Life cycle assessment of marine electrofuels compared with fossil fuels

Report summarizing FuelEU Maritime impacts by our Working Group dedicated to maritime

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NEW ENERGIES

The energies coalition for transport & logistics

Preamble

Electrofuels (also referred as e-fuels or synthetic fuels made from green hydrogen) currently under development are a promising solution to reach the decarbonisation ambitions of the maritime sector provided they deliver real and significant greenhouse gas (GHG) savings.

The New Energies Coalition launched a working group dedicated to e-fuels, and led by **ENGIE with the significant contributions of CMA CGM, TotalEnergies, Wartsila and Bureau Veritas.**

A total cost of ownership (TCO) study, completed in November 2021, looked into e-methane and e-methanol, and compared them to liquid hydrogen and e-ammonia. This study concluded that cost differences between each other were not significant, and needed to be complemented with an assessment of the GHG impacts of each of the fuel pathways.

Indeed, getting electrofuels to deliver real and significant GHG savings compared to fossil fuels triggers the need to identify and avoid GHG hotpots in production, transport and use pathways. Analysing only optimistic or best-case fuel pathways would not provide these learnings. Hence it is key to analyse plausible but rather high-emissions pathways and to identify the relative importance of GHG hotspots and likely sources of optimization.

This was the purpose of a new extensive study, carried out in 2023 and 2024, by the New Energies Coalition in collaboration with France Gaz Maritime and Evolen, and conducted by the consultancy Ricardo. The aim was to better understand the life cycle environmental impacts of four electrofuels (hydrogen, e-ammonia, e-methane and e-methanol) and compare them to fossil fuels VLSFO/MDO and LNG.

This report highlights the work on the subject and intends to inform decision-making on future marine fuels and support their development.

About New Energies

The NEW ENERGIES Coalition, initiated in 2019 by CMA CGM, is a consortium of key players in international supply chains, working across various sectors and industries.

Through a collaborative approach, they aim to develop innovative technologies and energy solutions to decarbonize maritime, air, and road activities worldwide.

Additionally, to address the need for a regulatory framework that encourages the recognition and development of new energies and low-carbon and renewable fuels, the members of the NEW ENERGIES Coalition produce studies and manifestos for public and private representatives in the transportation and logistics sector.

NEW ENERGIES thus operates on two levels: solutions and mobilization.

About Ricardo

Ricardo Energy & Environment, a trading name of Ricardo-AEA is a world-class environmental, engineering and strategic consulting UK-based company..

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Key take aways

A comprehensive well-to-wake assessment of conservative pathways for marine electrofuels was conducted to evaluate the GHG emission intensities of these fuels according to the FuelEU Maritime Regulation guidelines.

The findings indicate that all electrofuels considered (hydrogen, e-ammonia, e-methane and e-methanol) can meet FuelEU GHG intensity at leastlimits up to (and including) the 2040 threshold and mostly the 2045 threshold under conservative high-emissions pathways.

By avoiding or minimising high-emissions production stages, electrofuels can achieve over 90% GHG reduction compared to conventional fuels (VLSFO/MGO) and fully comply with the FuelEU 2050 limits by addressing the following priority areas:

- Utilizing renewable power in production processes and enhancing use of waste heat in the CO_2 capture process,

- Employing renewable or low carbon pilot fuels (electro- or bio-fuels) rather than fossil fuels, and reducing their proportions, through further engine R&D,

- Reducing N_2O emissions and methane slip through advanced engine R&D and methane production processesand aftertreatment R&D,

- Producing electrofuels near bunkering sites, with tankers powered by renewable or low carbon energies rather than fossil fuels,

Due to how similar the results for e-ammonia, e-methane and e-methanol are in this report, choices on which fuels should power future vessels may be based on predicted fuel availability, costs and practical concerns.

Context

The international maritime transport sector has a significant global GHG footprint (approx. 3% of global GHG emissions) that needs to be reduced to reach the climate ambitions. Steps are in progress to address this through EU and international policy developments, including:

EU level	IMO level
The **monitoring, reporting and verification** (MRV) of fuel consumption and CO_2 emissions (called data collection system (DCS) for the IMO level)	
Driven by the **EU Green Deal**, decisions for: - *Inclusion of the maritime sector in the EU's emissions trading system: i.e. putting a price on carbon, which sends a price signal to reduce GHG emissions.* - *The FuelEU Maritime initiative, which aims to increase the use of sustainable alternative fuels in European shipping by introducing limits on GHG emissions intensity of marine fuels.* - *An Alternative Fuels Infrastructure Regulation (AFIR), which, in building on the AFI Directive (AFID), requires EU Member States to **ensure the supply of shore-side electricity in ports.***	**IMO's GHG strategy** and associated ambition level to decarbonise, in terms of: - *Absolute* emissions, targetting net zero by 2050: with a reduction of at least 20%, striving for 30%, by 2030 and by **70%, striving for 80%, by 2040** compared to 2008 levels. - *Uptake of zero or near-zero GHG emission technologies, fuels and/or energy sources to represent at least 5%, striving for 10% of the energy used by international shipping by 2030.* **IMO measures** related to ship carbon intensity and energy efficiency standards for new and existing ships. And expected forthcoming new measures (technical and economic) to implement the ambition of the GHG Strategy.

The development and global introduction of alternative fuels and/or energy sources are key to meeting these ambitions since technology (energy efficiency) options alone are insufficient to decarbonise the sector at these levels.

Goal of the Study

The goal of the study was to **compare the well-to-wake environmental performance of e-methane and e-methanol with zero carbon electrofuels e-ammonia and liquified hydrogen. The electrofuels were also compared against existing (conventional) fossil fuels: LNG and very low sulphur fuel oil (VLSFO)**. The study was undertaken according to the requirements of RED & FuelEU Maritime.

The study assessed the use of these fuels in a container ship, across the same two routes that were studied and specified in the previous TCO study:

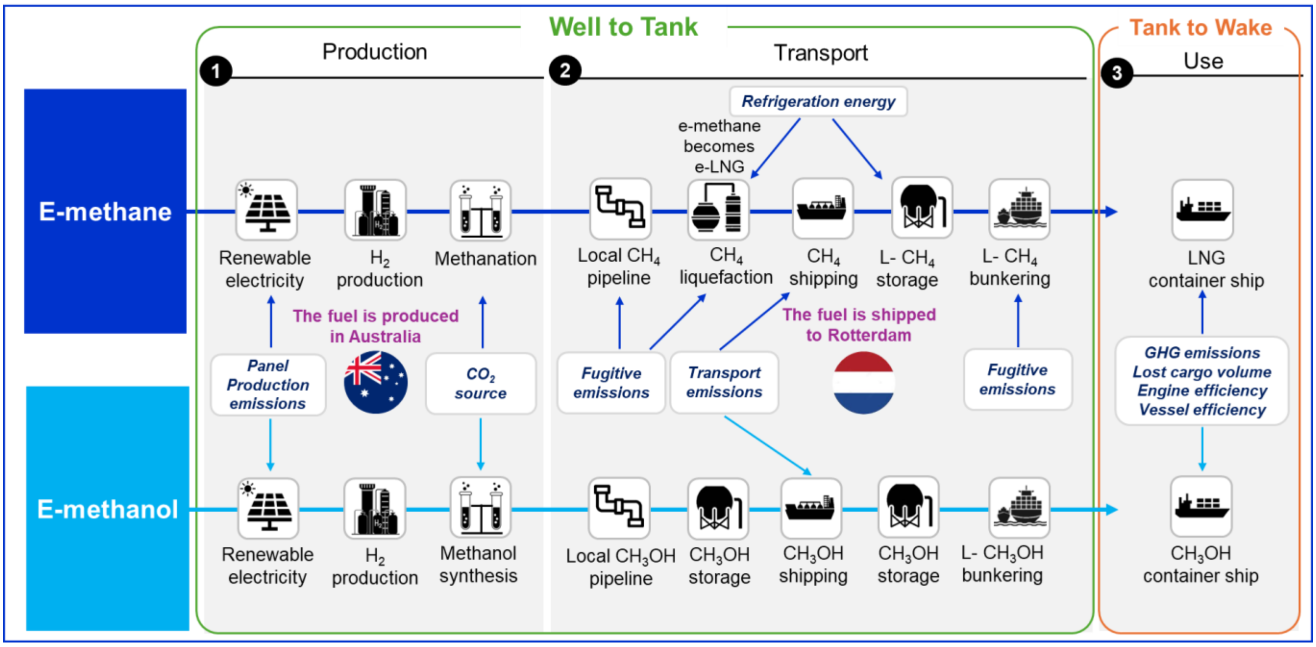
• An 84-day, 23 272 nm **deep sea** route between Rotterdam and Tianjin (and return)

• A 15-day, 2 714 nm **short sea** route between Rotterdam and the Baltic Sea (and return)

Production and use pathways assessed

According to the prospective scenario defined in this study[1], the electrofuels are assumed to be based on hydrogen feedstock produced by electrolysis in Western Australia using renewable solar electricity. The renewables, hydrogen feedstock resulting from electrolysis and electrofuel production are assumed to be relatively closely located to reduce transportation costs and emissions. Some production and liquefaction processes are assumed to use fossil fuels or non-renewable electricity to reflect a reasonable local situation. Produced fuels are shipped in conventionally fuelled vessels to Europe for bunkering. The two real-world example voyages assumed used specific examples of actual CMA-CGM container ships and their operational routes (deep-sea 23,000 TEU ship, and short-sea 2,000 TEU ship), making use of detailed speed-specific load factors across their voyages. Both routes assumed fossil pilot fuels are used with the electrofuels. Due to the early stage of electrofuel development, there are various data gaps and uncertainties; conservative assumptions were made which may over-estimate GHG intensities. Among the four electrofuels assessed, hydrogen was recognised as poorly suited for use on deep-sea routes due to its lower energy density and difficulty to be imported as a cryogenic liquid over long distances (e.g. from Australia to Europe for this considered short-sea routes).

Figure E1: Schematic of Well-to-wake lifecycle for e-methane and e-methanol



The following fuel pathways were assessed:

- E-methane* with two sensitivities of CO_2 source *(biomethane production & unavoidable industrial emissions)*
- E-methanol* with two sensitivities of CO_2 source *(biomethane production & unavoidable industrial emissions)*
- E-ammonia*
- Liquid hydrogen*
- LNG
- VLSFO

** assuming electricity from solar panels*

[1] The parameters of the prospective scenario defined here do not necessarily reflect the actual parameters that might be selected for a real project in the future.

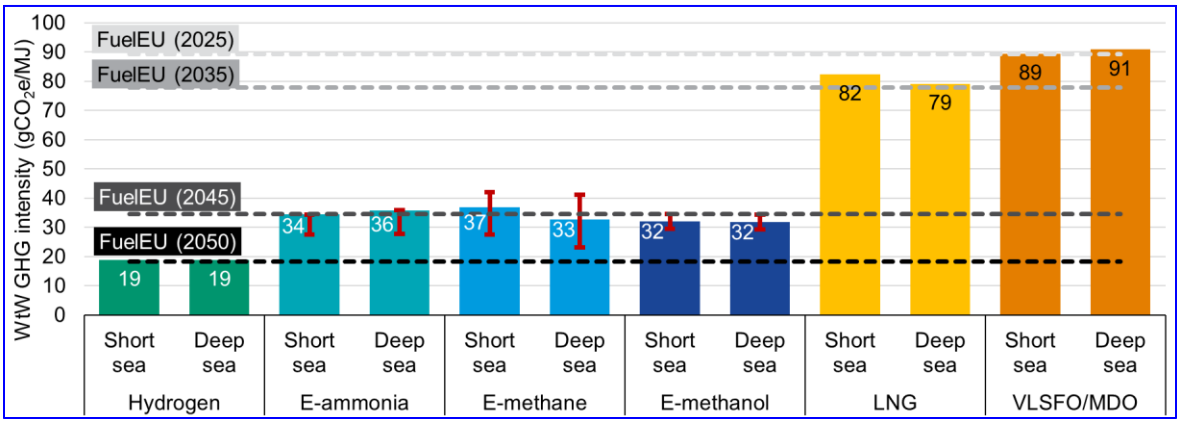
Total FuelEU GHG intensities from pathways assessed

For the conservative pathways assessed, the FuelEU well-to-wake (WtW) GHG intensities for e-ammonia, e-methane and e-methanol are similar, around 55-60% below fossil LNG and 60-65% below VLSFO/MDO[2]. The results for these three electrofuels are similar; the merit order could vary depending on the production pathway, the vessels and propulsion systems deploying these fuels and routes, while eventual fuel choices will depend on practical and commercial considerations. Specifically, the estimated GHG intensities of the conservative pathways considered for each fuel, when calculated according to the FuelEU Maritime rules (i.e. including the impacts of pilot fuels), shown in Figure E2, conclude that:

- Conventional liquid-fuelled vessels will not comply with FuelEU from 2025, and LNG may not comply from 2035, and so alternatives need to increasingly replace these fuels over this period.

- Depending on the pathways, the practical electrofuels (i.e. excluding hydrogen) would comply until 2040 or 2045. After 2050, e-ammonia, e-methane and e-methanol would require lower-emissions pathways than analysed here to comply.

Figure E2: Conservative pathway GHG emission intensities vs FuelEU limits (post-2034)



Assessing the make-up of GHG intensities yields opportunities

Analysis of the contributions to the total WtW GHG intensities from the conservative pathways assessed **identified the potential significant GHG intensity hotspots for the electrofuels that should be focused on** to ensure electrofuels meet the sector's needs of GHG performance (Figure E3).

The total WtW intensities are shown in solid red lines in the figure, atop the labelled major contributing components of the pathways. By identifying the major contributors, opportunities for improved WtW emissions can be identified. Hence, high-level estimates of a reasonable scenario of lower GHG intensities with many of those potential hotspots tackled are shown with a dotted purple outline. **This shows the significant impact of production pathways on total GHG emission intensities and how the industry can work to ensure electrofuels deliver significant GHG reductions.**

The results obtained after the implementation of pragmatic GHG reduction actions are shown in Figure E4 and demonstrate that **electrofuels can achieve over 90% GHG reduction compared to conventional fuels and fully comply with the FuelEU 2050.**

[2] These emissions levels include the GHG emissions from the pilot fuel, which is assumed to be fossil-based. These abatement levels should not be compared to the ones provided by the Renewable Energy Directive (RED), which mandates RFNBOs to reduce GHG emissions by at least 70% compared to a fossil reference, because the RED calculation excludes the emissions from the fossil pilot fuel.

Figure E3: Components of conservative pathways GHG intensities (deep-sea, post 2034)

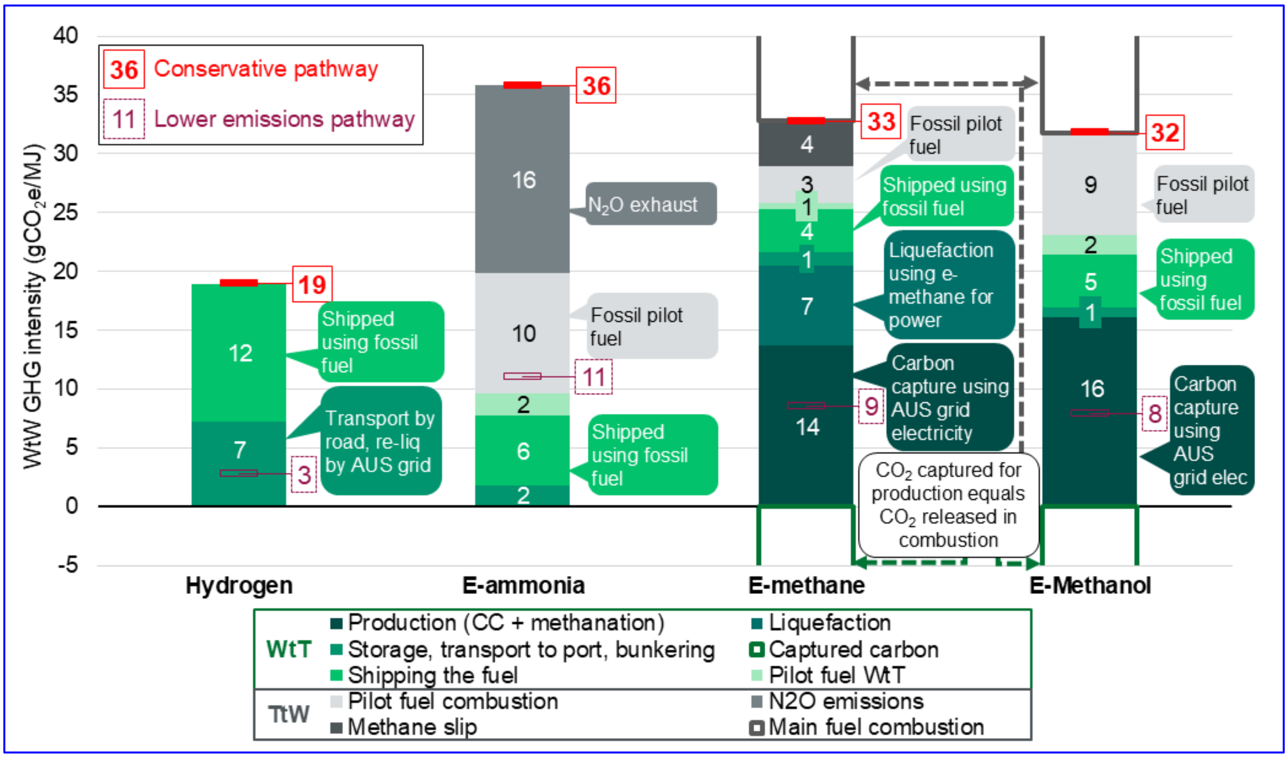
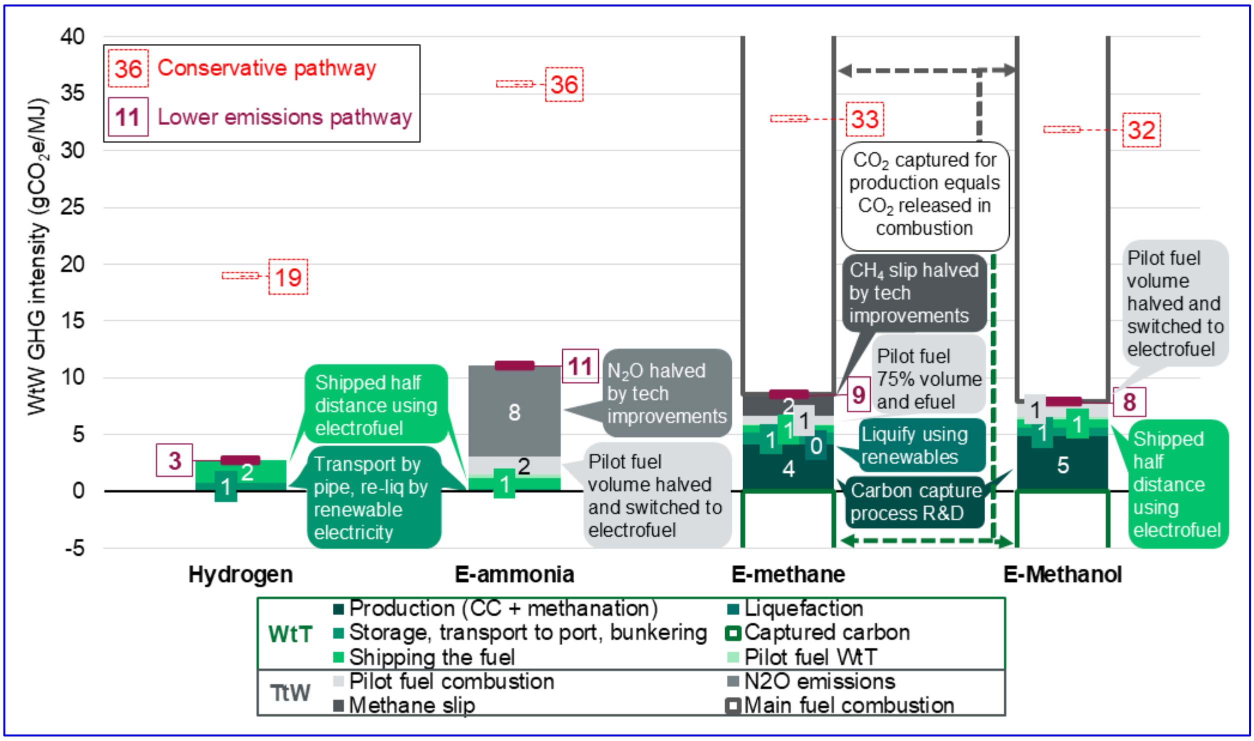


Figure E4: A potential lower-emissions scenario, after tackling hotspots (deep-sea post 2034)



Wider considerations

Several wider considerations were identified for legislators, technology developers, fuel producers and vessel owners and are summarized as follows:

- Robust certification of GHG intensity, e.g. under FuelEU Maritime, is essential for future maritime fuels, and accreditation of certification must be tightly controlled to ensure that high emissions pathways are avoided and truly low emissions fuel producers are incentivised.
- Fuel certification schemes should extend to the point of vessel bunkering, not just the production gate.
- Methane slip must be tightly reduced for methane-based fuels to meet legislation, particularly post 2045, which may require additional R&D investment.
- Robust and practical legislation on N_2O emissions is needed to ensure benefit on a total GHG basis for ammonia engines.
- Reducing the proportion of pilot fuel needed should be a target for R&D investment by engine manufacturers, both to reduce fossil CO_2 emissions today and the volume of potentially expensive low-carbon fuel needed in the future.
- Further policy development should study how to consider the life cycle impact of renewable generation and of infrastructure, which are currently considered as zero burden within the EU policy framework, in order to incentivise low-carbon upstream infrastructure.

Glossary

AFID	Alternative Fuels Infrastructure Directive - European Directive on the Deployment of Alternative Fuels Infrastructure.
AFIR	Alternative Fuels Infrastructure Regulation - Draft European regulation that will repeal the AFID.
CO_2(e)	Carbon dioxide (equivalent)
CH_4	Methane
Electrofuel	Fuel produced using ‘green’ electricity. Also referred to as e-fuel, power-to-x fuel, or RFNBO
ETS	Emissions trading system
EU	European Union
FuelEU	FuelEU Maritime Regulation (EU) 2023/1805 of 13 September 2023 on the use of renewable and low-carbon fuels in maritime transport
g	Grams
GHG	Greenhouse gas(es)
GWP	Global warming potential
IMO	International Maritime Organization
ISO	International Organization for Standardization
km	Kilometres
LCA	Life cycle assessment
LNG	Liquefied natural gas
MDO	Marine diesel oil
MJ	Megajoule (10^6 joules)
MRV	Measure, Reporting and Verification system
MW	Megawatt (10^6 watts)
N_2O	Nitrous oxide, a greenhouse gas
PV	Photovoltaic
RED	Renewable Energy Directive (2009/28/EC) as recast by Directive (EU) 2018/2001 and amended by Directive (EU) 2023/2413
RFNBO	Renewable fuel of non-biological origin, i.e. electrofuel
TEU	Twenty-foot equivalent unit
TtW	Tank to wake
VLSFO	Very low sulphur fuel oil
WtT	Well to tank
WtW	Well to wake: the sum of well to tank and tank to wake

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