REFOLUTION
Unlocking the potential of biofuels

Refinery integration, scale-up and certification for aviation and marine biofuels production

One of the primary objectives of REFOLUTION is to evaluate the suitability of hydrodeoxygenated pyrolysis oil (**HPO**) as a blending component for marine fuels. Laboratory analyses verified HPO quality and compliance with international standards. This validation is essential to support the decarbonization of current ships, which will remain in service well beyond 2040, requiring drop-in fuels fully compatible with existing engines and infrastructure. Furthermore, the research explores innovative applications, such as the use of HPO as a pilot fuel for methanol ignition, thus expanding the range of sustainable options for achieving the maritime sector's climate goals.

Compliance with ISO 8217 standards

In-depth analysis of the hydrodeoxygenated pyrolysis oil (HPO) samples produced within the REFOLUTION project has confirmed that these fuel fractions are, from a purely formal point of view, fully suitable for use in the marine sector according to the rigorous criteria established by the ISO 8217 standard.
Analytical results obtained on one HPO sample show these characteristics:

- **Density: 891 kg/m³ (maximum limit 900)**

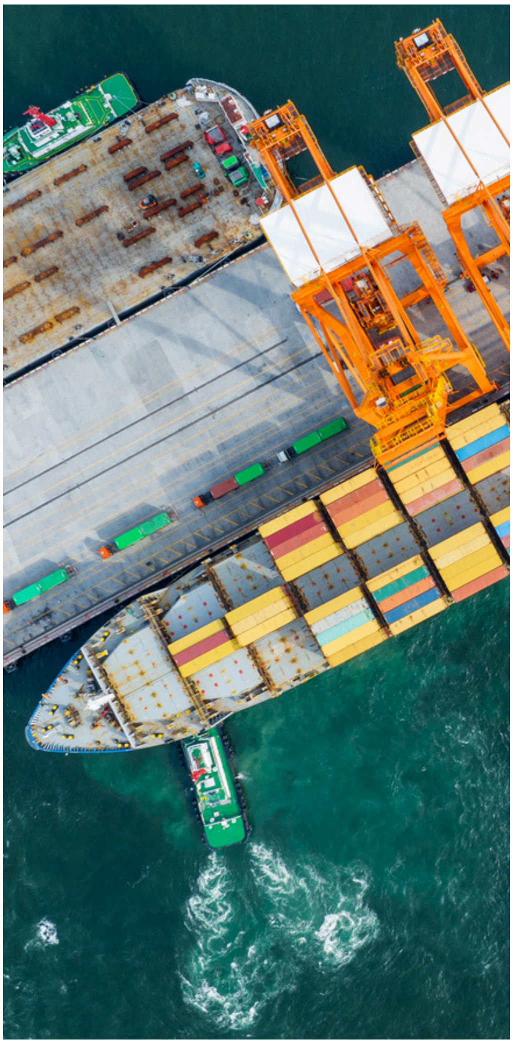
- **Kinematic viscosity (40°C): detected in a range between 3.3 and 4.1 mm²/s, falls well within the operating range of 2.0–11.0 mm²/s**

- **Sulfur content: < 1 ppm (extremely low compared to environmental limits)**

- **Water Content and Acidity: Very low values (Water < 31 ppm; TAN < 0.08 mgKOH/g), indicating high quality and chemical stability**

- **Cold Storage: Excellent properties, with a pour point of up to -36°C.**

The density of approximately 891 kg/m³, a value that is below the maximum limit of 900 kg/m³ foreseen for marine distillates and the kinematic viscosity at 40°C, guarantee adequate fluidity for existing injection systems.



Advanced chemical analysis (FT-ICR-MS)

HPO consists predominantly of cyclic, aliphatic, aromatic, and polyaromatic hydrocarbons, while minor fractions of polar, oxygen-containing compounds remain due to incomplete deoxygenation during upgrading. These species were selectively characterized by electrospray ionization high-resolution mass spectrometry, enabling the assignment of more than 1,000 molecular compositions. Compounds containing up to six oxygen atoms were detected, with mono-oxygenated species showing the highest signal intensity, tentatively attributed to mono- and diaromatic phenolic structures derived from lignin pyrolysis.
This molecular-level insight is critical for identifying the chemical drivers of insoluble sediment formation observed in stability tests, which poses a risk of injector clogging. The results provide a targeted basis for evaluating the potential of FCC co-processing, scheduled for Q1 2025, to further improve the fuel's chemical stability.

Blending methodology and compatibility

Tests evaluated the compatibility of HPO with polar and nonpolar components. The standard strategy involved blends with 30% HPO.

Distillate Fuels (DMB/MDO): Blends created with conventional marine distillates were found to be homogeneous and chemically stable. Tests revealed no critical changes in key parameters, confirming that these blends fully comply with the limits set by the ISO 8217 standard for density and kinematic viscosity. Water content and total acidity (TAN) also remained within established safety margins, ensuring the integrity of fuel systems.

HVO and FAME: Although HPO is formally compatible with these fuel carriers, analyses highlighted some technical challenge: the formation of sediments and small insoluble deposits. In blends with HVO, the appearance of solid particles was observed immediately after blending, while in combinations with biodiesel (FAME), sedimentation appeared during testing. Despite this, the acidity and water content parameters in the FAME blends remained within safe limits, although they showed a slight increase.

Methanol Innovation: Given the known challenges of methanol auto-ignition in combustion engines, the use of HPO as a pilot ignition fuel is proposed as a potential application. While not yet experimentally validated within the consortium, this concept could enable future pathways toward the large-scale adoption of methanol as a low-emission maritime fuel.

The effectiveness of the 30% HPO blend strategy lies in its ability to act as an immediate "drop-in" solution, without requiring fuel system redesign. Analyses have shown that **integration with distillate fuels** not only maintains blend homogeneity but also **benefits from the superior quality of HPO fuels**. These parameters ensure that kinematic viscosity remains within the limits of ISO 8217, preserving mechanical integrity and ensuring clean combustion.

For paraffinic and renewable biofuels, the appearance of **insoluble sediments** represents a critical **challenge**. Preventing clogging of high-precision injection systems is essential, a top priority for ensuring long-term engine reliability.

Finally, the application of HPO as a pilot fuel for methanol opens up **possibilities for decarbonization**. Since methanol is difficult to spontaneously ignite, HPO's high ignition power serves as a sustainable "trigger," overcoming the technical limitations of alcoholic fuels. This technical synergy is the bridge to the objectives of the next phase of the project, which will see the analysis of samples from the **FCC co-processing**. This development will allow us to verify whether integrated refinery processes can eliminate sedimentation phenomena, solidifying HPO as a cornerstone for achieving the emissions reduction targets set for 2040.

Fuel stability assessment

To simulate one year of storage, accelerated aging tests were conducted at 80°C for 14 days (equivalent to 12 weeks at 43°C according to the ASTM D4625 standard). The table below shows the results that emerged.

Table 1. Aging test results

Accelerating Factors	Visual Results	Impact
Accelerated aging tests demonstrated that the viscosity and density of 30% HPO blends remain stable over a simulated storage period of one year, with values staying well within ISO 8217 limits.	While viscosity and density remained stable, microscopy revealed insoluble deposits.	Even if present in small quantities, these sediments could affect engine performance, requiring further research to prevent their formation.

Conclusions

In conclusion, the in-depth analyses conducted on HPO samples confirm that, in purely formal terms, it is possible to obtain a fuel fraction suitable for marine use that fully complies with the parameters established by the ISO 8217 standard. Accelerated aging tests, which simulated a one-year storage period at room temperature, demonstrated high chemical stability of the 30% HPO blends, detecting no critical changes in viscosity and density. Water content and acidity (TAN) also remained within safety limits, despite a slight increase observed in blends containing biodiesel (FAME).

However, stability monitoring revealed a significant technical challenge: the formation of sediments and small insoluble deposits. Since these particles, even in small quantities, could compromise engine performance and clog injection systems, understanding the causes and preventing these deposits remains a top priority for the consortium.

Looking ahead, the next phase of the project will be crucial to consolidating these results. Focus will shift to analyzing samples from the FCC co-processing plant, expected to begin production in the first quarter of 2025. This step will allow us to assess whether integrating refinery processes can mitigate the sedimentation issues encountered, definitively paving the way for the adoption of HPO as a "drop-in" fuel for the existing shipping fleet, a vital requirement to achieve the 2040 decarbonization targets.

This project has received co-funding from the European Union's Horizon Europe Research and Innovation Programme under Grant Agreement N° 101096780.
This factsheet is based on D4.5 – Evaluation of fuel blend related to marine fuel standards on the basis of analytical results of UROS