S&P Global Commodity Insights

BIOFUELS VALUE CHAIN SERVICE (BVCS)

Long-term outlook for e-fuels in Europe

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S&P Global Commodity Insights synthetic fuels deliverables

E-fuels Capacities Database (Excel)

- A database with key information on operational and planned e-fuels projects globally
- **Coverage:**
  - E-SAF, e-diesel and e-gasoline projects
  - Not currently covering e-methanol projects
  - Location, stakeholders, pathway, status of the project, configuration, hydrogen source, CO2, CAPEX, start-date and capacity
- **Publication schedule:**
  - Monthly
- **Format:**
  - Excel with data and graphs on capacity build-up by market, technology, etc.

E-SAF Supply and Demand Balance (Excel and report)

- E-SAF supply/demand forecast with report on methodology and key findings
- **Coverage:**
  - e-SAF supply and demand volumes to 2050
  - Global, regional and market breakdowns
  - Feedstock demand forecast for green H_2 and CO_2 in e-SAF production
- **Publication schedule:**
  - Bi-annual
- **Format:**
  - Excel with data and graphs
  - PDF report with methodology and findings

E-fuel Technologies & Policy (Report)

- Report providing an introduction to e-fuel technologies and a review of key e-fuels policies
- **Coverage:**
  - EU, UK and US policy support
  - E-fuel / e-SAF funding programs
- **Publication schedule**
  - Bi-annual
- **Format**
  - PDF report with technology and policy profiles

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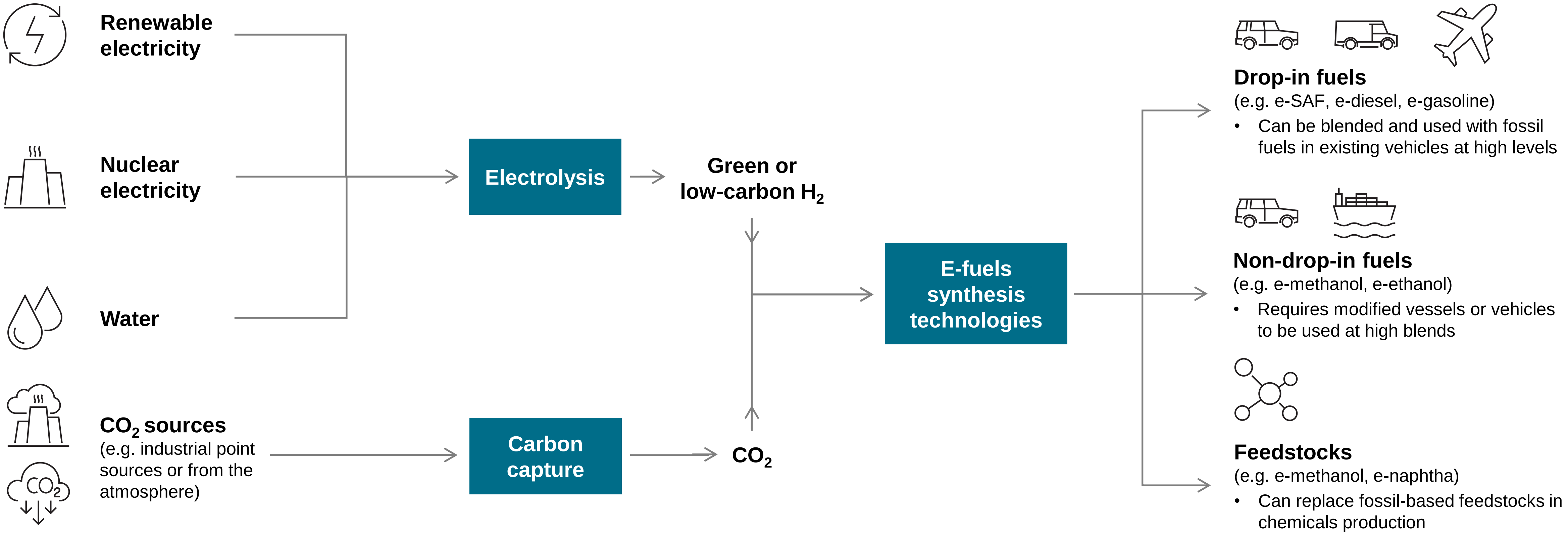
Introduction to e-fuels

E-fuels are synthetic fuels produced from hydrogen via electrolysis and captured CO_2

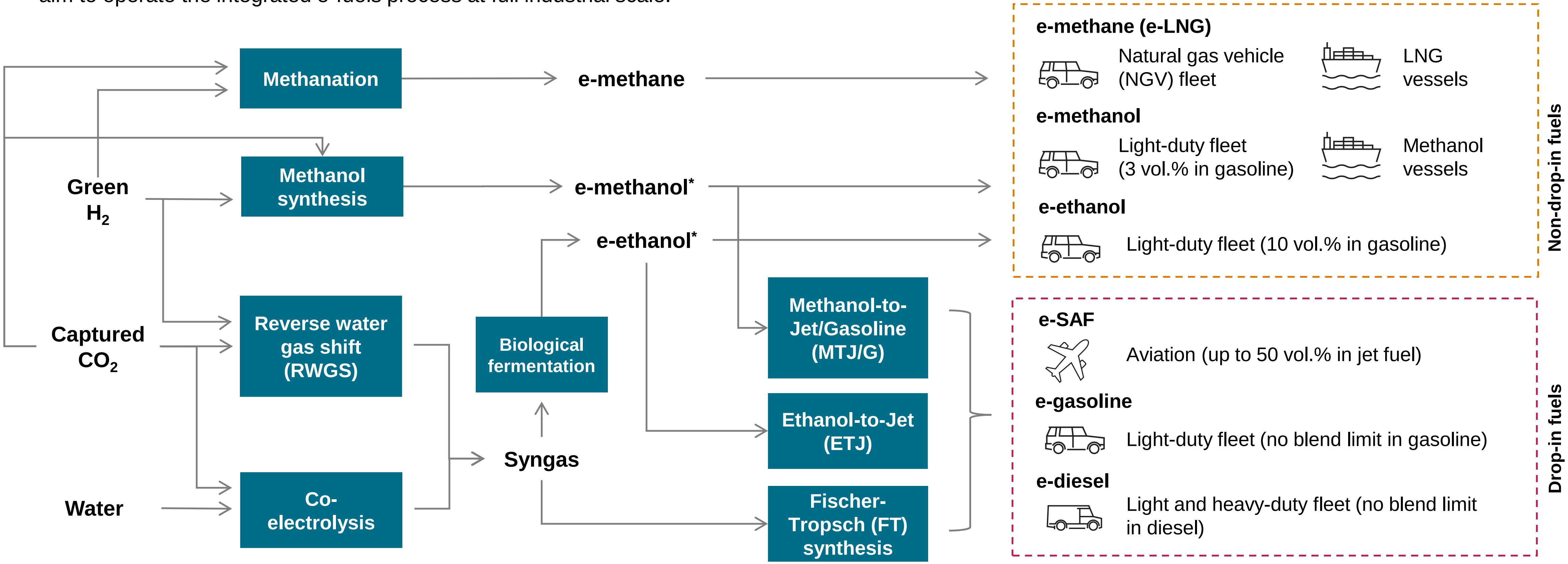
E-fuel production technologies can produce a range of liquid or gaseous drop-in and non-drop-in fuels to decarbonize various transport modes and sectors.



Source: S&P Global Commodity Insights.

There are different pathways to produce e-SAF and other e-fuel products, but most are at a low level of technological development today

- 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. Most e-fuels pathways are at pilot or demonstration scale today, but several commercial projects are planned in the next few years which aim to operate the integrated e-fuels process at full industrial scale.



*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.

With the exception of e-methanol synthesis, most integrated e-fuels pathways are currently at a TRL of 7 or lower

Pathway	E-fuel products	Drop-in fuels?	TRL	First commercial projects from:	Key project developers	Key technology licensors
E-methanol synthesis	Methanol	✕	7–8	2024/25	HIF Global; Air Liquide; European Energy; Liquid Wind; Orsted; Uniper	Carbon Recycling International (CRI); Topsoe; Siemens
Methanol-to-Jet/Gasoline (MTJ/G)	Jet fuel, gasoline, diesel, naphtha, LPG	✓	6–7	2026	HIF Global; European Energy; Metafuels	ExxonMobil; Honeywell; Topsoe; Thyssenkrupp
Ethanol synthesis via RWGS* and fermentation	Ethanol	✕	5	2028	ArcelorMittal; LanzaTech; Oxy Low Carbon Ventures (OLCV)	LanzaTech; Cemvita Factory
Ethanol-to-Jet (ETJ)	Jet fuel, diesel, naphtha	✓	6–7	2028	LanzaTech; LanzaJet; Vatenfall	LanzaTech; LanzaJet; KBR; Swedish Biofuels Axens; Honeywell;
Fischer-Tropsch (FT) synthesis routes	Jet fuel, diesel, gasoline, naphtha, LPG	✓	6–7	2026	Arcadia eFuels; British Petroleum (BP); Infinium; Nordic Electrofuel; P2X-Europe	Topsoe; BP; Johnson Matthey (JM); Ineratec; Infinium; Nordic Electrofuel
Methanation	Methane	✕	7	2026	Marubeni; Tree Energy Solutions (TES); Audi AG	Electrochaea; Hitachi Zosen

Data compiled Oct. 2, 2024.
*RWGS = reverse water gas shift.
Source: S&P Global Commodity Insights.

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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 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.

Policy landscape

The EU and UK currently have the most developed policy support for e-fuels, with a strong focus on the aviation sector

Summary of key global e-fuel policies

Mandates Incentives

Region	Policy	Period	Drivers	Sectors covered	Description
EU	**RED III**	2025 – 2030	Mandates	Road, maritime, rail, aviation	• Minimum 1% target of RFNBOs in EU transportation energy by 2030. • 1.5x multiplier for RFNBOs used in aviation and maritime.
EU	**ReFuelEU Aviation**	2025 – 2050	Mandates	Aviation	• Sets SAF targets to 2050, including a sub-target for synthetic aviation fuel. • Target starts at 1.2 vol.% in 2030 and rises to 35% by 2050. • Implemented via a penalty for non-compliance.
EU	**FuelEU Maritime**	2025 – 2050	Mandates	Maritime	• Sets GHG intensity reduction target for shipping energy use in the EU. • Sub-target for RFNBOs at 2% in shipping by 2034 if they account for <1% by 2031.
UK	**RTFO**	Now – 2032	Mandates	Road, maritime, rail	• Sets 'development fuel' targets in transport at 1.4 vol.% in 2024 and 2.9% by 2030. • E-fuels must compete with advanced biofuels, green hydrogen, renewable methane.
UK	**SAF Mandate**	2025 – 2040	Mandates	Aviation	• Sets SAF energy targets to 2040, including a sub-target for power-to-liquids. • Target starts at 0.2% in 2028 and rises to 3.5% by 2040. • Implemented via a certificate trading scheme and a high buy-out price.
UK	**SAF Revenue Certainty Mechanism**	From 2026 (proposed)	Incentives	Aviation	• Ongoing consultation to introduce a mechanism to provide price certainty for SAF. • Potentially a Contract for Difference (CfD) scheme, guaranteeing a minimum certificate price for SAF and PTL certificates.
US	**IRA**	From 2025	Incentives	E-fuels production	• Series of tax credits for CO_2 capture/utilization (45Q), green hydrogen production (45V) and clean fuel production (45Z), reducing cost of e-fuels production.

Compiled Oct. 2, 2024.

RED = Renewable Energy Directive; RTFO = Renewable Transport Fuels Obligation; IRA = Inflation Reduction Act; RFNBOs = Renewable Fuels of Non-Biological Origin

Source: S&P Global Commodity Insights.

RED III introduces a combined target for the use of advanced biofuels and renewable fuels of non-biological origin (RFNBOs) in transport

EUROPEAN UNION

	RED II (2018/2001)	RED III (revised directive)
Definition of energy in transport (“numerator”)	Road and rail	Road, rail, maritime and aviation, including international bunkers.
GHG intensity reduction of fuels by 2030	–	14.5% GHG intensity reduction or 29% renewable energy share in transportation (member states can choose; they can reduce the overall obligation if the cap on food and feed crops is lower than 7%).
Renewable energy share in transportation in 2030	14% (with double counting)	
Sub-target: Advanced biofuels and biogas (Annex IX-A)	3.5% (with double counting)	Common target for advanced biofuels and RFNBO of at least 1% by 2025 and 5.5% by 2030.
Sub-target: RFNBO	–	**Minimum share of RFNBO by 2030: 1%** Both advanced biofuels and RFNBOs can be double counted. Advanced biofuels and RFNBOs benefit from an additional multiplier of 1.2x and 1.5x, respectively, if used in aviation and marine sectors.
Cap on crop/feed-based biofuels and biogas	2020 share in energy in road and rail transport +1%, up to max 7%.	2020 share in energy in the transport sector +1%, up to max 7%.
Cap on Annex IX-B biofuels and biogas	1.7%	1.7% but member states can increase the limit (double counting allowed).
Electricity multiple counting	x4	x4 for road, x1.5 for rail

Data compiled Oct. 2, 2024.

RED = Renewable Energy Directive; RFNBO = renewable fuel of nonbiological origin; GHG = greenhouse gas.

Source: S&P Global Commodity Insights.

ReFuelEU Aviation and FuelEU Maritime set long-term targets for aviation and shipping

ReFuelEU Aviation introduces a volume-based target, with a sub-mandate on e-fuels

	2025	2030	2035	2040	2045	2050
Volumetric SAF target	2%	6%	20%	34%	42%	70%
E-fuels submandate		1.2%*/2%**	5%	10%	15%	35%

ReFuelEU will be enforced via a penalty for non-compliance, set at a minimum level of 2x the difference between the average yearly conventional jet fuel price and the relevant SAF price. EU Member States have until 2024 end to provide information on the specific penalty calculation methodology.

FuelEU Maritime targets GHG intensity reductions (vs. 2020 baseline, well-to-wake basis)

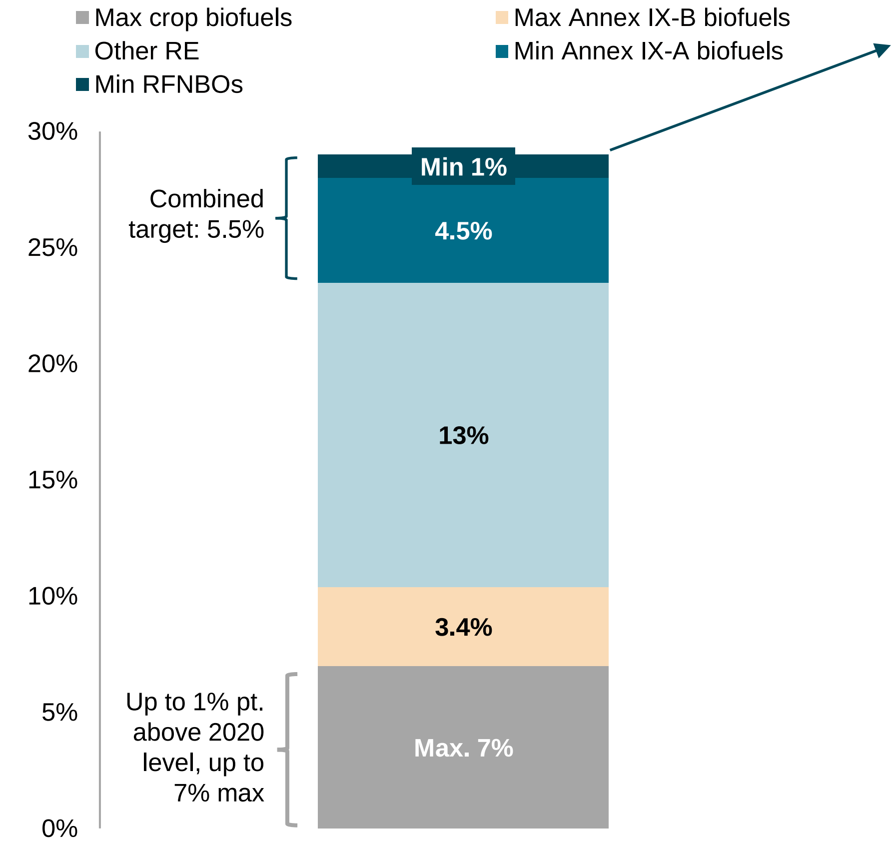
	2025	2030	2035	2040	2045	2050
GHG intensity reduction target	-2%	-6%	-14.5%	-31%	-62%	-80%

FuelEU will be enforced via a penalty for non-compliance, which is proportional to the extent by which a shipping operator misses the GHG intensity reduction target for a reporting period. A 2% RFNBO energy target will be set from 2034 if RFNBOs account for <1% of the shipping fuel mix in 2031.

*Average for the 2030-2031 period. Minimum 0.7% each year.
**Average for the 2032-2034 period. Minimum 1.2% each year.
Source: S&P Global Commodity Insights.

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



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)
- H_2 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)

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.

Hydroprocessing with green H_2 in refineries and e-SAF in aviation have the lowest cost of compliance, contributing a large share to the 1% target

The 1% RFNBO target will be met by the lowest-cost compliance option, which will be influenced by RFNBO production costs and the specific policy support available, such as sector-specific mandates, multipliers and penalties:

Hydroprocessing RFNBO H_2 in refineries/biorefineries is the lowest-cost compliance option. Based on operational and planned electrolysis capacity and announced offtake agreements, hydroprocessing at refineries could meet around 27% of the target.

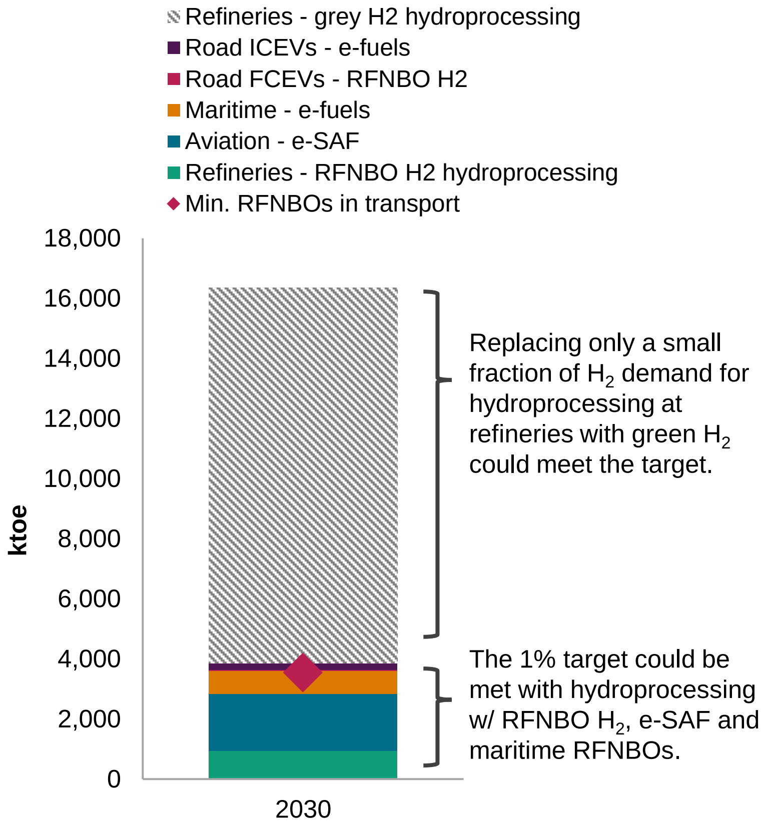
E-SAF in aviation has strong policy support (mandates, penalties for non-compliance and 1.5x multiplier). Based on planned capacity, the 1.2 vol.% sub-target can be met, which would contribute 53% of the target.

RFNBOs in maritime receive a 1.5x multiplier and have a target under FuelEU Maritime but must compete with other renewable energy options. Based on vessel fleet forecasts, status of e-fuel projects and announced offtake agreements, this could meet 22% of the target.

RFNBOs in road will play a minor role in meeting the target due to limited direct policy support and no multipliers compared to aviation and maritime, meaning they may be outcompeted by other renewables:

- Green H_2 in FCEVs will be limited by a small fleet size due to high up-front vehicle costs.
- ICEVs using e-fuels are exempt from the 2035 ban, but production costs are 4-5x higher than fossil fuels, which current policy support does not bridge. Without significant cost reduction, e-fuels in road may be outcompeted by fossil fuels and BEVs. This will limit their contribution to the by-products of e-SAF plants.

Compliance options for the 1% RFNBO target, after double counting and multipliers



Data compiled Oct. 2, 2024.

FCEVs = fuel cell electric vehicles; ICEVs = internal combustion engine vehicles; BEVs = battery electric vehicles

Source: S&P Global Commodity Insights.

The UK SAF Mandate sets targets for SAF use to 2040, including a sub-target for power-to-liquid SAF, with associated buy-out prices

Targets

- The targets apply to operators supplying more than 450,000 litres per year of jet fuel, on an energy basis.
- Includes separate PtL sub-target and a cap on the contribution of HEFA from segregated oil and fat feedstocks*. This aims to incentivize the development of novel SAF production technologies.

	2025	2028	2030	2035	2040
SAF target (main obligation)	2%	10%	10%	15%	22%
PtL sub-mandate		0.2%	0.5%	1.5%	3.5%
Cap on **HEFA** (% of total SAF)	2%	5.8%	7.1%	7.8%	7.8%

Buy-out mechanism

- Suppliers can meet the obligation by supplying SAF or purchasing certificates to meet a shortfall through a certificate trading scheme.
- Under a buy-out mechanism, suppliers who fail to meet the main obligation or PtL obligation must pay a buy-out penalty per shortfall amount to the target.
- The buy-out price is expected to be a permanent fixture of the SAF mandate; the price is significantly higher than initially proposed due to updated evidence on production costs.

Obligation	Initially proposed (March 2023)	Final (April 2024)
Main SAF	£2,567 per ton ($3,370 per ton)	**£5,875 per ton ($7,710 per ton)**
PTL SAF	£3,525 per ton ($4,620 per ton)	**£6,250 per ton ($8,200 per ton)**

*Segregated oil or fat is defined as "a material that is capable of being used as a transport fuel directly, after extraction, or after conversion by transesterification, into a usable fuel, irrespective of any blend wall limits on use".

Source: S&P Global Commodity Insights, UK Government.

Tax credits in the US provide support for e-fuels production, but there are weak drivers for domestic e-fuels demand at federal or state level

UNITED STATES

Demand drivers

- At federal level, there are no targets for the use of e-fuels under the RFS, resulting in weak drivers for supply to domestic markets.
- At state level, e-fuels may compete with biofuels and other renewables to meet targets under clean fuel standards, based on costs and GHG savings. However, without further policy support, their high cost means e-fuels are likely to be outcompeted.
- E-fuel demand in the US will therefore mainly be driven by voluntary bilateral offtakes between producers and airlines or companies aiming to meet GHG emissions reduction targets.

Production cost support

- The Inflation Reduction Act (IRA) offers tax credits relevant to several parts of the e-fuels production process:
  - These are issued by the Internal Revenue Service and Department of Energy once a project's lifecycle report has been assessed and all relevant conditions met.
  - IRA tax credits help reduce the production cost of e-fuels closer to the level of HEFA, potentially making the US one of the most competitive countries for production, depending on energy and feedstock costs.
  - An 'anti-double dipping' provision prohibits a facility from receiving all IRA tax credits, which may unfairly benefit single market participants.

Key Inflation Reduction Act (IRA) tax credits

Tax credit	Base amount	Description and eligibility	Period
CCUS (45Q)	**Point source:** $60 per ton CO_2 utilized; $85 per ton CO_2 stored	• Applies to CCUS projects in the US beginning construction before 2033 • Credit can be realized for up to 12 years from commissioning	2022 – 2045
	Direct air capture: $130 per ton CO_2 utilized; $180 per ton CO_2 stored		
Clean Hydrogen Production (45V)	**Meets wage requirements:** $0.60–3.00 per kg H_2	• Applies to clean H_2 projects in the US beginning construction before 2033 • Credit can be realized for up to 10 years from commissioning • Credit received is proportional to lifecycle GHG savings of H_2 • Max credit for H_2 with GHG intensity of <0.45 $kgCO_2e$	2022 – 2043
	Misses wage requirements: $0.12–0.60 per kg H_2		
Clean Fuel Production (45Z)	**Non-aviation fuel:** $0.20–1.00 per gal ($610–3,040 per ton)	• Applies to clean fuel projects in the US • Fuel must have a lifecycle GHG intensity of <47.4 gCO_2e/MJ • Credit received is proportional to GHG saving of fuel and whether wage requirements are met	2025 – 2027
	SAF: $0.35–1.75 per gal ($1,070-5,330 per ton)		

RFS = Renewable Fuel Standard

Data compiled Oct. 2, 2024.

Source: S&P Global Commodity Insights.

Outside of policy, a small amount of e-SAF demand could be driven by voluntary commitments between airlines, corporates and e-fuel producers

Key e-SAF investments and agreements

Investor/Buyer	Target/Seller	Deal type	Announced	Offtake volume (if applicable)	Duration	Start
American Airlines	Prometheus Fuels	Offtake agreement	2021	Up to 30 kt in total (10 million gal)	–	–
United Airlines	Dimensional Energy	Equity investment /offtake agreement	2022	At least 871 kt (300 million gal)	20 years	2030
DCC Shell Aviation Denmark	Arcadia eFuels	Offtake agreement	2022	~55 kt per year (18 million gal)	–	2028
United Airlines Ventures	-	Investment fund	2023	–	–	2023
Icelandair	IdunnH2	MoU	2023	Up to 45 kt in total (14.8 million gal)	–	2028
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
United Airlines Ventures	OXCCU	Equity investment	2023	–	–	–
Microsoft	Dimensional Energy	Equity investment	2023	Undisclosed	–	2028+
Amazon	Infinium	Equity investment/ offtake agreement	2023	Undisclosed	–	–
Alaska Airlines, Shopify	Twelve	Offtake agreement	2024	Undisclosed	–	2026
Etihad Airways	Twelve	MoU	2023	–	–	–
Cathay Pacific	SPIC	Strategic partnership/MoU	2024	Undisclosed	–	2026+
International Airline Group	Twelve	Offtake agreement	2024	785 kt in total (260 million gal)	14 years	2026

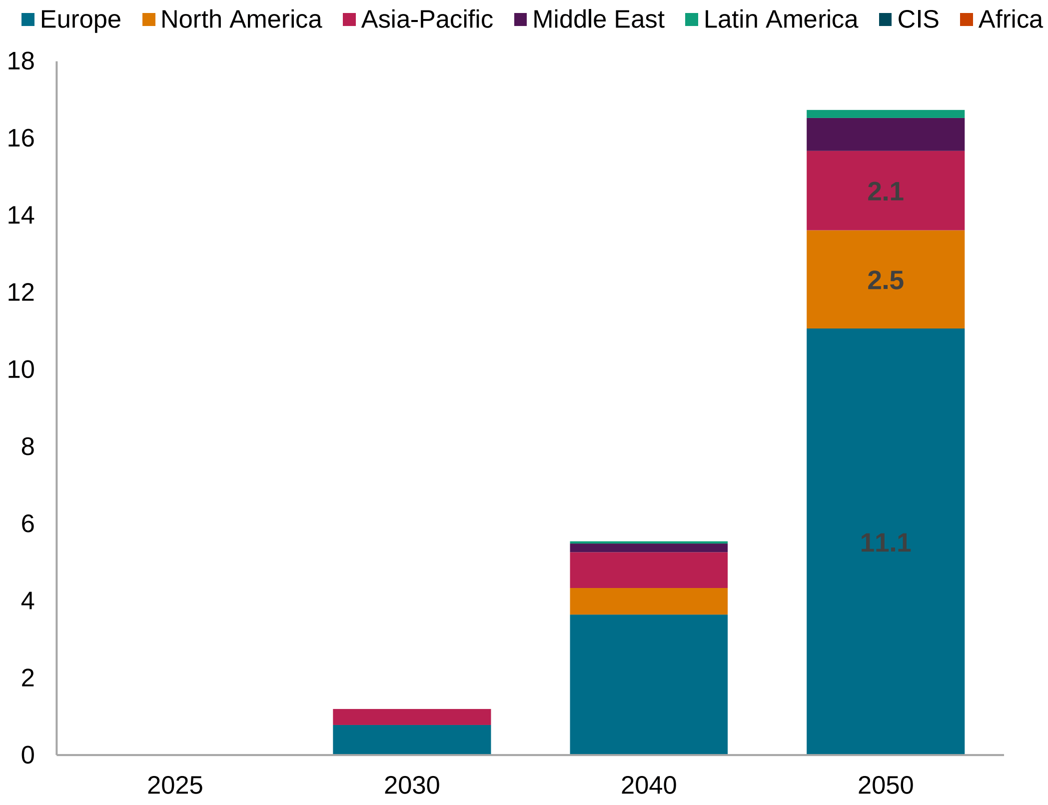
Data compiled Oct. 2, 2024.
Source: S&P Global Commodity Insights.

Market outlook

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

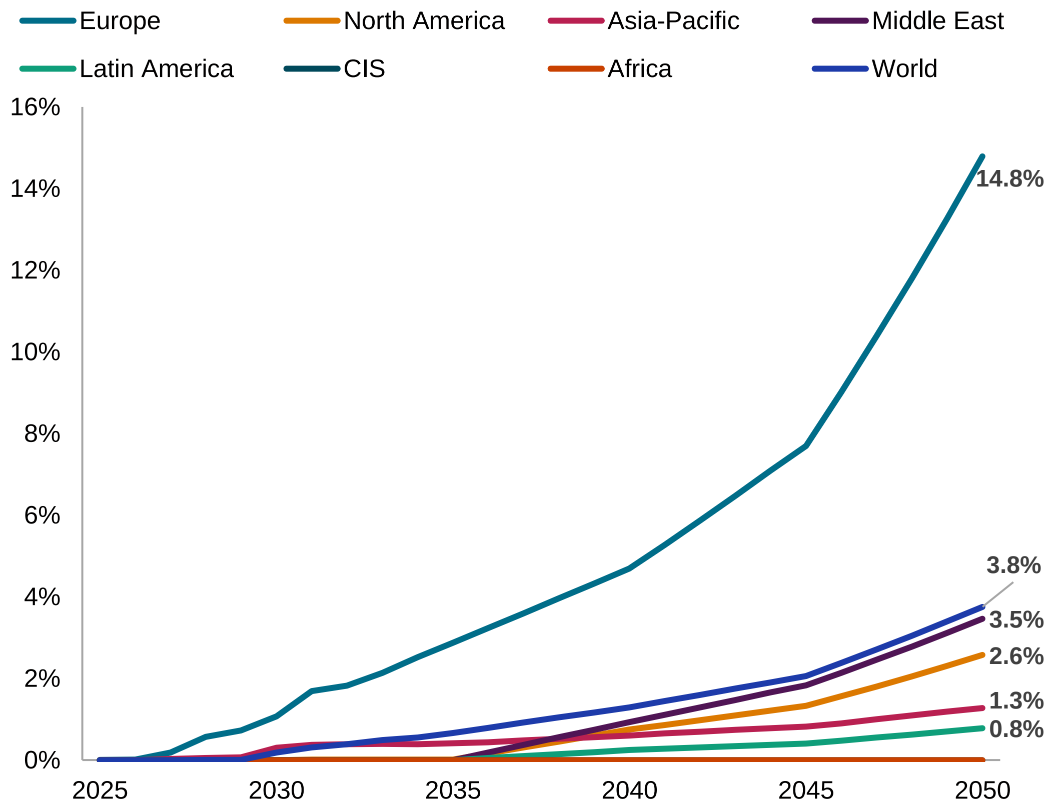
Global e-SAF demand outlook

Million 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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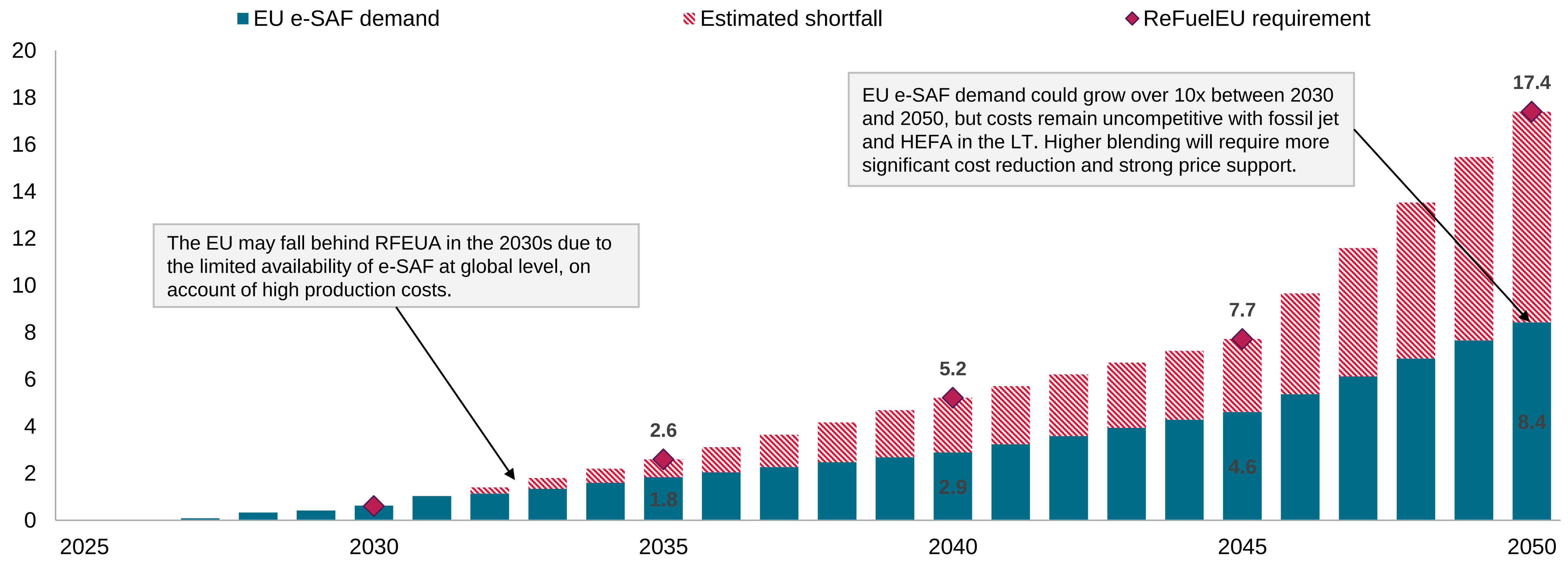
In S&P Global's base case, the EU falls behind long-term targets under ReFuelEU due to the high cost and limited availability of e-SAF

EU e-SAF demand outlook vs. ReFuelEU requirement

Million metric tons per year

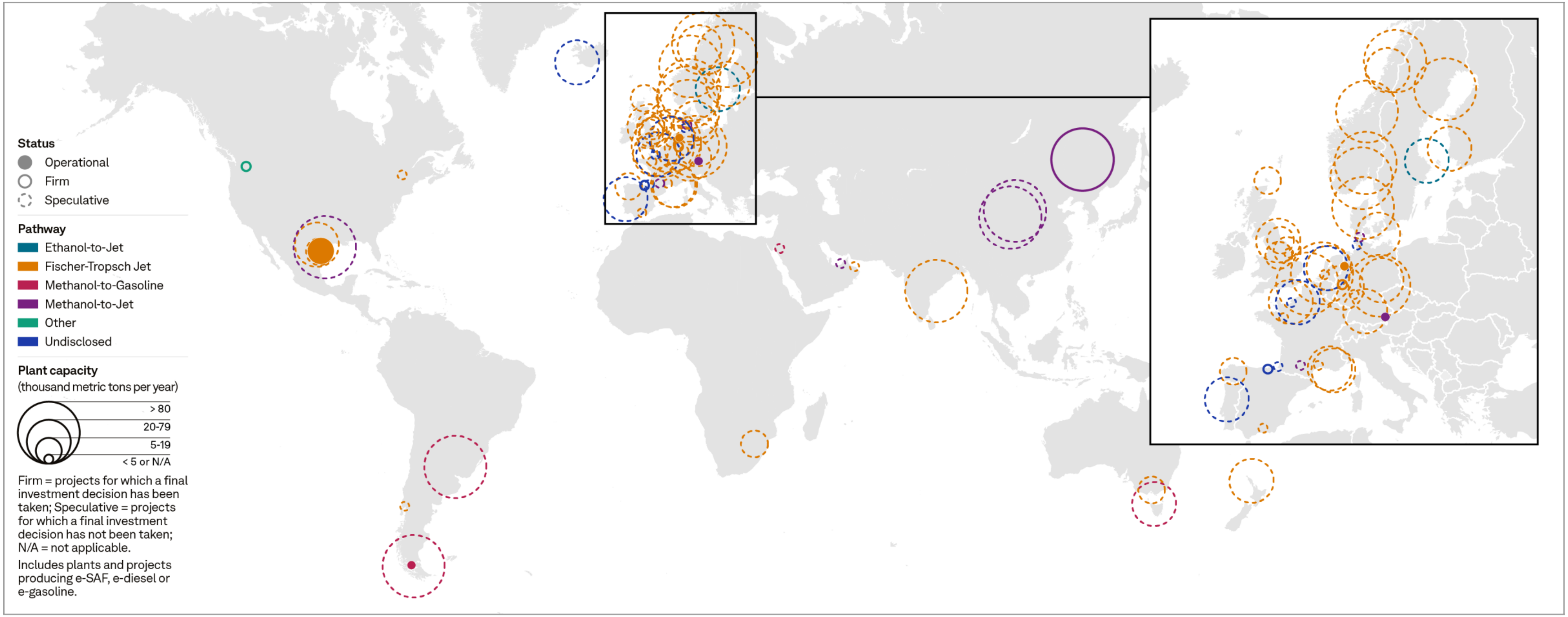


Data compiled November 01, 2024.

Source: S&P Global Commodity Insights.

More than 70 e-fuel projects have been announced globally, but most commercial-scale projects are yet to reach FID

Global e-fuel plants and projects

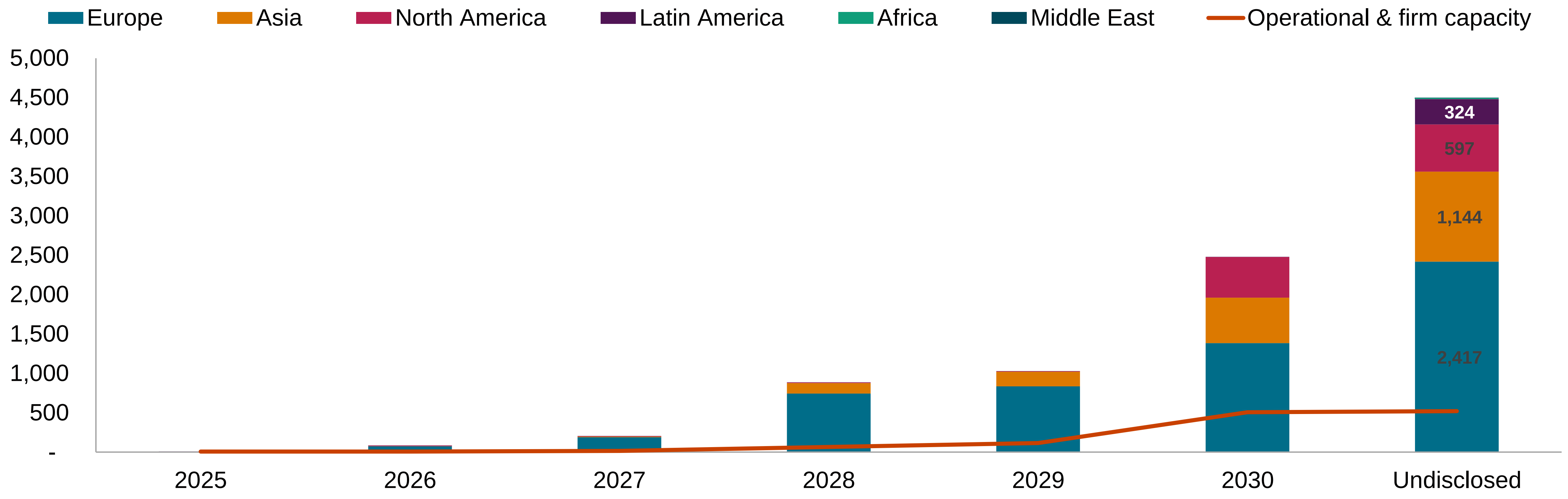


Data compiled Nov. 5, 2024.
Source: S&P Global Commodity Insights: IC-2014744.

E-fuels capacity will be initially concentrated in Europe and Asia

Announced global e-fuels production capacity

Thousand metric tons per year



Data compiled November 01, 2024.

Source: S&P Global Commodity Insights.

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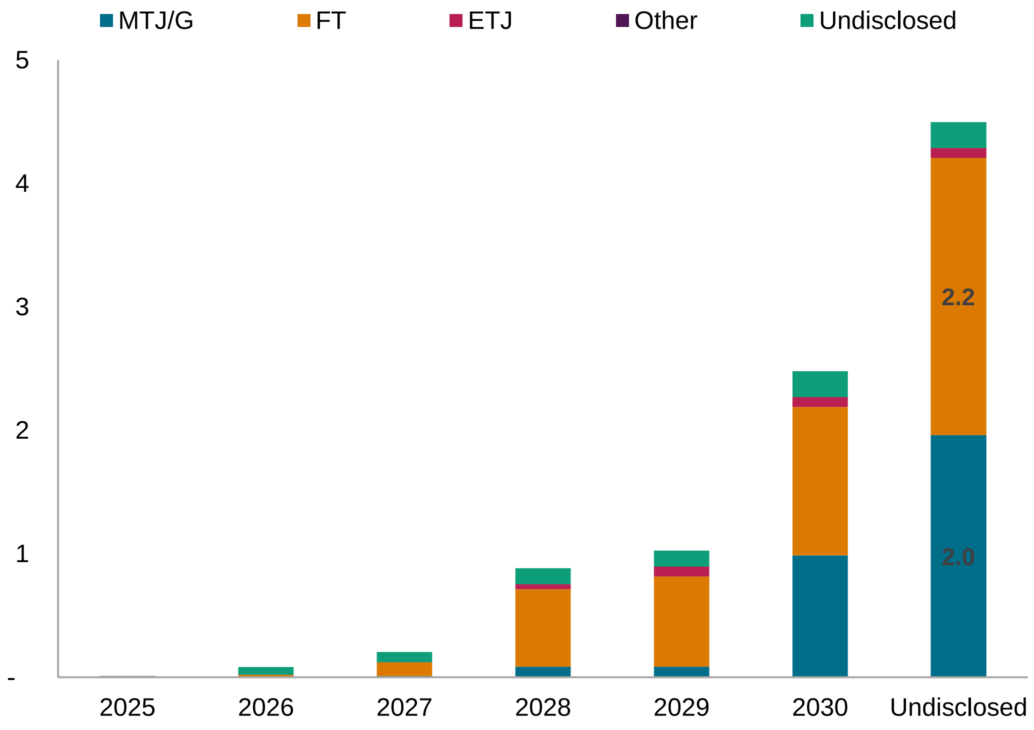
The large majority of e-fuels projects are focused on e-SAF production

FT and MTJ/G are emerging as the dominant pathways in the short- to medium-term

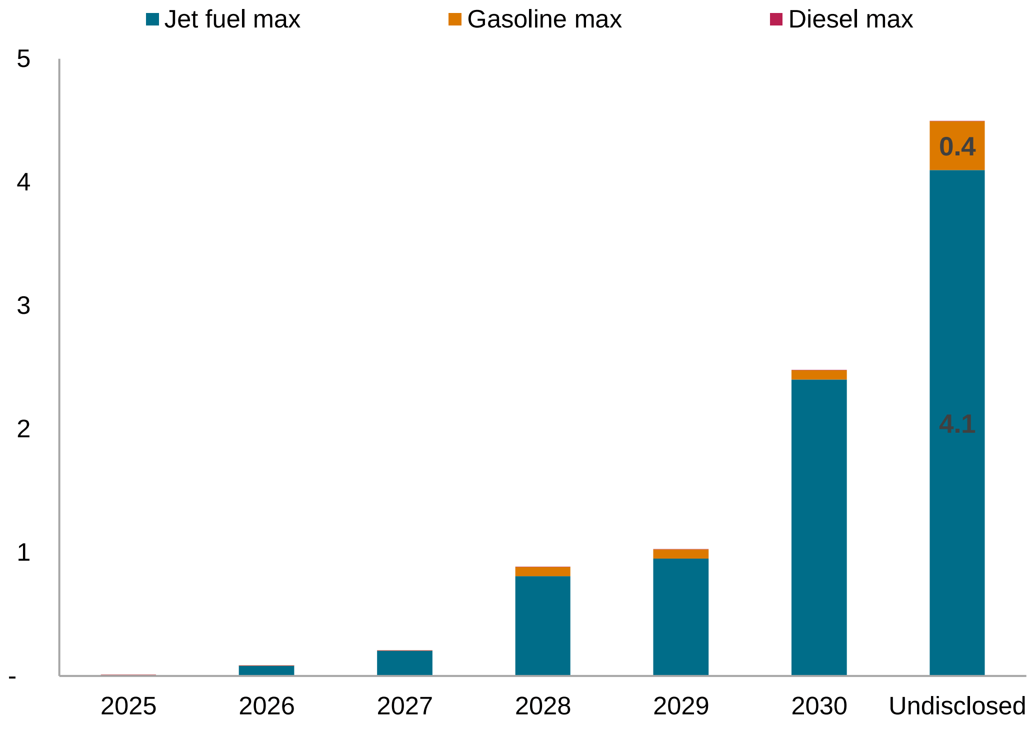
Announced global e-fuels production capacity by pathway

Million metric tons per year



Announced global e-fuels production capacity by plant configuration

Million metric tons per year



Data compiled November 01, 2024.

Source: S&P Global Commodity Insights.

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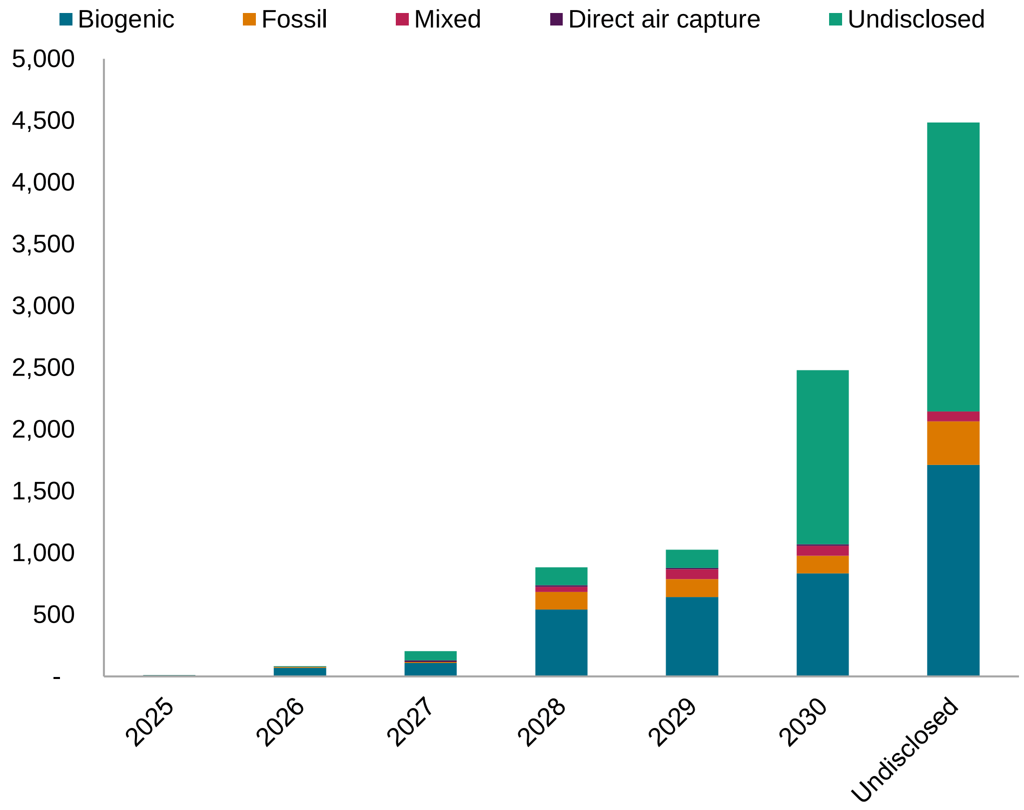
Most projects will use hydrogen from on-site electrolysis

Producers favor biogenic CO_2

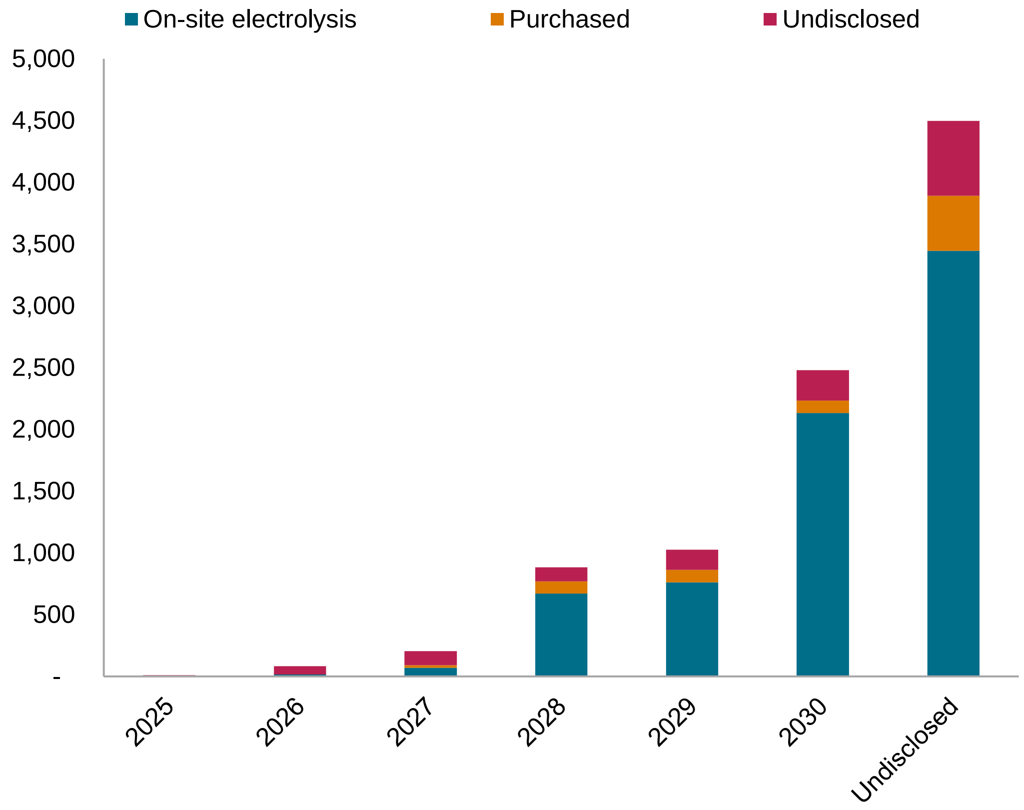
Announced global e-fuels production capacity by CO2 source

Thousand metric tons per year



Announced global e-fuels production capacity by hydrogen supply

Thousand metric tons per year



Data compiled November 01, 2024.

Source: S&P Global Commodity Insights.

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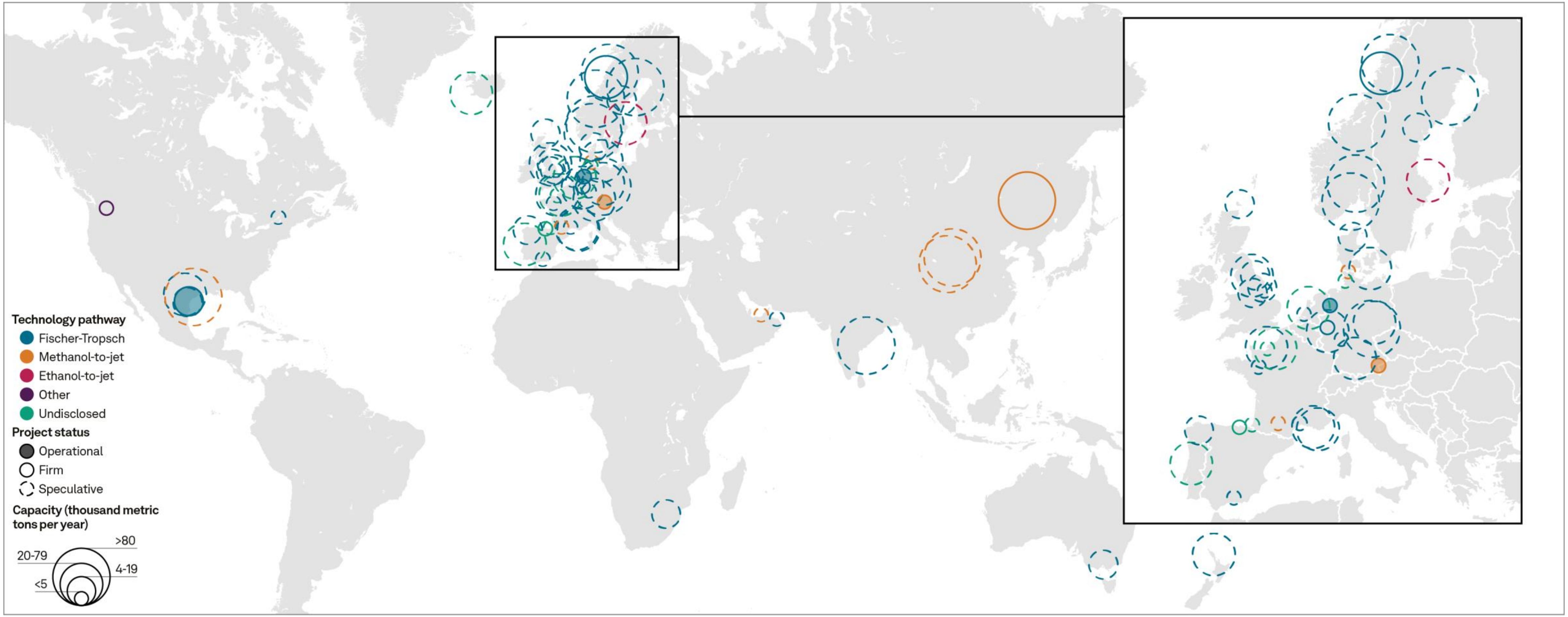
The majority of the e-fuels projects are for e-SAF and are concentrated in Europe, but there are also large projects planned in North America and Asia-Pacific

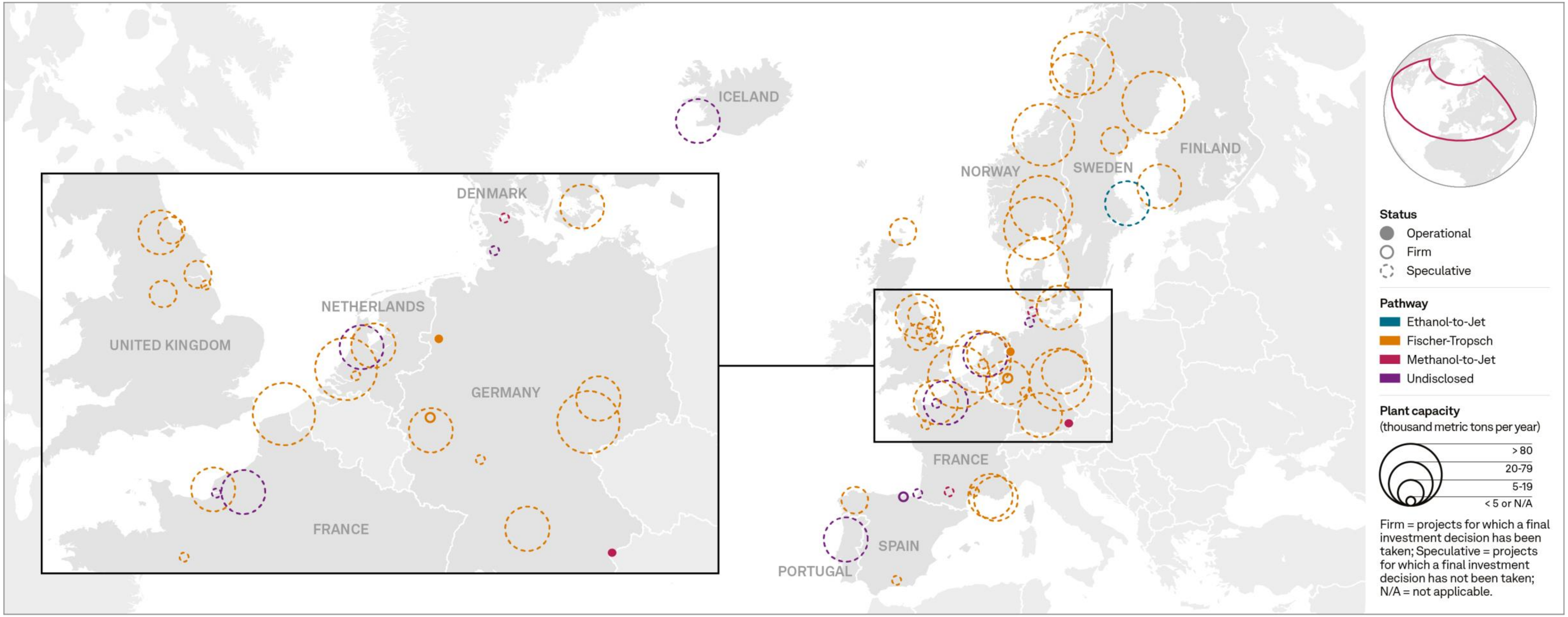
Global e-SAF projects



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

Over 50 announced e-SAF plants and projects in Europe, but most remain at the early planning stage and no commercial-scale project has yet reached FID

Europe e-SAF plants and projects



Data compiled Nov. 5, 2024.

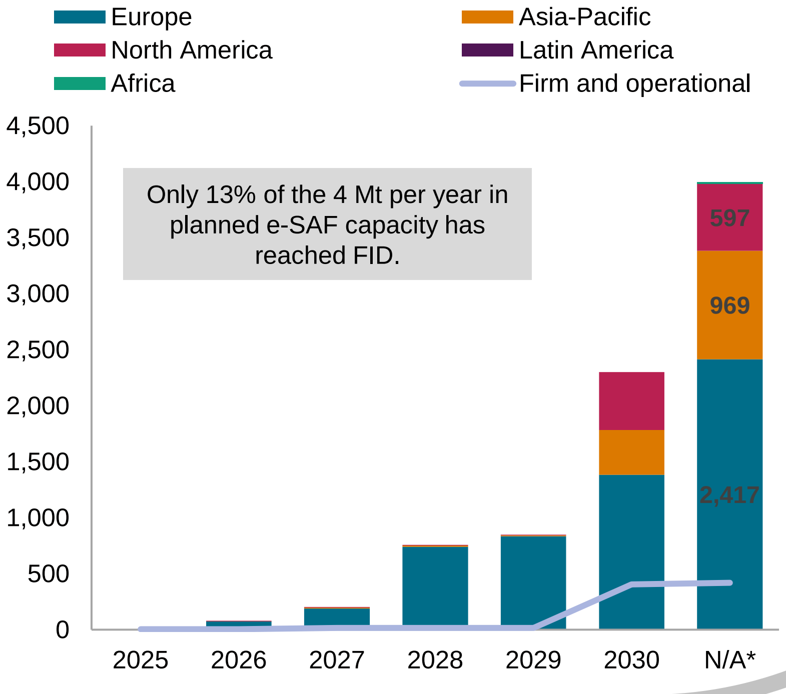
Source: S&P Global Commodity Insights: 2014743.

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



Policy and market uncertainty

While policy support is growing for e-SAF/e-fuels in the EU, UK and 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.

Data compiled Oct. 2, 2024.

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

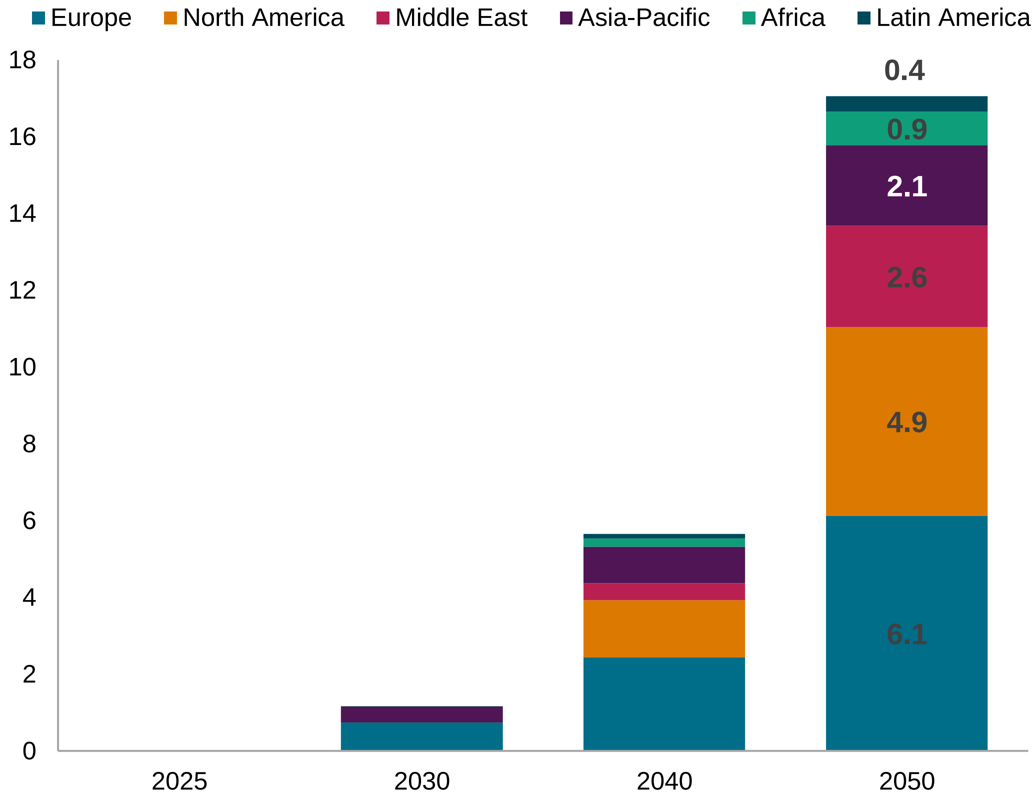
Source: S&P Global Commodity Insights.

e-SAF production will scale to meet demand as technologies mature/costs decrease, with the US, Nordic Countries and the Middle East 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 country 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 country 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

Million metric tons per year



Data compiled Oct. 2, 2024.

Source: S&P Global Commodity Insights.

S&P Global Commodity Insights

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