Sustainability Insights | Research

E-fuels: A Challenging Journey To A Low-Carbon Future

March 25, 2024

E-fuels could eventually play an important role in decarbonizing certain sectors, but the cost barriers are significant.

This research report explores an evolving topic relating to sustainability. It reflects research conducted by and contributions from S&P Global Ratings' sustainability research and sustainable finance teams as well as our credit rating analysts (where listed).

This report does not constitute a rating action

Authors

Sustainability Research

Terry Ellis
London
terry.ellis@spglobal.com

Credit Ratings

Rachel Gerrish
London
rachel.gerrish@spglobal.com

Gaetan Michel
Paris
gaetan.michel@spglobal.com

Contributors

Pierre Georges
Paris

Vittoria Ferraris
Milan

Tim Axtmann
Oslo

Lai Ly
Paris

S&P Global
Ratings

In this research, S&P Global Ratings examines the current status of e-fuels. We define these as potentially low-carbon derivatives of hydrogen that could directly replace conventional liquid fossil fuels. We explore how e-fuels can be produced, how they can support energy transitions, and the potential financial and environmental impacts. To this end, we assess current policy support and investment in these solutions and identify key challenges to scalability. We focus mainly on Europe, which has made the most significant policy moves. We draw on S&P Global Ratings' analysis, data from S&P Commodity Insights, and other published research. This research continues our exploration into the solutions and technologies to transition.

Key Findings

- Synthetic fuels, or e-fuels, could support decarbonization objectives across numerous sectors. We think aviation and shipping will be the main users of future e-fuels. Policy moves in Europe will likely create a market for these fuels, but huge investment will be required to supply the inputs that make them a low-carbon solution.
- Economic models for e-fuels remain uncertain for now. High input-energy requirements present a significant cost barrier for both producers and consumers. There are material technological hurdles still to overcome and, beyond carbon, e-fuels still emit other pollutants. Other environmental exposures could persist.
- We see limited credit impact in the next decade given modest regional ambitions regarding e-fuel use. They will have time to plan, but aviation and shipping companies in Europe might need to make difficult choices in the next decade as regulations take effect.

E-fuels' scalability challenges at a glance

E-fuels could **significantly reduce lifecycle greenhouse gas emissions** compared to fossil fuels, but need around **6x the energy** to produce.

Producing e-fuels is likely to be **2x-6x more expensive** than fossil and biofuels in the short term, driven by hydrogen prices.

Most e-fuel technologies are in the **piloting phase**, requiring **significant investment** to mainstream.

Air and water pollution issues will likely persist, **posing challenges** for some operators.

E-fuels Are Emerging As Potential Low-Carbon Alternatives To Liquid Fossil Fuels

Oil use is at an all-time high and will likely remain important to the global energy system for some time yet. This is despite many countries, organizations, and companies tightening decarbonization policies. While some uses of liquid fuels have viable alternatives, others (such as industrial-process heat supply or high-energy-density aviation fuel) will be more challenging technically to replace with low-carbon electrification solutions. From power production to industrial use and transportation, the wide range of oil-based products for both fuel and feedstock is likely to remain for many years, even in countries with more ambitious decarbonization goals.

Carbon-based e-fuels—also referred to as electrofuels, synthetic fuels, or power-to-liquids—are emerging as potential replacements for liquid fossil fuels. They have a similar chemical composition to conventional liquid fossil fuels but are synthesized through processes that use hydrogen along with electricity, carbon dioxide, and other inputs. As a result, carbon-based e-fuels do not rely on fossil-hydrocarbon extraction and can be used on their own or blended with conventional fossil fuels. They include substitutes for traditional carbon-based fuels such as e-diesel, e-kerosene (which can be classed as a Sustainable Aviation Fuel [SAF]) and e-methanol. Non-carbon-based e-fuels can also be produced—for example e-ammonia, which is nitrogen-based. A key benefit is that e-fuels can generally be used in existing internal combustion engines (ICEs) and fuel infrastructure designed for conventional fossil fuels, meaning that their adoption would not necessarily require many changes to existing assets. In this sense, e-fuels could be a viable solution for sectors facing difficult engineering hurdles to embracing other decarbonization solutions.

What is the difference between biofuels and e-fuels?

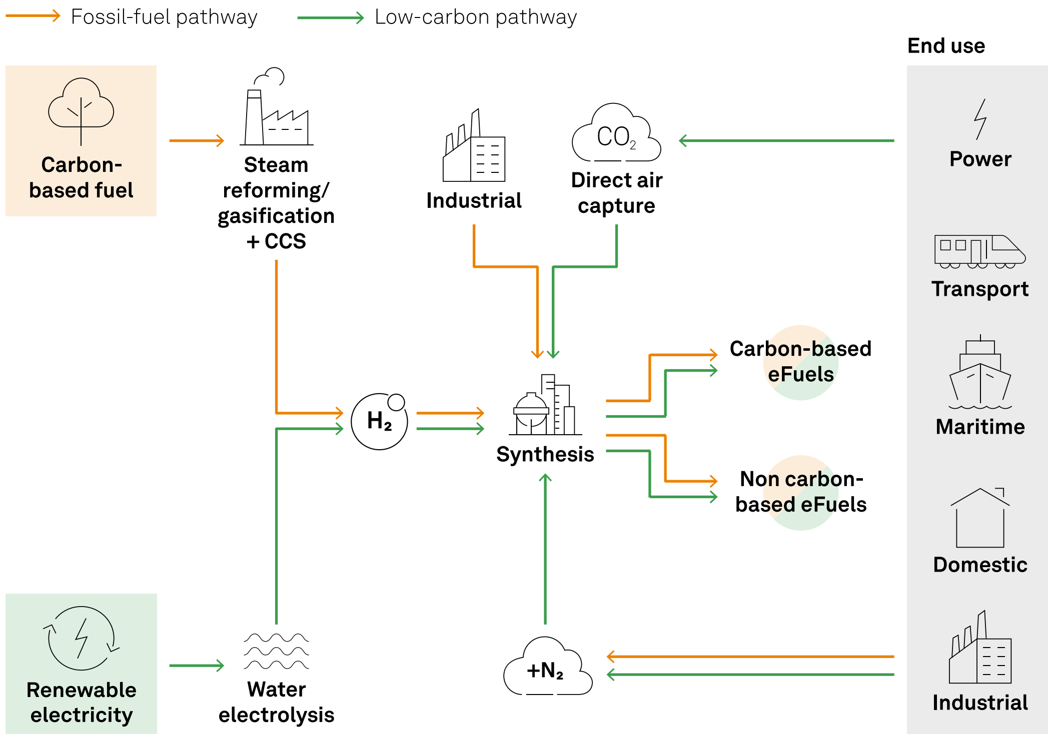
Biofuels and e-fuels share the concept of using carbon cycles to remove carbon from the atmosphere, and re-release it when the fuels are combusted. However, they are created using different feedstocks. Modern biofuels involve growing specialized crops or using agricultural residues that naturally contain carbon—the carbon is removed from the atmosphere as the crops grow—and are subsequently processed into fuels. Biofuels have been used for some time, especially in the transportation sector, but on a small scale compared to fossil fuels. In contrast, e-fuels rely on mechanically capturing carbon dioxide from the atmosphere before being combined with hydrogen and then synthesized into fuels.

The key benefit of e-fuels is avoiding virgin hydrocarbon extraction and the associated incremental carbon release when used. Because carbon-based e-fuels are chemically similar to fossil fuels, they still emit carbon dioxide in varying quantities when burned. However, these emissions can be netted off from the captured carbon originally used to synthetize the fuel, potentially offering an overall neutral carbon balance on a lifecycle basis. But if the input carbon dioxide for an e-fuel is captured, for example from coal power, the total carbon stock in the atmosphere would still eventually increase. Ammonia contains no carbon (like hydrogen) and when used as a fuel emits some nitrogen (which can pollute in the form of nitrogen oxides) and water vapor, which, while being a greenhouse gas, is short-lived and less potent. While non-carbon-based e-fuels are cheaper and easier to make, they are more difficult to store and handle, and incompatible with existing vessel and aircraft technologies.

E-fuels can potentially be very-low-emission alternatives to oil-based fuels if production processes use renewable energy and green hydrogen inputs (see chart 1). E-fuel production is complex and energy intensive, and is not necessarily always low carbon. Lifecycle carbon emissions therefore mainly stem from how the hydrogen and power needed for production are sourced. If fossil-fueled power were used in the production process (either directly or via utilities) then the carbon reduction benefits compared to conventional fuels would be lower.

Chart 1

Renewable feedstocks drive e-fuels' potential green credentials



Notes: CCS--Carbon capture and storage. H2--Hydrogen. N2--Nitrogen. Source: S&P Global Ratings.

Some Policymakers Have Identified A Clear Decarbonization Role For E-fuels

The European Commission sees e-fuels as potentially part of a mix of solutions and refers to them throughout its "Fit for 55" legislative package. The Commission's policy measures include quotas and other targets for renewable fuels of non-biological origin in aviation and shipping, and for road vehicles, that support e-fuel use (see table 1). The EU supports research and development (R&D) through its Horizon 2020 and Horizon Europe programs, including grants for pilot production plants and for modifications to existing assets so they can use e-fuels, but Europe's net-zero targets imply much more significant investment will be required. While the EU appears to view e-fuels as part of a future fuel mix for transportation, some aspects remain less clear. These include how fuels will be certified, how much investment will be needed, and how benefits can be calculated to ensure e-fuels deliver on their low-emissions promise.

The U.S. Inflation Reduction Act could also support the development of e-fuel infrastructure. The act offers tax relief on most of the key components of the production process, such as renewable power, hydrogen production, and carbon capture. However, tax credits for SAF and the Biden Administration's ambition to produce three billion gallons per year by 2030 focus mainly on bio-based SAFs rather than synthetic fuels derived from hydrogen and carbon. The U.S.

EPA's proposed rules for road vehicles, like the EU approach, will likely be technology-neutral, leaving the door open for the use of e-fuels.

Table 1

EU policy developments are setting the stage for the development of e-fuels

Policy	Detail
Renewable Energy Directive (2023/2413)	The proposed update to Renewable Energy Directive (RED III) has set a target for e-fuels to have a 1% share of the transport energy mix by 2030 as part of an overall transport sector renewable energy target of 29%. In the EU, e-fuels will be required to demonstrate at least a 70% carbon reduction compared to fossil fuels if they are to count toward these targets, and to demonstrate they are produced from new renewable energy capacity.
Regulation on ensuring a level playing field for sustainable air aviation (2023/2405)	The regulation plans to set minimum shares of SAF in the overall fuel mix at EU airports. The current proposal for SAF is 2% in 2025, 6% in 2030, 20% in 2035, 34% in 2040, 42% in 2045, and 70% by 2050. Synthetic fuels have their own sub-objectives for minimum shares in the overall fuel mix at EU airports: 1.2% in 2030, 5% in 2035, 10% in 2040, 15% in 2045, and 35% in 2050 of overall fuel use.
Regulation on the use of renewable and low-carbon fuels in maritime transport (2023/1805)	Regulation has been agreed to reduce emissions in the maritime sector, requiring operators of vessels of more than 5,000 gross tonnes (GT) to reduce the carbon intensity of energy used by 6% by 2030, 31% by 2040, and 80% by 2050. Notably the regulation includes dedicated incentives for using e-fuels, which will initially allow them to be double-counted toward targets in order to stimulate demand.
Regulation on carbon dioxide emission standards for passenger cars and light vehicles (2023/851)	The regulation states that EU car manufacturers must achieve 0g carbon-dioxide/km fleet-average by 2035, rather than mandating specific technologies. The regulation notes that fuels will be developed to allow new vehicles to run exclusively on carbon-dioxide-neutral fuels (we note that as current regulations target car producers rather than users, further legislation could aim to guarantee that new cars use only green e-fuels rather than conventional fossil fuels).

Source: EU Regulations, S&P Global Ratings.

A key step to transparency will be the global harmonization of rules and classifications, helping to substantiate low-carbon claims consistently across jurisdictions (see the S&P Global Ratings and S&P Global Commodity Insights report "Hydrogen: New Ambitions and Challenges"). To support any decarbonization claims, some bodies—such as the EU—have stated that the production process must be completely free of hydrocarbons. The EU uses the descriptor "renewable fuels of non-biological origin (RFNBO)" in its regulations, and other stakeholders refer to "green fuels" (such as green ammonia). The EU Taxonomy recognizes e-fuels under its "hydrogen-based synthetic fuels" activity, provided they demonstrate at least a 70% reduction in life-cycle emissions compared to a fossil fuel equivalent, implying the use of renewable power and green hydrogen.

Aviation And Maritime Shipping Could Be The First To Embrace E-fuels

While e-fuel production is currently minimal, initiatives in the transport sector are beginning to promote them as a part of those sectors' decarbonization solutions. However, they will likely have to rely on a range of partners to build capacity.

E-fuels could be a solution for the transportation sector to meet its obligations

The main carbon regulations for airlines are the U.N.-sponsored International Civil Aviation Organization's (ICAO) Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) and the EU's Emissions Trading System (EU ETS). Both schemes incentivize the use of SAF for airlines. Furthermore, the EU's aviation fuel regulations stipulate minimum shares of SAF at EU airports from 2025, and of e-fuels from 2030. The EU ETS also applies to shipping (phased through to 2026) and the EU maritime fuel regulation—which will require shippers to reduce the carbon intensity of their fuels—applies to vessels above 5,000 GT that use EU ports.

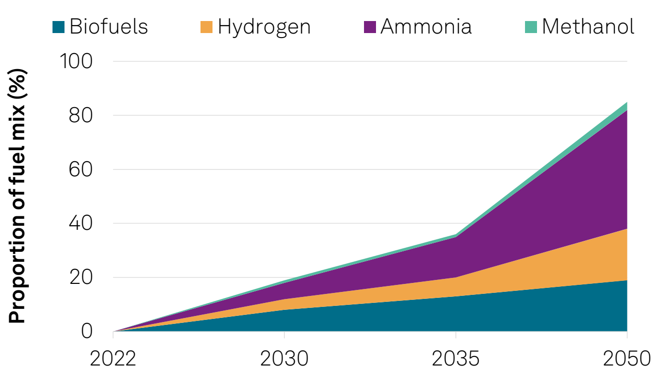
SAF production for aviation has been negligible to date and mainly focused on biofuels or waste-derived fuels. The International Air Transport Association (IATA, an airline trade body) estimates that SAFs could contribute to about 65% of the emissions abatement aviation needs to reach net-zero carbon dioxide emissions by 2050. For now, however, it expects SAFs will represent only about 0.5% of fuel consumption in 2024, which it estimates will add $2.4 billion to the global aviation fuel bill. Sustainable biofuels are scarce, and cost a prohibitive two-to-eight times more than conventional fuels. There are also concerns about land availability to produce the inputs and competing demand from other types of agricultural use. This suggests that e-fuels (blended with other fuels and as part of an array of solutions) could become increasingly important to aviation's longer term net-zero targets. The IEA's net zero scenario foresees e-fuels supplying around one third of fuel to aviation by 2050 (see chart 2). However, it will be extremely costly to scale up production and will likely need regulatory support and material government investments.

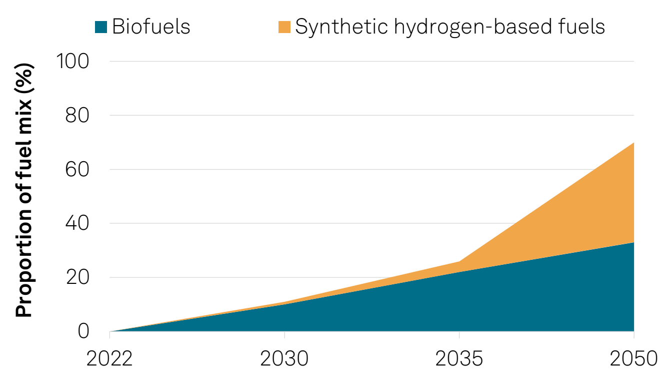
Maritime shipping has started to adopt decarbonization goals and e-fuels could play a part. In 2023 the International Maritime Organization (IMO; 175 member states) adopted its Strategy on Reduction of GHG Emissions from Ships. This includes targets to reduce the carbon intensity of shipping by at least 40% by 2030 (compared to 2008) and achieve 5%-10% energy share from zero or near-zero carbon technologies (including hydrogen, biofuels, and e-fuels) by the same date. The strategy also includes a broader ambition to reach net-zero emissions as close to 2050 as possible, but this will require huge investment in new vessels and greener technologies and fuels. Shipping companies could potentially adopt low-carbon e-methanol, e-ammonia, and e-LNG to meet the IMO targets. However, there are important questions regarding their potential wider environmental impacts, for example in the event of an accident or spill.

Chart 2

Demand for low-carbon fuels will soar from 2035, according to the IEA's net-zero scenario

Left panel: shipping; right panel: aviation





Note: The charts represent the share of expected energy demand. To support emission reductions consistent with a net-zero scenario, the IEA assumes that these fuels would be produced in a low-carbon way. Source: IEA, S&P Global Ratings.

Given the present momentum in electric vehicle (EV) uptake, it is less clear how a market for e-fuel-powered road vehicles might take shape. While there is a significant shift to EVs in many major markets, OEMs have so far been slower to produce smaller more-affordable EVs. There will also still be many older ICE vehicles in use in the 2030s, and electrification and hydrogen fuels for trucks remain much less advanced than for cars. These factors could leave room for e-fuels to play a role in decarbonizing ICE vehicles in some jurisdictions or for certain vehicle classes. That said, we expect e-fuel use in road vehicles to be much less widespread than in shipping or aviation.

Early movers are leveraging partnerships to drive e-fuel production

Aviation and shipping players, traditional energy majors, utilities and chemical companies, and specialized start-ups are teaming up, each bringing experience in aspects of the production process. Chemical companies could be well placed to develop ammonia and methanol-based e-fuel projects, leveraging their existing technologies and process knowledge. Companies such as Air Products And Chemicals Inc., Air Liquide S.A., and Linde PLC are already investing in hydrogen capacity and have the potential to expand their ammonia markets to shipping applications (see "Decarbonizing Chemicals Part 1: Sectorwide Challenges Will Intensify Beyond 2030").

For now, e-fuel investments are focusing mostly on aviation and shipping, while the pathway for car manufacturers is less clear:

- In aviation, many airlines are already subject to carbon and SAF regulations and will therefore likely use more SAFs in the future. Norwegian, Etihad, International Airlines Group, and AirFrance-KLM are examples of some of the companies that have directly invested in e-fuel production or agreed to offtake, while other airlines remain more focused on SAF-based biofuels for now.
- Shipping could move more quickly, with companies such as Maersk and CMA CGM already investing in new vessels capable of running on ammonia and methanol (initially traditional sources and later on their low-carbon e-fuel equivalents) with increasing numbers of offtake agreements signed (see S&P Global Commodity Insights news). Fuel suppliers are responding, including with significant investments across Europe and in Saudi Arabia's NEOM, set to house a green ammonia mega plant when it opens in 2026.
- Car manufacturers' positions on e-fuels vary. For example, the Volkswagen brand has declared no interest in the development of e-fuels as it moves aggressively into electrification. Premium and luxury brand Porsche, however, with much lower sales volume targets, sees potential for e-fuels and has set up investment partnerships. Stellantis and Renault have tested e-fuels on a range of engines but remain committed to electric-only in the EU through to 2030.

Green finance mechanisms can support investment in e-fuels and other clean technologies. NEOM and Yara International have used green issuance to support investments in green ammonia production, for example. AP Moller-Maersk issued green bonds (2021 and 2023) partly to finance new vessels capable of operating on low-carbon methanol. More broadly, we observe investments in green hydrogen and carbon capture and storage in many green frameworks.

Investment currently lags what will be needed to increase e-fuel inputs—including in renewable electricity, hydrogen, and captured carbon dioxide. Hydrogen and SAF currently attract only a small slice of clean energy investment (see S&P Global Ratings and S&P Global Commodity Insights' report Renewable Energy Funding in 2023: A "Capital Transition" Unleashed). Given the nascent technological readiness of e-fuels' individual production components and their integration (see next section) most investment activity to date has focused on R&D and pilot-scale production facilities. In the activity we assessed, companies' disclosures about investment size were limited. That said, we were able to discern significant capital spending at only a small number of facilities at present, such as those of e-fuels provider HIF Global. With the EU setting future e-fuel quotas, scaling up will likely need further incentives if momentum is to build.

Scalability Will Challenge E-fuel Adoption By 2050, With Manageable Credit Risk For Now

Current e-fuel production falls very far short of meeting the EU's 2050 net-zero goal, but could eventually ramp up. According to S&P Commodity Insights, only two permanent e-fuel production facilities operate today, producing around 30,000 metric tons per year. Speculative estimates foresee many more facilities opening up, producing up to 1.1 million metric tons per year globally by 2030. However, the European Aviation Safety Agency says that to meet the EU's 2050 goal alone, 12.7 million metric tons would be needed by 2050. This implies a substantial additional deployment of e-fuel production technologies to meet Europe’s policy targets, let alone global goals.

We see limited credit risks relating to the use of e-fuels in the next decade given the expected slow build-up of technology and production capacity. While some of the technologies are already mature and in use in other sectors, combining them to produce e-fuels at scale is still nascent. Some companies have taken small steps, but Europe's policy ambition implies significant investments to achieve the renewable energy, carbon feedstocks, and processing technology required. Also, rules on how to demonstrate low-carbon benefits will give buyers of e-fuels more confidence, but these are yet to be developed and harmonized. That said, given the relatively modest targets for 2030, companies have time to plan and related investments are likely to remain limited in the near term.

We identified four key challenges facing e-fuel scalability in the coming decade, set out below. Each could influence companies' decisions as they navigate regulations and their own decarbonization ambitions. The challenges are energy intensity of production, cost impacts, technological hurdles, and managing other pollution emissions.

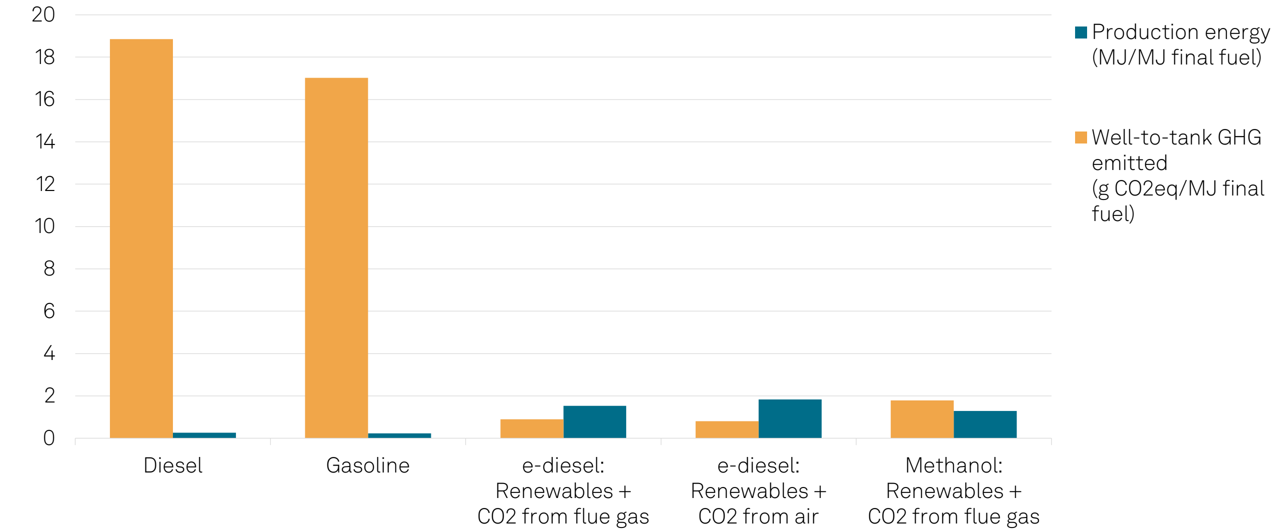
Challenge 1: E-fuel production requires significant energy inputs

According to EU studies, the energy inputs required to produce low-carbon e-fuels are much higher than their fossil fuel equivalents and electrification options when comparing well-to-tank energy use (see chart 3). One of the major challenges of e-fuel production is the end-to-end energy efficiency involved in producing and then using them. Each stage of production—including hydrogen production, carbon capture, and then fuel synthesis—requires energy inputs and at each stage there are efficiency losses. Because of this, using e-fuels would be less efficient in applications where electrification or direct hydrogen use is possible, particularly as electric motors and heat pumps are much more efficient than combustion engines.

While renewable deployment is already key to many countries’ energy policies, e-fuels as a substitute for fossil fuels essentially implies a much larger electricity supply is needed. Lifecycle emissions can be significantly reduced using e-fuels, but the production-energy burden could see shifts from the oil and gas sector to utilities. We think this will add to the pressure utilities already face in scaling up infrastructure for renewables, and the transmission and energy storage systems that could be required. For the EU's commitment on e-fuels' contribution to SAF alone, we estimate the renewable capacity needed to support this demand would reach 380 terawatt hours by 2050, equivalent to 6% of the EU's planned electricity supply in that year. Extending e-fuels' use beyond aviation would further increase this demand.

Chart 3

Low-carbon e-fuel production emits less CO_2, but has 6x the energy input of fossil fuels



g—Metric gram. GHG—Greenhouse gas. MJ--MegaJoule. Source: Prussi, et al., S&P Global Ratings.

Challenge 2: Costs could be significant

A main potential use for e-fuels is in aviation and shipping—however for these sectors energy is a key input cost and price elasticity can be a challenge, in our view (see "Europe's Airlines To Bear Highest Carbon Costs," published April 3, 2023). With current e-fuels production at very low levels, significant investment is required to produce them at scale and demand will drive costs up both for producers and consumers. Many industry commentators expect e-fuels to be more expensive than bio-SAF, for example, in the next decade or two (see chart 4).

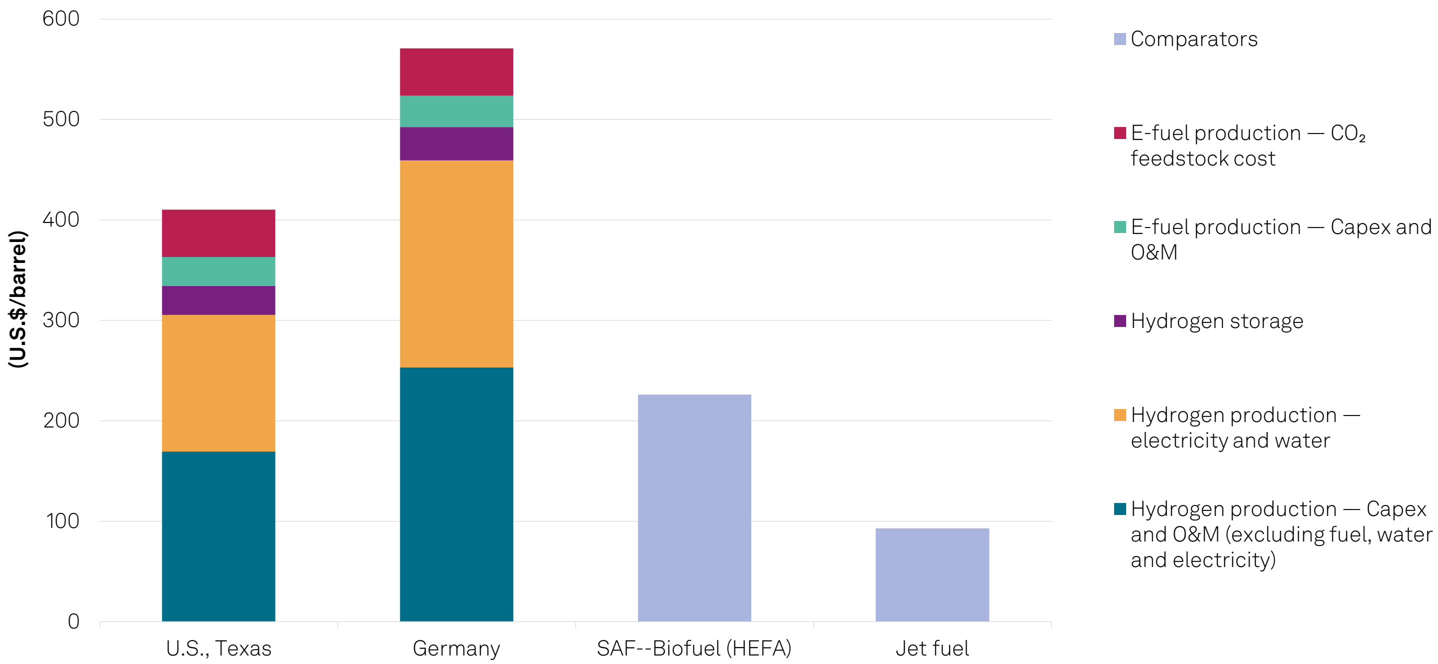
For developers and producers, cost drivers will include the type of renewable energy used and its location, carbon dioxide capture (especially for direct air capture), and transportation. Key investments are being made in clean hydrogen production, either costly carbon capture capacities for blue hydrogen or entirely renewable energy sourcing for green hydrogen production through the electrolysis of water. Competition for hydrogen in other uses could also be an important influence. The actual synthesis process step to convert hydrogen and carbon dioxide into the final e-fuel product will likely only be a small part of the overall cost (see chart 4). Conversely, the costs of building and running nascent carbon dioxide management infrastructure at scale—including clean capture, storage, transportation, and distribution—are likely to represent a significantly higher portion of production costs. E-fuel facilities co-located with other industrial processes could benefit from shared infrastructure.

As low-carbon e-fuel supplies will likely remain constrained, competition between different sectors could make establishing markets difficult, or drive up prices. For end-users, e-fuels are likely to cost more than today's traditional fossil fuels. According to S&P Commodity Insights, for example, conventional aviation fuels will likely be cheaper than e-fuels (or biofuels) even with announced IRA incentives in the case of production in the U.S. The big players are likely to seek to secure supply contracts, teaming up with majors in the oil and chemical sectors. While supply remains highly constrained, however, companies with more ambitious decarbonization targets or greater regulatory obligations will likely pay a premium as a result. The ability to pass on costs to customers will be a key factor, with some companies—typically the higher rated—better able to do so than others.

Chart 4

Hydrogen production drives e-fuel costs, with a price premium

Estimated production costs for low-carbon e-fuels production the U.S. and Germany in 2025 according to S&P Global Commodity Insights, compared to biofuels and conventional fuels



Note: Data is based on S&P Global Commodity Insights' standard assumptions in its "Economics of low-carbon hydrogen end use in industry--V2.5" model, and the forecast prices from the Biofuels and Feedstocks Price Database. The e-fuels cases assume use of Fischer-Tropsch synthesis. Capex--Capital expenditure. O&M--Operations and maintenance. Source: S&P Global Ratings, S&P Global Commodity Insights.

Challenge 3: Production faces technological challenges

The scaling of e-fuel production is constrained by the availability and maturity of renewable energy, green hydrogen production, and carbon capture technologies, which we see as a source of potential risk for early investors. While parts of the synthesis process are more mature and already used in the chemical sector, operating production plants that can combine all these technologies are still at the pilot stage (see table 2), increasing the complexities for producers. There are multiple mature options for generating renewable power, which could be developed either on- or off-site. Green hydrogen production via electrolysis and carbon capture can be achieved in multiple ways, but examples of full-scale operations remain limited. Direct air capture methods for sourcing carbon dioxide—key to low-carbon e-fuels—are much less advanced (see "Carbon capture, removal, and credits pose challenges for companies"). The most common transport fuels—gasoline, diesel, and kerosene—can be synthesized using the well-established Fischer-Tropsch process. These have been in operation for decades and are well understood albeit using mostly fossil fuel inputs.

More investment in engines capable of using e-fuels, especially for shipping, is also key to their momentum. While fuels such as methanol and ammonia and their e-fuel variants are not yet commonplace, new power trains and new ships are being designed to take advantage of them. Initially, at least, the fuels used might not be low-carbon e-fuels but could increase market penetration for the technology, enabling a future switch to lower-carbon alternatives. However, for shipping and aviation, other technology options (such as direct hydrogen use) are also still in the development phase.

Table 2

Most e-fuel technologies are still in the piloting phase

IEA's technology readiness levels (TRL) of key low-carbon e-fuel technologies, and comparators

Group	Technology	TRL	Descriptor
EFuel production	Chemical methanation	7	Pre-commercial demonstration
	Biological CO2 methanation	7	Pre-commercial demonstration
	CO2 and water co-electrolysis via Fischer-Tropsch	6	Full prototype at scale
	Ammonia via electrolysis	8	First of a kind commercial
	Methanol via electrolysis	7	Pre-commercial demonstration
Shipping	Ammonia ship engines	6	Full prototype at scale
	Methanol ship engines	9	Commercial operation in relevant environment
	Biogas ship engines	10	Integration needed at scale
Aviation	Direct hydrogen combustion	4	Early prototype
	Hydrogen fuel cell	7	Pre-commercial demonstration
	Battery electric plane	5	Large prototype
Road	Battery electric passenger cars	10	Integration needed at scale
	Hydrogen passenger car	6	Full prototype at scale
	Hydrogen truck	7	Pre-commercial demonstration

Note: The IEA's TRL is based on a scale of 1 to 11, where 1 is the initial idea and 11 is proof of stability and growth.
Source: IEA ETP Clean Energy Technology Guide, S&P Global Ratings.

Challenge 4: E-fuels cannot fully avoid other pollution emissions

Just like the fossil fuels that e-fuels might replace, other air pollutants such as nitrogen oxide and dioxide (NOx) will likely persist, which we think could keep companies that use e-fuels exposed to environmental issues. ICEs produce NOx and particles as a by-product of incomplete combustion. They are a particular issue for road transportation and cause air quality problems in many cities. With EVs many of these emissions are avoided, which could improve air quality in polluted areas. Air and water pollution is also an issue around ports and airports, and with e-fuels existing risks would likely remain. Because e-fuel production can be tightly controlled, it may be possible to reduce pollutants from combustion, particularly particles and sulphur dioxides, but it is unlikely that they will be completely avoidable.

Availability of water is an important consideration for green hydrogen production via electrolysis, but less so for the synthesis step of e-fuel production. The main electrolyzer technologies available today require the use of freshwater, meaning for some water-stressed locations it would not be viable or would compete with other industrial and agricultural demands.

Electrolysis with saline water is in development and could potentially open up more locations for production where water impacts could be reduced.

Accidental pollution issues will also remain for e-fuels. Damage to storage facilities or to storage on vessels would likely result in land or marine contamination. Ammonia in particular can be hazardous to both human health and the wider environment. Consequently, vessels and bunkering will require additional safety measures to minimize the risk of accidental release.

Looking ahead

We think e-fuels could be one of the potential solutions for decarbonizing some hard-to-abate, hard-to-electrify sectors such as aviation and shipping. Emissions reduction is possible, while making minimal changes to existing vehicles, vessels, and infrastructure in many cases. The EU has already begun to lay the groundwork for e-fuels' potential role in transportation, foreseeing a more significant role in the 2030s and beyond for e-fuels that are created from renewable feedstocks. But compared to the ambition there appears to be a significant development gap, with planned and announced projects not yet able to fill it.

For now, we see limited credit risk for the transportation sector given the scale and timeline that regulations require. **Still, we find potential longer-term risks.** The significant energy demand required to produce e-fuels coupled with the current state of technology development is likely to pose some challenges to wider adoption, while potentially increasing costs. However, e-fuels may appear today as a necessary solution to a pathway to net zero for transportation. Operators, especially those in Europe, face a complex set of hurdles and potentially increasing costs, before deciding on when to act and which technologies to embrace.

Related Research

- Europe's Airlines To Bear Highest Carbon Costs, April 3, 2023
- Carbon capture, removal, and credits pose challenges for companies, June 8, 2023
- Decarbonizing Chemicals Part One: Sectorwide Challenges Will Intensify Beyond 2030, Sept. 7, 2023
- Renewable Energy Funding in 2023: A "Capital Transition" Unleashed, Sept. 14, 2023
- Hydrogen: New Ambitions and Challenges, Feb. 15, 2024
- Economics of low-carbon hydrogen end use in industry — V2.5 Jan. 9, 2024

External Research

- Prussi, M., Yugo, M., De Prada, L., Padella, M., Edwards, R. and Lonza, L., JEC Well-to-Tank report v5, Publications Office of the European Union, Sept. 23, 2020
- International Energy Agency, ETP Clean Energy Technology Guide
- International Air Transport Association, Net zero 2050: sustainable aviation fuels
- International Maritime Organization, 2023 IMO Strategy on Reduction of GHG Emissions from Ships
- European Union Aviation Safety Agency, European Aviation Environmental Report 2022

Editor

Julie Dillon

Digital Designer

Joe Carrick-Varty