

The holy grail of transport decarbonisation?

by Ewa Kochańska

A report by the International Transport Forum and the Corporate Partnership Board, ***The potential of e-fuels to decarbonise ships and aircraft***, makes an argument that while across their life cycle, e-fuels can generate dramatically lower land, water, and greenhouse gases (GHG) than fossil fuels, it is all dependent on the carbon footprint of electricity used to produce them. The authors explain how interlocked e-fuel deployment is with green hydrogen and renewable electricity production, technological innovation, and well-thought-out government action.

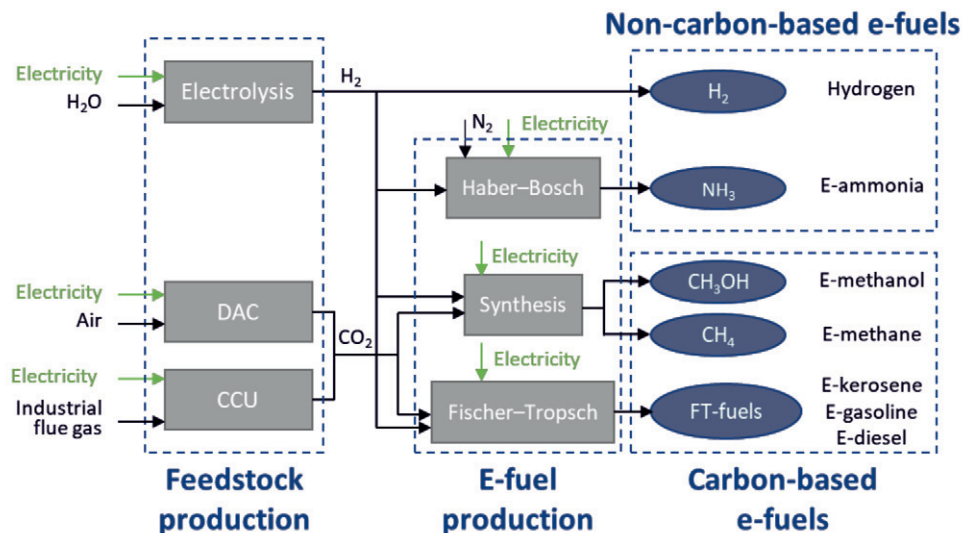
E-fuels can be in a gas or liquid form and are produced from renewable or decarbonised electricity. Gas e-fuels include renewable hydrogen and e-methane. Hydrogen (H₂) is produced by electrolysis using (renewable) electricity making it the simplest of all e-fuels. Liquid

e-fuels include e-methanol and e-crude (synthetic crude oil), producing e-kerosene and e-diesel, while synthetic ammonia (NH₃) can be in a gas or liquid form. Ammonia can be produced by combining hydrogen and nitrogen via the Haber-Bosch process. It has an advantage over pure hydrogen fuel

because its liquid form and higher energy density make it easier to handle.

E-fuel options in maritime include green hydrogen, ammonia, and e-methanol. At the same time, e-diesel and e-methane can serve as drop-in substitutes for marine diesel and liquefied natural gas.

Fig. 1. Pathways for producing e-fuels



Notes: DAC = direct air capture; CCU = carbon capture and utilisation; FT = Fischer-Tropsch.

Source for fig.1 and tabs. 1-2: The potential of e-fuels to decarbonise ships and aircraft (2023)

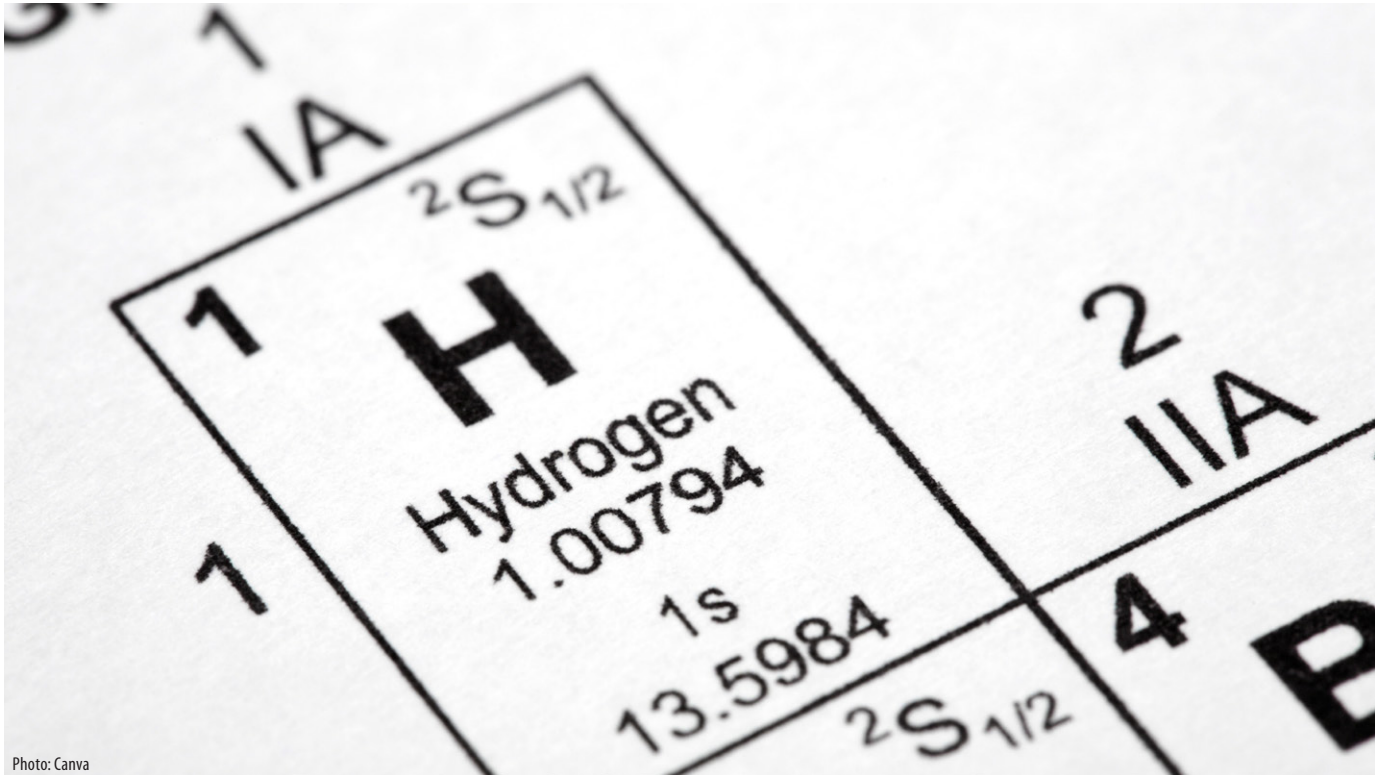


Photo: Canva

Hydrogen

Hydrogen, the simplest and the most abundant element in our environment, has garnered quite a bit of interest as a fuel, especially green hydrogen produced from renewable or nuclear electricity. Unfortunately, at this point, the most commonly utilised hydrogen – over 99% of production – comes in grey, generated through steam reforming from natural gas. This method emits fewer emissions (but not by much) than black or brown hydrogen – produced using coal.

Green hydrogen is also so alluring as a fuel of the future because in liquid form it has three times the energy density of heavy fuel oil (HFO) and is a nearly zero-waste fuel, as its only by-product is water vapour (although it does produce ‘minimal’ GHG emissions in the form of nitrogen oxides, which, a.o., aren’t neutral to human health).

Disadvantages of hydrogen include space: if using hydrogen directly as a fuel in liquid form (instead of producing other renewable fuels), it requires almost eight times more

space than, e.g., the energy equivalent found in marine gas oil. Other logistics issues pose even more challenges since storing liquid hydrogen needs exceptionally low temperatures (under -253°C). Because of the extreme temperature, insulation is vital: air condensation on pipework could lead to explosions; this is in addition to the overall threat of leaks on board simply because hydrogen is so highly explosive. Then again, the empty salt caverns used for natural gas can be utilised for land storage.

Ammonia

Many hydrogen-as-marine-fuel problems can be resolved using it as part of a more forgiving chemical compound such as ammonia. It, like hydrogen, does not produce carbon emissions when burned in engines, but unlike hydrogen this time, it can be stored in liquid form at just -33°C (or under 10 bar pressure).

Furthermore, liquid ammonia

– compared to hydrogen – has a higher volumetric energy density, is not explosive, and can utilise liquefied petroleum gas storage tanks. Ammonia is also readily available because it is commonly used for fertilisation.

Nonetheless, it has its drawbacks: toxicity even in small amounts poses serious concerns for vessel crew, personnel,

and the marine environment. Its production process is also energy intensive and currently uses fossil fuels. Also, while “ammonia can be a hydrogen carrier for vessels if split in an upstream process on the ship to release hydrogen,” this process diminishes systemic energy efficiency, “making it less practical than its direct use without splitting,” according to the report.

Methanol

E- methanol is another option for maritime which has also seen an uptake in interest, as it is one of the easiest fuels to handle and is compatible with existing, albeit modified, ship engines and infrastructure. And while it requires larger tanks than, e.g., diesel

oil (two-to-three times), they don’t have to be cryogenic or pressurised; therefore, the initial investment for the shipowner is relatively low.

Emissions-wise, when burned, methanol only produces nitrogen oxide in very small amounts. Methanol is also biodegradable,

mixes with water, and is less toxic to the environment than gasoline or diesel in case of a spill. It can also be used in fuel cells.

Alike other ‘potential greens,’ for the time being, most methanol is made using fossils such as natural gas or coal. Further,

since the producers are still trying to figure out the demand for e-methanol, its production level remains a question mark. As

such, the stakeholders are left uncertain whether there will be enough of it and at what price point. Still, as the report points

out, methanol is “already available through existing infrastructure in more than 100 ports globally.”

Obstacles: environmental, economic, and technical

E-fuels garner much attention simply because some versions will have to be used under existing International Maritime Organization (IMO) regulations. But it is largely unknown what environmental consequences a large-scale use of e-fuels could bring – direct, such as spills, or indirect, like climate change.

Equally significant are the financial constraints of e-fuels, currently significantly more expensive than fossil bunker. Renewable ammonia costs about \$720-1,400/tonne and is expected to fall to \$310-610/t by 2050; 90% of that high price is dependent on hydrogen costs. The commonly used shipping intermediate fuel oil and HFO cost about \$450/tonne.

Additionally, liquefied hydrogen and ammonia are lower energy density fuels than typical shipping bunkers (4.6 and 3.1 times lower, respectively). Also, neither one of the e-fuels is a drop-in fuel in maritime. “This means that the speed of their adoption in the maritime sector is partly constrained by the turnover of the shipping fleet and the speed that ammonia/hydrogen-capable powertrains enter new builds or retrofits,” points out the report.

Next up for consideration are carbon-based e-fuels, a very convenient option in

decarbonising maritime due to their similarity to fuels already in use and drop-in capabilities, with little modification to engines and fuel infrastructure. Carbon-based e-fuels qualify as green/blue thanks to several technologies, a.o., carbon capture technologies that remove carbon dioxide (CO₂) either from the atmosphere or the processes that emit it. These technologies include carbon capture and storage (CCS), which ‘grabs’ CO₂, transports it away from the site, and stores it in deep geological formations. There is also carbon capture and utilisation (CCU), which uses CO₂ from industrial point sources to produce e-fuels, and direct air capture (DAC), which is one of the most expensive methods and removes the CO₂ from the atmosphere – to be stored or reused, in a solid (known as S-DAC) or liquid form (L-DAC). The last method, however, requires high-temperature process heat, which, for now, is provided via the combustion of natural gas – again releasing CO₂. While that CO₂ can also be directly captured during the process before it pollutes the air, that significantly lessens the efficiency of the initial CO₂ capture. The S-DAC variant does not require the same high-temperature heat but costs 1.5 times more than L-DAC.

Furthering the carbon-based e-fuel generation methods topic, the report discusses the Fisher-Tropsch (FT) process and methanol synthesis, which are catalytic reactions producing liquid hydrocarbon (HC) fuels from syngas (a mixture of carbon monoxide and hydrogen). Fuels produced this way from fossil feedstock are not e-fuels, but both FT and methanol synthesis can produce carbon-based e-fuels by using CO₂ feedstocks from DAC or CCU with hydrogen from electrolysis. Further, since FT and methanol synthesis create excess heat as a side product, waste heat recovery or combining them with other processes that involve heat (e.g., DAC or high-temperature hydrogen electrolysis) can improve the efficiency of all processes involved.

However, there are economic barriers to carbon-based e-fuels, such as the price; the cost of carbon-based e-fuels depends on the price of hydrogen and CO₂ feedstock (with the former responsible for 66-83% of the price). Since the costs of renewable hydrogen and DAC carbon depend on the costs of green energy used during the production process, the economic viability of e-fuels will always rely on the affordability of renewable energy.

Tab. 1. Feasibility of e-fuels compared to the most commonly used fossil fuels

E-fuel	Gravimetric energy density (lower heating value) [MJ/kg]	Density at atmospheric pressure (atm) and 20°C [kg/m ³]	Volumetric energy density [MJ/l]	Boiling point [°C]	Technical feasibility in shipping
Hydrogen [H ₂]	120	0.08	0.0108 (at atm); 3.12 (350 bar); 8.5 (liquid)	-252	Potentially feasible
(E-)Ammonia (NH ₃)	18.8	0.73	12.8 (liquid)	-33	Potentially feasible
(E-)Methanol (CH ₃ OH)	19.9	0.79	15.6	65	Feasible
(E-)Methane (CH ₄)	50	0.67	0.0378 (atm); 20.8 (liquid)	-163	Feasible
Diesel fuels (MGO, MFO, VLSFO, HFO)	~43	0.82	~41	>250	Feasible

No future fuels without renewables: public support – welcomed!

The contrast between the carbon footprint of fossil bunkers and e-fuels is that the former use relatively little electricity during production, and their carbon emissions are generated for the most part during combustion. Regarding environmental sustainability, e-fuels’ ability to decrease GHG emissions depends on the carbon intensity of the energy used to produce them and, in the case of carbon-based e-fuels, the origin of the CO₂. Therefore, since the global energy mix

still relies on fossils, the expansion of renewable electricity is critical if e-fuels are to be the answer to maritime’s decarbonisation efforts.

“Additionally, all e-fuels rely on renewable hydrogen; the electrolyser capacity to produce hydrogen from renewable energy is one of the main impediments to the widespread adoption of e-fuels,” says the report. In 2020, just 0.03% of the total hydrogen supply was green. The global green hydrogen capacity must increase by 6,000 to 8,000

times compared to 2021 to fulfil the Paris Agreement climate goals.

Next, it must be considered that due to the scarcity of green hydrogen, at least in the beginning, various sectors will compete for it. Hence, regulatory preference should be made for industries that cannot decarbonise without H₂, while the remaining sectors should be prioritised based on their decarbonisation potential.

Price-wise, as things stand at present, e-fuels cannot compete with conventional



bunkers. While costs may decrease with growth in production, demand, and technological innovation, they will not fall below the current fossil levels since these price points do not reflect ecological costs.

When reaching the climate objectives of the next few years, e-fuels can complement biofuels, which are more financially accessible, but may face sustainability challenges in decarbonising economies. “Targeted support for e-fuels within broader low-carbon fuel strategies, for example, through multipliers in incentive programs or sub-targets within fuel mandates, could enable the industry to make them a mainstream technology,” says the report.

Governments can manipulate the carbon price as an emissions trading system or by carbon taxes. The latter option targets CO₂ emissions generated from fuel combustion but should also include other consequences, such as air pollution and energy security. Regulation-imposed carbon-pricing schemes can increase the price point of fossil fuels, creating a chance for e-fuels to compete. These methods are usually met with some ‘creativity’ from the regulated actors who seek ways of getting around them – in this situation, by using other emissions-decreasing solutions instead of investing

in e-fuels. Carbon price manipulation can work only as long as cheaper options than e-fuels are unavailable.

Consequently, the report advises enacting more fuel blending mandates and low-carbon fuel standards (LCFS). The former measure promotes low-carbon fuel production investment because it lowers carbon intensity. It requires blending conventional fuels with low- or zero-carbon fuels to decrease carbon footprint, leaving the blending responsibility with entities such as fuel suppliers or ship operators.

Furthermore, LCFS set a lifecycle-based carbon intensity target for fuels sold in a given area and allow regulated actors to trade credits to comply: fuels with a lower carbon intensity than the set standard generate credits – and those above it result in deficits. The regulated entities in this scenario are fuel suppliers and companies which produce, import, distribute, or sell fuel. The fuel blending mandates and LCFS offer more targeted incentives than carbon pricing as they bring a determined quantity of fuels to the market; however, they do not offer price certainty.

This is where governments must provide financial instruments for research & development and first production assets in the e-fuel sector by assisting in securing

financing from lenders, offering subsidies, or providing incentives. “Programs may focus on industry activities that would not be realised without government support, for example, where high uncertainty related to a new technology holds back private investments,” says the report.

The report points out that the IMO’s strategy for reducing GHG emissions to meet the Paris Agreement targets does not consider the entire lifecycle emissions of fuels – instead, focusing on direct CO₂ emissions only, creating an environment where the adoption of inappropriate fuels can and will happen.

A regulation proposed by the European Commission in 2021 – FuelEU Maritime – covered this issue with specific targets about GHG fuel intensity – well-to-wake. The targets aim to reduce the GHG intensity of fuels in maritime by 2% by 2025, 13% by 2035, and 75% by mid-century. FuelEU seeks to achieve 6-9% renewable and low-carbon fuel adoption in 2030 and 86-88% by 2050.

Another policy promoting the take up of e-fuels in maritime is the Clydebank Declaration, an initiative launched at 2021’s COP26 in Glasgow calling for establishing by 2025 at least six “green shipping corridors” only for vessels with zero emissions.

Tab. 2. Financial instruments to assist investments in decarbonisation technologies¹

Instrument	Description
Debt service reserves	Governments keep cash deposits to make interest and principal payments in case a private borrower fails to make scheduled payments.
Government-held	The public agency agrees to take on a lower priority position for debt repayment than senior debt holders, allowing senior debt holders to be repaid fully before other debt holders. This eases the borrower’s access to private capital.
Credit insurance products for bond financing	Government insurance agrees to make bond payments in case the issuer defaults.
Public loans and loan guarantees	Include export credits for technology, where governments can lend directly to the private sector or act as a guarantor for the private sector to obtain a market loan with a lower interest rate.
Grants	Can fully or partially cover payments on private loans or specific project expenses.
Co-investment	Helps share commercial risk between the public sector and private partners.
Market commitments	Governments guarantee the purchase of a number of aircraft or an amount of fuel that meets specified emission characteristics. In the case of fuels, these include offtake agreements – i.e. arrangements between a producer and a buyer to purchase or sell the (low-carbon) energy that will be produced.
Contracts for Difference	Commit the government to pay part of all of the cost difference between conventional fuels, vessel or aircraft and lower-emission versions.
Tax incentives	Advantageous tax treatment of R&D expenditures and incomes attributable to R&D or patents.

¹ The list is not exhaustive

Significant proliferation vs bold-turned-flop announcements

Fundamentally, e-fuels offer vital sustainability benefits over fossil fuels, enabling maritime to lower the sector’s emissions in a meaningful, long-lasting way.

The International Transport Forum and the Corporate Partnership Board underline in their *The potential of e-fuels to decarbonise ships and aircraft* that effective government policies can help

bring e-fuels to scale by concentrating on significant renewable energy proliferation, which will be necessary to meet the global energy demand for the next two to three decades.

Yet, their publication also underscores that relevant regulation currently targets e-fuel carbon intensity only at the point of combustion rather than cover the entire

fuel lifecycle. Additionally, governments’ “bold announcements” about decarbonisation are often not backed by actual investments, which are vital to widespread growth in the production of e-fuels.

Clearly, e-fuels are only useful in sectors such as maritime if they can be produced sustainably and inexpensively compared to their fossil counterparts. □