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News

- Innovation and Industry

- Climate, environment and circular economy
- Life cycle analysis (LCA)

Faced with the carbon neutrality ambitions set by the IMO and European regulations, a study commissioned by CMA CGM and conducted by IFPEN analyzes the greenhouse gas (GHG) emissions of alternative marine fuels. The focus is on methanol and ammonia, with an in-depth assessment of their performance in terms of decarbonization and compliance with regulatory frameworks. Objective: To guide future technological choices for more sustainable maritime transport. Summary.

> **Access to the report** (PDF 17 MO)

> **Study summary** (PDF 2 MO)

In response to the increasing need for maritime decarbonisation illustrated by the ambitious 2050 net-zero greenhouse gases (GHG) emissions targets set by the International Maritime Organization (IMO) and EU regulations, this Life Cycle Assessment (LCA), commissioned by CMA CGM, evaluates the greenhouse gas emissions of alternative marine fuels, focusing on methanol and ammonia. These fuels are assessed across multiple production pathways as follows, to determine real-world emissions performance and compliance with regulatory frameworks:

- **E-methanol:** Produced from renewable hydrogen (electrolysis) and captured CO? (from flue gases or direct air capture).
- **Bio-methanol:** Derived from biomass gasification, using waste wood or cultivated wood as feedstock.
- **E-ammonia:** Synthesized from renewable hydrogen (electrolysis) and nitrogen from the air via the Haber-Bosch process.
- **Blue ammonia:** Produced using hydrogen from natural gas reforming (SMR or ATR), with carbon capture and storage (CCS) applied.
- **And VLSFO** (Very Low Sulphur Fuel Oil), for the sake of having a comparison with a fossil-based fuel.

Methodology and Scope

This study provides a comprehensive assessment of alternative marine fuels, focusing on the role of electricity source variations, transport distances, and regulatory frameworks in determining their true decarbonization potential. The LCA assesses 17 production regions, each with different electricity grid intensities, transport distances to bunkering ports, and fuel conditioning requirements. It also includes prospective analyses for 2035 and 2050, incorporating global energy decarbonization trends and evolving regulatory landscapes. This provides a robust, data-driven evaluation of the decarbonisation potential of methanol and ammonia-based fuels for maritime transport. The study evaluates:

- Variations in local electricity grid mix, reflecting the carbon intensity of national energy grids and their impact on fuel production emissions.
- Renewable electricity following the RED methodology, which assumes zero emissions from renewable sources, aligning with regulatory accounting methodologies.
- Full cradle-to-grave (CTG) accounting, incorporating the emissions from renewable energy infrastructure, offering a more comprehensive decarbonisation assessment.
- Carbon capture processes, including flue gas capture (industrial sources) and Direct Air Capture (DAC), which has higher energy demands.

Key Findings

E-Méthanol

- Average fuel WtW emissions per MJ for e-methanol across 17 locations, assuming fully powered by renewable energy with cradle-to-grave emissions, carbon captured from flue gases in up to 2035 and from Direct Air Capture in 2050, are 16 ± 4 gCO?eq/MJ (2025), 12 ± 3 gCO?eq/MJ (2035) and 5 ± 1 (2050) [with ± values representing mean absolute deviation].
- Average fuel WtW emissions per MJ for e-methanol across 17 locations, assuming carbon capture is powered by natural gas and auxiliary processes are powered by local electricity, are 26 ± 7 gCO?eq/MJ (2025), 14 ± 4 gCO?eq/MJ (2035) and 7 ± 1 (2050). Under this configuration, these emissions meet the 70% reduction threshold for RFNBO compliance under RED only from 2035 onwards.
- In container unit transportation WtW GHG emissions (gCO?eq/TEU.km), e-methanol is fit for decarbonisation, achieving an average 70% reduction (range 60-80%) compared to VLSFO. However, it

relies on the availability of biogenic CO? and its capture, which may present logistical and scalability challenges.

Bio-Méthanol

- Supply chain for waste wood and gasification efficiency losses are the most important contributors.
- RED compliance is met in all regions reaching (~95% GHG reduction)
- In container unit transportation WtW GHG emissions (gCO?eq/TEU.km), bio-methanol is fit for decarbonisation and offers the highest reduction potential. It achieves on average 80% lower WtW emissions (range 75-85%) compared to VLSFO, provided that sustainable biomass feedstocks are used. Transporting finished bio-methanol rather than raw biomass significantly reduces emissions.

E-Ammonia

- Average WtW emissions per MJ for e-ammonia across 17 locations, assuming fully powered by renewable electricity with cradle-to-grave emissions, are 17 ± 4 gCO?eq/MJ (2025), 12 ± 3 gCO?eq/MJ (2035) and 5 ± 1 (2050). These emissions meet the 70% reduction threshold for RFNBO compliance under RED from 2025 onwards.
- In container unit transportation WtW GHG emissions (gCO?eq/TEU.km), e-ammonia achieves an average 50% reduction (range 35-85%) compared to VLSFO. While fit for decarbonization, its effectiveness is currently constrained by lower engine efficiency, high pilot fuel needs, and N?O emissions. As this technology is still in its early stages and rapidly evolving, these findings are subject to significant uncertainties, therefore conclusions should be considered with caution and not considered as definitive. Further research and vessel design optimization are required to improve performance and reduce uncertainties.

Blue Amonia

- Average WtW emissions per MJ for blue-ammonia across 17 locations, assuming a natural gas-powered Steam Methane Reforming unit with MEA carbon capture and storage up to 2035, and a natural gas-powered Auto Thermal Reforming Unit with VPSA carbon capture and storage in 2050, are 83 ± 12 gCO?eq/MJ (2025), 61 ± 6 gCO?eq/MJ (2035) and 29 ± 4 (2050). These emission levels fail to meet the 70% reduction threshold for LCF (Low-Carbon Fuels) compliance under the Gas Directive in both 2025 and 2035, mainly due to due to methane and CO2 emissions associated with the natural gas supply chain and the process used to produce blue hydrogen. Even under optimistic scenarios with reduced upstream blue hydrogen emissions, it only meets the 70% reduction threshold in 6 out of 17 regions by 2050.
  • In container unit transportation WtW GHG emissions (gCO?eq/TEU.km), blue ammonia achieves on average slightly higher emissions than those of VLSFO. Hence, blue ammonia is not currently a viable decarbonisation option. However, under specific conditions—such as optimized upstream blue hydrogen production using ATR technology—it may serve as a transitional solution until e-ammonia production scales up. However, such conditions were only considered to become widely adopted in 2050 for this study.

Final considerations

This LCA provides an advanced and comprehensive assessment of the decarbonization potential of methanol and ammonia for maritime transport. While e-methanol and bio-methanol offer the highest reduction potential, e-ammonia offers decarbonization benefits but requires further technological development to address efficiency, pilot fuel use, and N?O emissions. Blue ammonia remains unsuitable for deep decarbonization unless substantial improvements in methane emissions control and carbon capture technology are realized. Strategic decisions in the broader shipping industry must account not only for regulatory compliance but also for the full life-cycle emissions and the feasibility of adopting alternative fuels.

Evaluation of alternative marine fuels for the decarbonization of maritime transport
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