

REFOLUTION technical update. Marine distillate properties, kinetic modeling, and FuelEU Maritime compliance

Introduction

The global maritime sector's sustainability journey is accelerating at an unprecedented pace. As the maritime industry makes a decisive push toward climate neutrality, navigating the global and European regulatory landscape has become one of the most complex challenges for both shipowners and fuel producers.

The IMO Strategy 2023 charts a clear course toward net-zero emissions by 2050, but the real challenge today lies in aligning with the rules and adopting scalable and economically viable technological solutions. In this issue, we highlight key takeaways from our recent webinar, "Navigating Maritime Decarbonization between IMO and EU Policies."

During the event, high-level experts analyzed how crucial regulatory instruments, including the FuelEU Maritime Regulation and the extension of the EU ETS to the maritime sector, are shifting the market's focus toward a "well-to-wake" approach. This perspective assesses the environmental impact of fuels throughout their entire life cycle, imposing strict sustainability criteria (in line with RED III and the EUDR) that exclude food crops and valorize forest residues and biogenic waste.

But regulatory compliance is only the starting point. For this reason, the newsletter focuses on concrete technological solutions that can transform legal constraints into market opportunities. Inside, we present the project's latest achievements and results, including:

- VTT's advanced tests on marine distillates: results obtained in pilot plants demonstrate that hydrotreated biocrude derived from woody biomass possesses optimal chemical and physical properties, making it a perfect "drop-in" replacement for traditional Marine Gas Oil (MGO).
- SINTEF's cutting-edge kinetic modeling: officially presented at EUBCE 2026, this technology allows for the precise simulation of co-feeding of stabilized pyrolysis oil directly into existing European refineries, optimizing yields and tracking the share of biological carbon.

Together, these innovations demonstrate how REFOLUTION is translating challenging European policy objectives into scalable, competitive, and market-ready realities, reducing the carbon footprint by 60% and improving production cost efficiency by 50%.

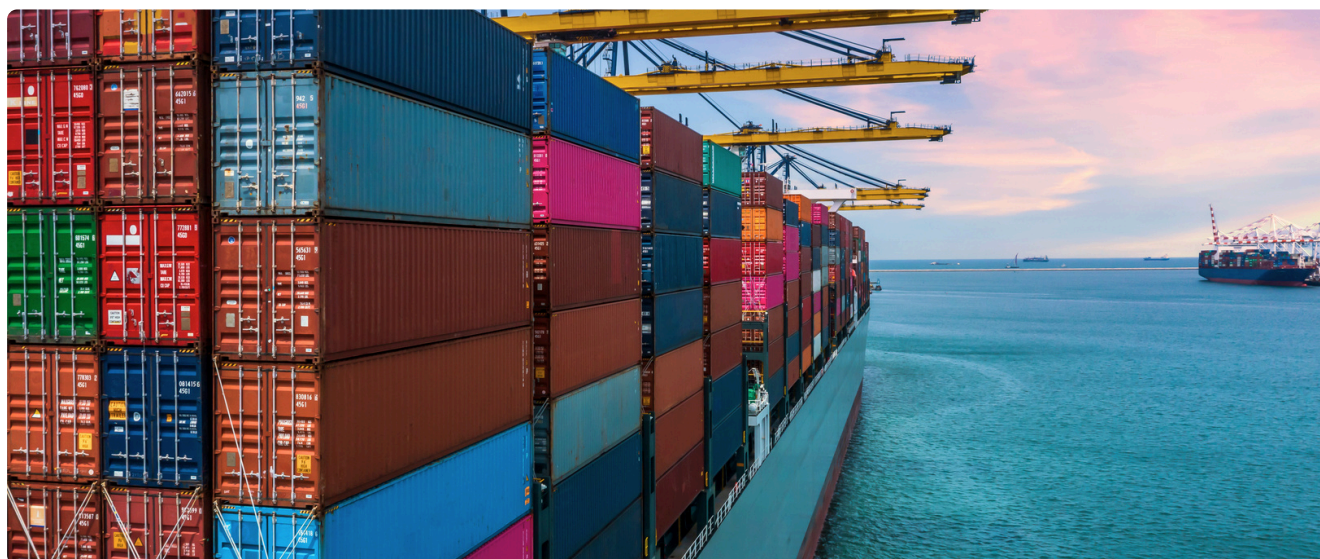
Beyond the regulations of the maritime transition

The webinar "Navigating Maritime Decarbonization between IMO and EU Policies," organized as part of the REFOLUTION project, was held on March 18, 2026. The event brought together five experts to explore the evolving regulatory landscape and technological innovations driving the decarbonization of the maritime sector.

A key point emerging from the discussion was that the main challenge is no longer the absence of climate targets. With the IMO Strategy 2023 setting the course towards net-zero emissions by approximately 2050 and the adoption of the IMO Net-Zero Framework, the direction is clear. Stakeholders instead emphasized the urgent need for greater regulatory harmonization at the global level to avoid market fragmentation and ensure a level playing field for the maritime sector.

While the IMO provides the global regulatory framework, the European Union is accelerating the transition through ambitious policy instruments. The extension of the EU Emissions Trading System (EU ETS) to maritime transport introduces a direct financial cost for greenhouse gas emissions, while the FuelEU Maritime Regulation shifts the focus from "tank-to-wake" emissions to a "well-to-wake" (WtW) approach. This broader perspective assesses the environmental performance of fuels throughout their life cycle, from raw material sourcing and production to their final use onboard ships.

As a result, sustainability requirements now extend well beyond ship operations, placing increasing emphasis on the origin and production pathways of alternative fuels. Regulations such as RED III and the EU Deforestation Regulation (EUDR) establish strict sustainability criteria, excluding biofuels derived from food crops or associated with indirect land-use change (ILUC). As a result, demonstrating that biofuels are produced exclusively from sustainable feedstocks, such as forest residues and other eligible waste streams, has become not only an environmental requirement but also a prerequisite for market access. In this context, projects like REFOLUTION play a crucial role in supporting the transition to sustainable marine fuels by developing technologies that combine high environmental performance with compliance with the ever-evolving European regulatory framework.



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Technological solutions, cost analysis, and the role of REFOLUTION

A comparative analysis of decarbonization solutions, ranging from advanced biofuels to e-fuels (or RFNBO, such as e-methanol and e-ammonia), highlights how the main barrier to large-scale deployment is not only technological, but also economic.

Data from the BIOMAR 2025 study by Politecnico di Torino indicates that, despite the high theoretical potential for reducing emissions of synthetic fuels, advanced biofuels currently offer the lowest costs per unit of CO₂ equivalent saved (Marginal Abatement Cost). Industrially, the market is already responding to these trends: the adoption of methanol-fueled dual-fuel propulsion systems now accounts for nearly 10% of the global tonnage currently on order at shipyards.

REFOLUTION's research activities also fit within this context, aimed at optimizing thermochemical and catalytic conversion processes for the production of advanced drop-in biofuels from woody biomass and forest residues.

The project aims to improve the cost-effectiveness of biofuels by 50% and reduce the overall carbon footprint associated with their production cycle by 60%.

Finally, to mitigate the high financial risks associated with initial investments in new energy supply chains, the webinar speakers emphasized the importance of adopting strategic and market-based tools. Among these, the flexible pooling mechanisms provided by the FuelEU Maritime Regulation, which allow companies to offset emissions on a fleet-wide basis, and the establishment of Green Shipping Corridors play a key role. These, configuring specific trade routes supported by public-private partnerships, allow for the concentration of operational efforts, zero emissions, and testing the effectiveness of new technologies under real market conditions.



Source: Canva

Empirical evidence: technological innovations, sustainability metrics, and market dynamics

From a technological perspective, researchers at the Finnish research center VTT presented advances in thermochemical liquefaction and hydrotreatment (HDO) processes for fast pyrolysis and hydrothermal liquefaction (HTL) oils derived from woody biomass and forest residues. Tests conducted in pilot plants and on fixed catalyst beds confirmed that the severity of the hydrodeoxygenation process does not significantly alter the boiling range or density of the final marine distillate; the resulting drop-in biofuel exhibits optimal characteristics (with sulfur levels confined to approximately 4 mg/Kg and a pour point of -34°C), qualifying it as a perfect substitute for marine gas oil (MGO).

In parallel, in the e-fuels supply chain, the European "UP-TO-ME" project (coordinated by VTT) demonstrated the technical feasibility of producing e-methanol from point sources of CO₂ and green hydrogen derived from wastewater treatment plants and anaerobic digestion of sewage sludge.

This synthetic fuel, successfully tested on a Volvo Penta D16 marine engine retrofitted with a low-pressure dual-fuel kit, has replaced up to 40% of traditional fossil fuels, although the clear need for exhaust gas aftertreatment systems to reduce particulate matter and residual emissions emerged. In addition to engine and chemical performance, the panel of experts dedicated a broad session to environmental impact monitoring methodologies, highlighting that a holistic sustainability assessment cannot be limited to calculating global warming potential (GWP) or land use (LUC) alone. In line with the RED III directives and the EU Taxonomy, the Life Cycle Assessment (LCA) and Techno-Economic Assessment (TEA) models developed within REFOLUTION integrate indicators previously considered secondary, such as human toxicity, terrestrial acidification, aquatic ecotoxicity, water scarcity, and the footprint of atmospheric particulate matter. The methodological approach favored by stakeholders requires the use of primary process data to avoid the biases typical of secondary commercial databases.

From a regulatory perspective, the analysis highlighted how the inclusion of methane and nitrous oxide in the EU ETS and the FuelEU Maritime Regulation starting in 2026 requires strict controls not only on exhaust emissions (Tank-to-Wake) but also on the entire fuel extraction and production cycle (Well-to-Tank). Finally, on a macroeconomic level, the BIOMAR 2025 study from the Politecnico di Torino confirmed that benchmark fossil fuels, such as Very Low Sulphur Fuel Oil (VLSFO) and MGO, maintain significantly lower energy costs per Gigajoule (GJ) than any advanced biofuel or e-fuel on the market. Nonetheless, among sustainable options, advanced biofuels have the lowest Marginal Abatement Cost (MAC) per tonne of CO₂ equivalent saved.

To bridge this economic gap and mitigate investment risks arising from the current global geopolitical and regulatory uncertainty (such as the postponement of the IMO discussions on the Net-Zero Framework until 2026), experts identify the FuelEU Maritime pooling mechanism as a key market lever. This tool enables the flexible redistribution of compliance surpluses among different vessels: according to the technical analyses shared in the webinar, the use of a single unit fueled by liquefied biomethane (LBG/LBM), a highly overcompliant fuel according to the Well-to-Wake methodology, is theoretically capable of offsetting the emissions deficit of a fleet of 32 to 40 vessels fueled by heavy fuel oil (HFO). Consequently, Maritime Green Corridors are not just isolated technology testing platforms, but actual integrated commercial ecosystems designed to standardize bunkering infrastructure, eliminate port-to-port supply uncertainty, and accelerate the industrial scalability of advanced energy carriers.

Refinery Co-processing: SINTEF Modeling Approach as presented at EUBCE 2026

At the 34th European Biomass Conference & Exhibition (EUBCE), held in The Hague from May 19 to 22, 2026, SINTEF colleagues presented the latest and most significant developments in the field of decarbonization of commercial transport.

Bernd Wittgens (SINTEF) presented the results of the study **"The Effect of Pyrolysis Oil Co-feeding in Fluid Catalytic Cracking (FCC): a Lumped Modeling Approach"** which focused on the integration of stabilized biocrude into existing refining infrastructure in Europe.

Fast pyrolysis technology represents a mature solution for converting lignocellulosic biomass into a versatile liquid bio-oil. However, to be used in existing refineries without causing polymerization or degradation, crude bio-oil must undergo a mild hydrogenation process that reduces its acidity and high oxygen content (typically between 35% and 50% by weight). The core of the innovation presented at EUBCE lies in the development of a lumped kinetic model capable of accurately simulating the co-feeding of this Stabilized Pyrolysis Oil (SPO) up to 20% with traditional Vacuum Gas Oil (VGO) directly into Fluid Catalytic Cracking (FCC) units. The introduction of SPO is introduced into the system along with oxygenated compounds (such as phenols and furans), which, together with CO, CO₂ and water, influence the final yield.

The developed model allows us to:

- Predict yield variations of key products (naphtha, kerosene, LCO, bottoms, coke, and fuel gases) as the SPO co-feeding percentage varies (from 4% to 20%).
- Track the biological share (green carbon tracking) in final distillates (naphtha and kerosene), a factor that will be experimentally validated through sophisticated analyses of biogenic carbon content.
- Optimize the overall process, minimizing the impact of oxygenates on the quality of drop-in fuel intended for the marine and aviation sectors.

Industrial synergy and kinetic model structure:

SINTEF's predictive model is based on a lumping and delumping approach: chemical classes are defined based on their normal boiling point (NBP), and up to 10 representative molecules are mapped for each class (such as toluene, xylene, and benzene for the naphtha fraction, or decalin and tetralin for kerosene).

To accurately tune the parameters, the model was constrained to real experimental data (elemental analysis, SIMDIST simulated distillation curve, and detailed chemical composition). This level of precision was achieved thanks to close collaboration with REFOLUTION partners: BTG Bioliquids and BTG (Netherlands), which are key to the development and delivery of the fast pyrolysis and bio-oil stabilization technology.

SINTEF's kinetic model represents a strategic decision-making tool for European refiners. The next key step, scheduled for the third quarter of 2026, will be the validation of the model on a significantly larger pilot plant (with a throughput of 20 kg/h) at VTT's facilities in Finland. This step will be crucial to consolidate the technology's economic feasibility and industrial scalability, laying the foundation for a concrete and sustainable green transition in long-distance heavy-duty transport.



Source: Canva

The REFOLUTION project started in January 2023 and will end in December 2026. Coordinated by SINTEF, the project brings together 14 partners from 8 European countries, driven by strong industrial leadership, the consortium includes key market players across the resource-process (upstream/reactor/catalyst/downstream) product spectrum. This ensures a powerful driving force for technology development throughout the entire production chain, addressing challenges in critical EU sectors related to energy and transportation.

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