vehicles or fuelling infrastructure without major overhauls.



*Alcohols like methanol and ethanol can be used directly as a fuel, or as a feedstock for further synthesis.

Source: S&P Global Commodity Insights.

E-fuels are attracting interest as they face fewer feedstock constraints than biofuels, but commercial barriers still exist to scale-up

Opportunities

Minimal physical feedstock constraints. The potential of renewable energy and CO_2 sources (e.g. from the atmosphere) are abundant, meaning there are technically no limitations on scaling up e-fuels supply.

High GHG saving potential. CO_2 is emitted when e-fuels are combusted, but as CO_2 is also used in their production, their use is considered carbon neutral. On a lifecycle basis, GHG savings can be up to 90% vs. fossil fuels, depending on sources of feedstock and energy used and any CCS.

Compatibility with existing fuel value chains. Many e-fuels are ‘drop-in’ fuels, which are chemically/molecularly similar to fossil fuels. This allows them to be used in existing vehicles and fuel infrastructure at high blends without major overhauls.

Flexibility in product slates. E-fuels technologies can produce a range of drop-in and non-drop-in fuels, which can be used to decarbonize multiple transport modes and sectors.

Challenges

High production costs. E-fuels currently cost several times more to produce than fossil fuels and biofuels. This is mainly driven by the high cost of green hydrogen production, as well as the CAPEX of e-fuels technologies and equipment. In the absence of policy support, costs will remain uncompetitive.

Policy and regulatory uncertainty. Whilst policy support for e-fuels is growing in the EU, UK and the US, there remains some uncertainty in how specific legislation will be implemented and the associated impact on e-fuels markets.

Technical challenges. Most e-fuel technologies are still at a pilot or demonstration stage today, with challenges in integrating multiple early-stage conversion technologies together to achieve stable and efficient production.

Challenges with project financing. Owing to policy uncertainty, technology risks and high upfront CAPEX, investors have been slow to provide financing for e-fuels projects, the majority of which have not reached FID.

Source: S&P Global Commodity Insights.

SAF Fundamentals

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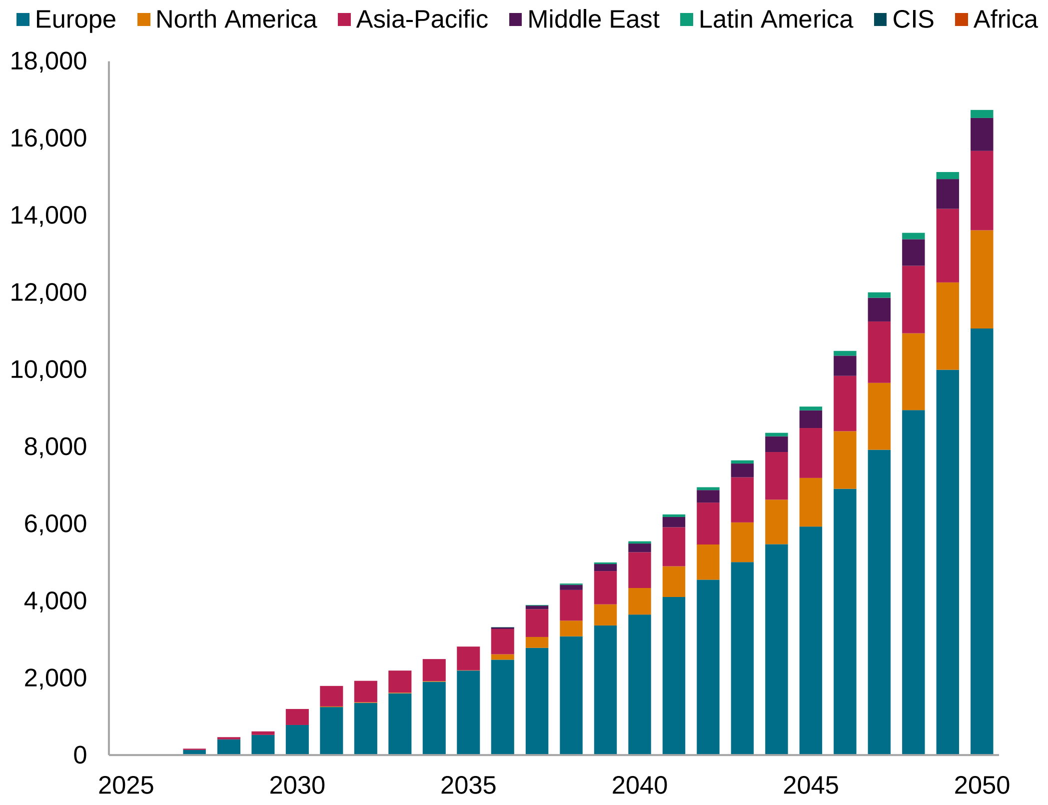
Global e-SAF demand could reach almost 17 MMt per year by 2050. European markets account for 66% of demand in 2050, driven by mandates

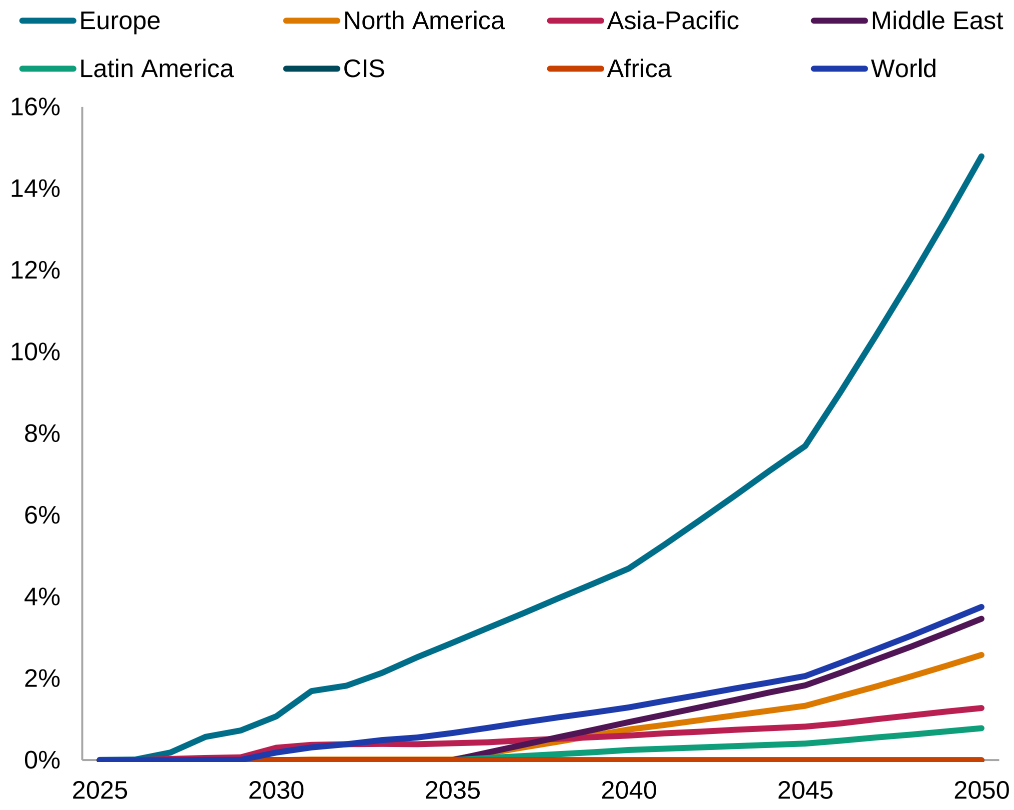
Global e-SAF demand outlook

(Thousand metric tons per year)



Global e-SAF blend rate outlook

(Vol.% blend rate in jet fuel pool)



Data compiled Oct. 2, 2024.

CIS = Commonwealth of Independent States.

Source: S&P Global Commodity Insights.

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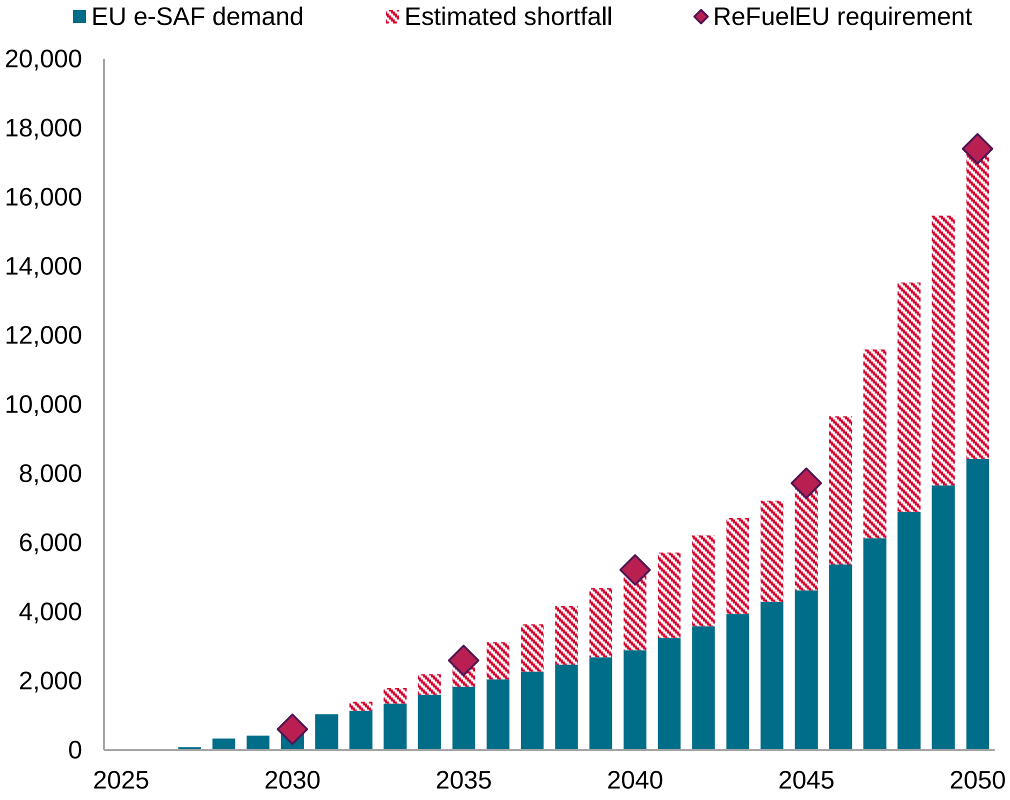
In the base case, the EU falls far behind long-term targets under ReFuelEU due to the high cost and limited availability of e-SAF

EU e-SAF demand outlook vs. ReFuelEU

(Thousand metric tons per year)



Data compiled Oct. 2, 2024.

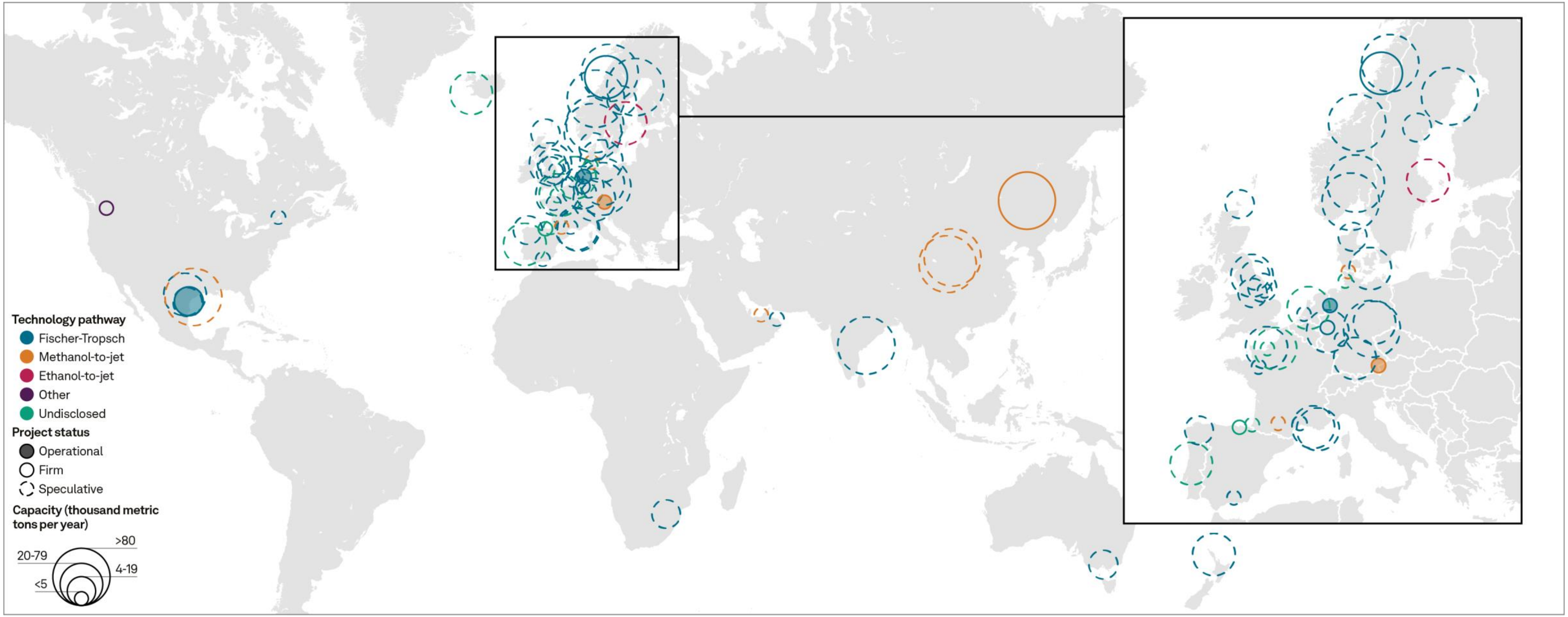
*See the 'Overview of E-fuels Technology & Policies' report for high-level commentary on e-fuel production economics.

Source: S&P Global Commodity Insights.

- E-SAF demand in the base case is forecasted for each market based on its track record in meeting past mandates, its current position on climate and renewable fuels policy, and the availability of e-SAF supply.
- From 2030, the EU is expected to fall behind the e-SAF sub-targets in ReFuelEU. By 2040, we forecast a shortfall quantity of 2.3 million metric tons (MMt) per year and by 2050, this reaches nearly 9 MMt per year.
- This is due to the limited availability of e-SAF at global level, with supply unable to scale sufficiently quickly to meet demand. The supply of green hydrogen and CO_2 (biogenic or DAC) is expected to be sufficient to meet mandated volumes.
- Rather, e-SAF supply is likely constrained by high production costs, which inhibits the large-scale investment needed to significantly ramp-up production. Investment in projects has been limited to date, resulting in no major projects in Europe reaching FID.
- In the long term, we expect e-fuel production costs to reduce significantly – potentially by up to 60% between 2025 and 2050 in some locations (e.g. the US Gulf Coast, Middle East and parts of Europe). However, costs will remain uncompetitive with HEFA and fossil jet fuel without further support*.
- Higher e-SAF blending will require levers on both the supply and demand side. Further production cost reduction, driven primarily by falling LCOH and CAPEX of e-fuels plants, as well as stronger policy and market support will both be important for making e-SAF more competitive.

The majority of announced e-SAF projects so far are in Europe, but there are also large projects planned in North America and Asia-Pacific

Global e-SAF projects



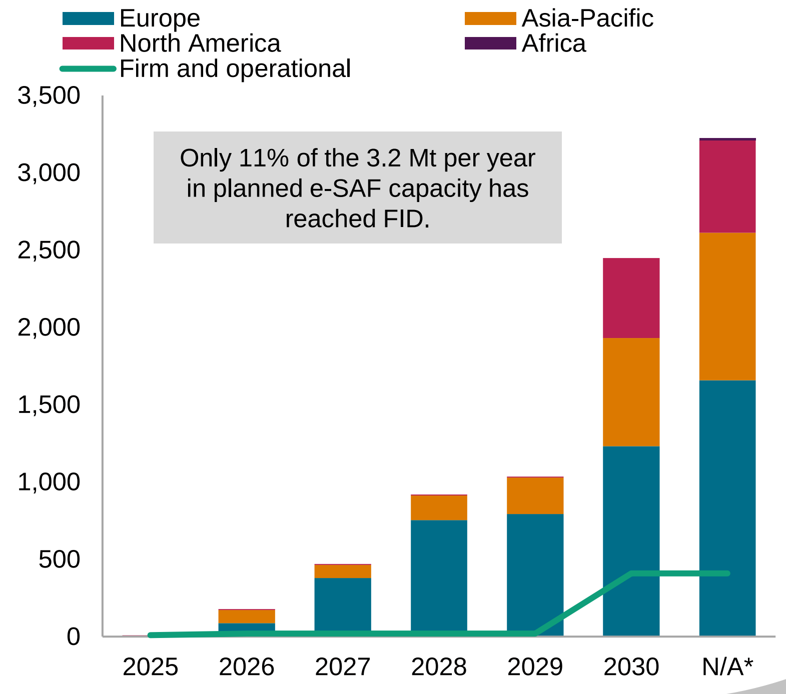
Data compiled Oct. 2, 2024.
Source: S&P Global Commodity Insights: IC-2014469.

The e-SAF sector is currently facing several headwinds, with the majority of planned projects yet to reach FID

Challenges with e-fuels development

Announced global e-SAF production capacity

(Thousand metric tons per year)



Data compiled Oct. 2, 2024.

*N/A = Not available (includes projects with no start-date publicly announced).

The above data is available in the E-fuel Capacities Database on Platts Connect.

Source: S&P Global Commodity Insights.

Policy and market uncertainty

While policy support is growing for e-SAF/e-fuels in the EU, UK and the US, there remains uncertainty in how key policies such as ReFuelEU will be implemented (e.g. the level of support and penalties). This is currently resulting in a lack of clarity on the market value and business model of e-SAF.

Technology risks

Most e-fuel pathways are at a low level of technological maturity today, with facilities operating at pilot or demonstration scale. There remain technical risks associated with integrating multiple conversion technologies in a single process at full industrial scale.

Reliance on other key value chains

E-fuel production requires a source of green hydrogen and captured CO_2. While electrolysis and CO_2 capture technologies are mature, we have yet to see projects and supply chains develop to the level required for large-scale e-fuel production.

Project financing

Owing to policy uncertainty, technology risks and high upfront CAPEX, investors have been slow to provide finance for projects. Progressing projects to FID may require greater policy certainty and public funding and incentives to derisk private investment.

e-SAF production will scale to meet demand as technologies mature/costs decrease, with the US, Middle East and Nordic economies the most competitive regions

- The key drivers of e-SAF production will be:

Location of existing and planned capacity

Policy support, mandates and government funding/incentives

Availability and cost of green hydrogen and captured CO_2

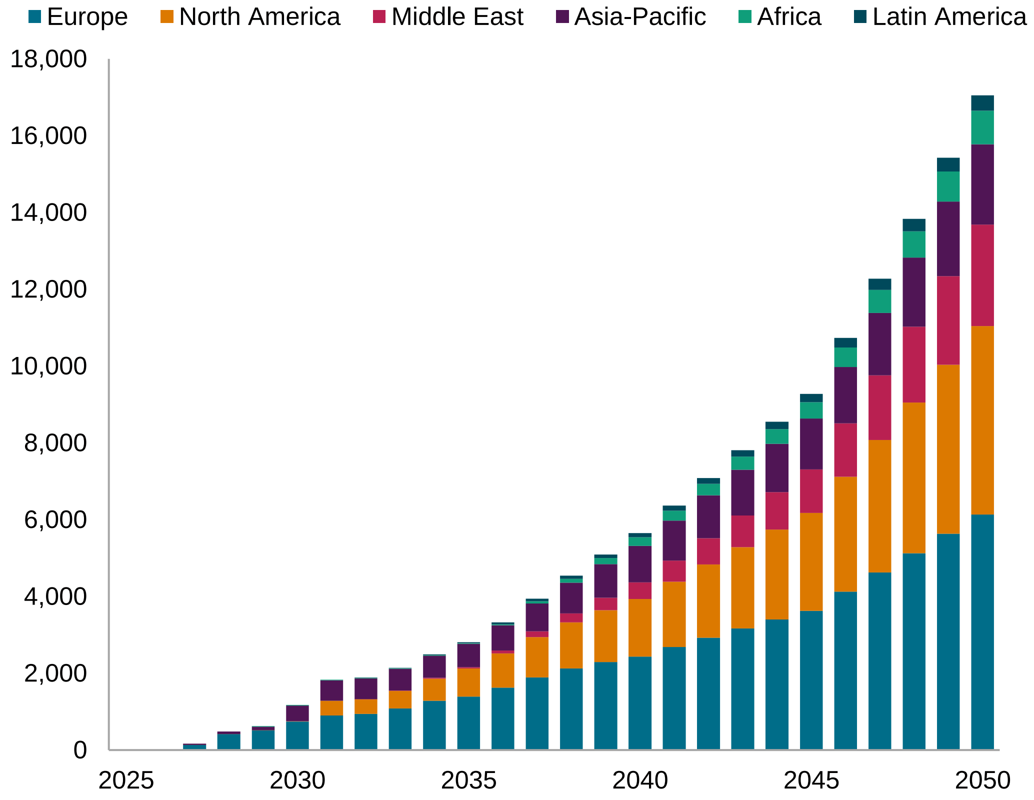
Cost of capital and economy risk

Strategic location and trade routes

- **Europe:** dominates short-term production due to existence of strong policy support and existing announced projects. The share of production decreases longer term as other regions become more cost-competitive.
- **North America:** due to a high supply of green hydrogen and CO_2 at low cost, the US becomes the most competitive economy for production.
- **Middle East:** a low LCOH combined with established crude and refined product value chains mean the Middle East becomes a key e-SAF producer and the second-largest regional exporter in the long term.
- **Asia-Pacific:** Australia and China dominate production. Both already have planned large e-fuel projects which aim to service key Asia-Pacific markets.

Global e-SAF production outlook

(Thousand metric tons per year)



Data compiled Oct. 2, 2024.

Source: S&P Global Commodity Insights.

Private Commitments

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Key e-SAF investments and agreements (1/2)

Investor/Buyer	Target/Seller	Deal type	Announced	Offtake volume (if applicable)	Duration	Start	Background
American Airlines	Prometheus Fuels	Offtake agreement	2021	Up to 30 kt in total (10 million gal)	–	–	Non-binding agreement to purchase e-SAF from future Prometheus Fuel facilities. American Airlines has a net-zero target for 2050.
United Airlines	Dimensional Energy	Equity investment /offtake agreement	2022	At least 871 kt (300 million gal)	20 years	2030	Equity investment made by United Airlines in the US-based start-up, including a commercial commitment to e-SAF offtake from 2030.
DCC Shell Aviation Denmark	Arcadia eFuels	Offtake agreement	2022	~55 kt per year (18 million gal)	–	2028	Agreement for the offtake of all e-SAF produced at Arcadia's first facility in Vordingborg, Denmark, scheduled for commissioning in 2028.
United Airlines Ventures	-	Investment fund	2023	–	–	2023	United Airlines Ventures (UAV) launched the Sustainable Flight Fund to invest in SAF start-ups, worth over £200 million in capital. Participation from over 22 corporates, including banks, airlines, software companies and technology licensors.
Icelandair	IdunnH2	MoU	2023	Up to 45 kt in total (14.8 million gal)	–	2028	MoU for the offtake of e-SAF from 2028 onwards from IdunnH2's planned project in Iceland. Icelandair has a 50% carbon emissions reduction target for 2030, and net-zero target for 2050.
Norwegian Air	Norsk e-Fuel	Equity investment	2023	7 kt per year, rising to 29 kt per year (2.3, rising to 9.5 m. gal)	–	2028	Norwegian became a shareholder in Norsk e-Fuel with an investment of up to $6 million, to co-develop the Mosjoen plant in Norway, planned from 2028.

Data compiled Oct. 2, 2024.
Source: S&P Global Commodity Insights.

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Key e-SAF investments and agreements (2/2)

Investor/Buyer	Target/Seller	Deal type	Announced	Offtake volume (if applicable)	Duration	Start	Background
United Airlines Ventures	OXCCU	Equity investment	2023	–	–	–	UAV made an undisclosed investment in UK e-SAF start-up OXCCU, who raised $22 million in Series A. A demonstration project is planned in the UK from 2026.
Microsoft	Dimensional Energy	Equity investment	2023	Undisclosed	–	2028+	Microsoft invested an undisclosed amount in the US e-fuels start-up Dimensional Energy, who raised $20 million in Series A. Microsoft will offtake e-SAF from Dimensional's planned project in New York state.
Amazon	Infinium	Equity investment/ offtake agreement	2023	Undisclosed	–	–	Amazon had previously invested in Infinium from their Climate Pledge Fund in 2021. Further offtake agreement announced for e-diesel from Infinium's Texas facilities.
Alaska Airlines, Shopify	Twelve	Offtake agreement	2024	Undisclosed	–	2026	Both companies to purchase e-SAF from the US start-up Twelve, beginning with volumes from a planned demonstration facility in Washington, the US.
Etihad Airways	Twelve	MoU	2023	–	–	–	MoU to collaborate on advanced production and use of Twelve's e-SAF in Etihad's network, starting with an international demonstration flight.
Cathay Pacific	SPIC	Strategic partnership/MoU	2024	Undisclosed	–	2026+	MoU signed for the purchase of e-SAF from four SPIC e-SAF projects in China, each with a capacity of 50-100 kt/year. Expected commissioning from 2026 onwards.
International Airline Group	Twelve	Offtake agreement	2024	785 kt in total (260 million gal)	14 years	2026	IAG to purchase one-third of its 2030 SAF target, to be supplied from Twelve's demonstration project in Washington and future projects.

Data compiled Oct. 2, 2024.
Source: S&P Global Commodity Insights.

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