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D3.2 Summary report on membranes operation

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Abbreviation	Definition
CO ₂	Carbon Dioxide
N ₂	Nitrogen
O ₂	Oxygen
CCM	Carbon Capture Machine
HF	Hollow Fibre
PAA	Polyacrylic Acid
STP	Standard Temperature and Pressure
TEA	Techno-Economic Assessment
TEE	Thermoelectric Element

EXECUTIVE SUMMARY

This deliverable reports the work carried out under various project tasks related to membranes for CO₂ capture with focus on Task 3.2 (Tailor CO₂ and water capture membranes) and the membrane-related activities of Subtask 2.2.2 (Carbon Capture) within the Green Marine project. The content integrates results from the first and second reporting periods (RP1 and RP2) and focuses on membrane development, module fabrication, upscaling, pilot design, commissioning, and validation using marine diesel exhaust gas.

During RP1, flat-sheet and hollow-fibre polymeric membranes for CO₂ separation were developed and characterized at laboratory scale. Both surface-modified flat-sheet membranes based on amine-grafted polymers and enzyme-modified hollow-fibre (HF) membranes developed using commercial porous supports coated with a CO₂-selective enzyme layer were optimized to achieve high CO₂/N₂ selectivity at conditions representative of marine exhaust gas. Gas permeation experiments were performed at laboratory level with membrane area between 20 and 500 cm² using mimic diesel exhaust gas as feed under varying feed compositions, temperatures, and pressures to quantify membrane permeance and selectivity and to provide input data for subsequent process modelling.

Based on laboratory results, membrane development progressed in RP2 towards pilot-scale implementation. Membrane preparation protocols were scaled up from bench-scale samples to pilot-scale modules with membrane areas up to several square meters: from 20 cm² at lab scale to 2 m² membrane area, pilot scale, a 1000x factor scale-up. A decision was taken to continue primarily the upscaling using HF geometry due to availability of commercial, large area, pilot size non-CO₂ selective hollow fibre modules.

A mobile, compact, real time remote controllable membrane pilot unit was designed and constructed by SINTEF to enable land-based testing with real diesel exhaust gas. The pilot was engineered to operate under marine-relevant conditions and to allow integration of pre-treatment technologies, exhaust gas conditioning, water condensation, and vacuum operation, able to handle 150 m³/h flow rate diesel exhaust and cool down flue gas from 400°C to 20° C. This compact mobile pilot unit (Length 1200 x Width 840 x Height 2200 mm) is unique, whereas previous membrane pilot units where the size of half a 40 ft ship container. The sizing was in accordance with the end user requirements to ensure integration into the engine room of the CalMac ship.

Land based testing of the membrane pilot was conducted in Limassol, Cyprus, using exhaust gas from a marine diesel genset. Under the operating conditions achieved, the membrane system demonstrated CO₂ enrichment from approximately 5.5–6.5% in the feed gas to values up to approximately 19% in the permeate stream. This was very close to the maximum achievable (21% CO₂) under the operating process conditions, corresponding to a CO₂ enrichment factor of approximately three to four.

The testing campaign also faced operational limitations related to short engine operating time, sensors failure during operation, and overall capture process. These limitations provided valuable input for further optimisation of membrane modules, pilot operation, and test procedures in the future. Overall, the results confirm the technical feasibility of membrane-based CO₂ capture from marine diesel exhaust at pilot scale and support further development towards extended land-based testing and future onboard demonstration within the Green Marine project. For water capture, insufficient operation time could not capture sufficient water to be assessed.