

Modular Carbon Capture, Storage and Offtake in the Maritime Shipping Industry

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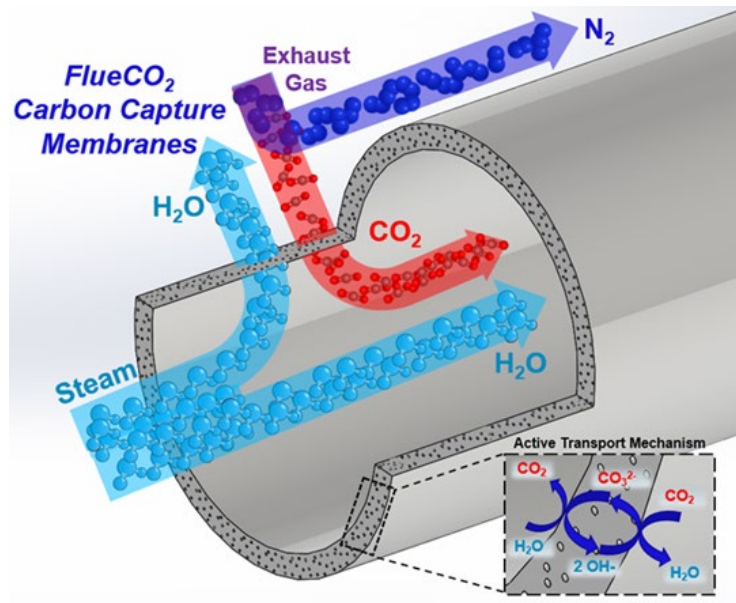
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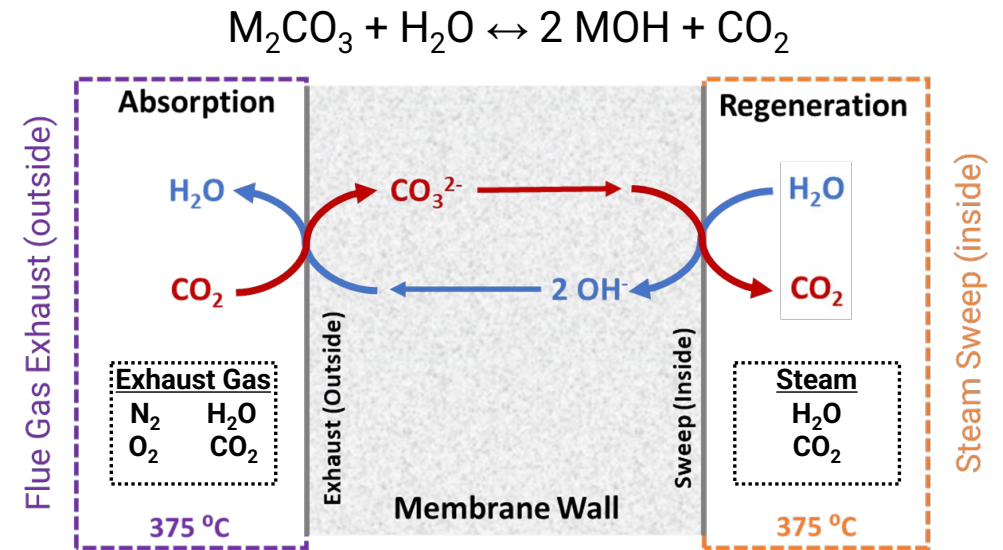
Technology Overview

FlueCO₂ Membrane

- Liquid Phase: molten carbonate (CO_3^{2-}) + molten hydroxide (OH^-)
- Solid Phase: porous ceramic, mechanical support and liquid retention
- Operation: Application of a low pressure (LP) steam sweep drives separation



Completely inorganic membrane enables stable operation between 250 °C and 550 °C

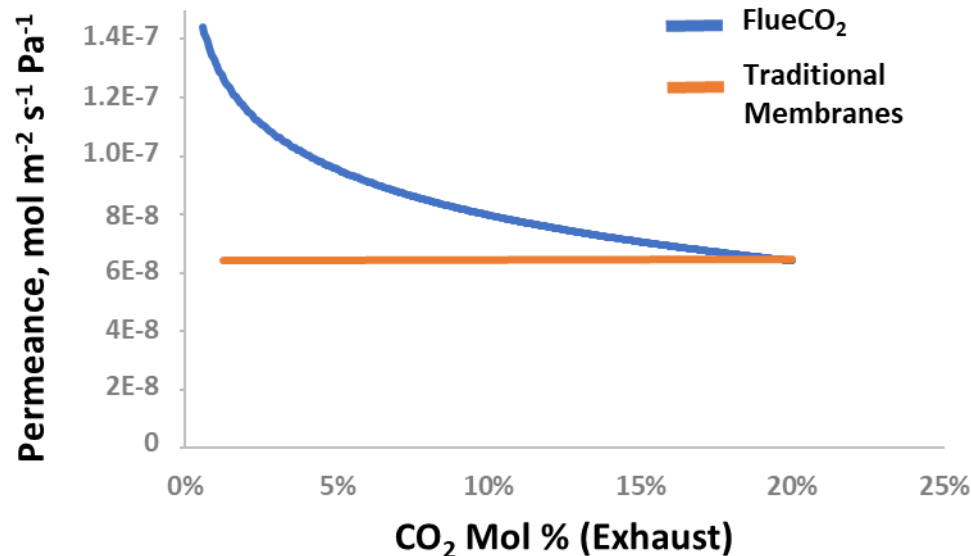


Continuous absorption and regeneration on each side of the membrane (~isothermal)

Technology Advantages

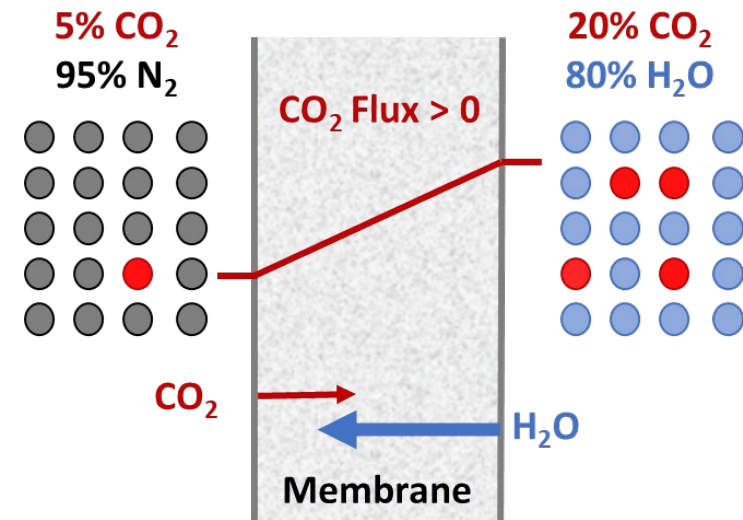
High Performance at Low CO₂ Concentrations

- Membranes typically show a stable permeance at low CO₂ concentrations
- FlueCO₂ permeance increases as the concentration of CO₂ decreases



Uphill Transport Capabilities

- Flux through a traditional membrane slows down as the sweep gas CO₂ concentration increases
- FlueCO₂ continues to transport CO₂ uphill to drastically reduce the steam sweep requirements

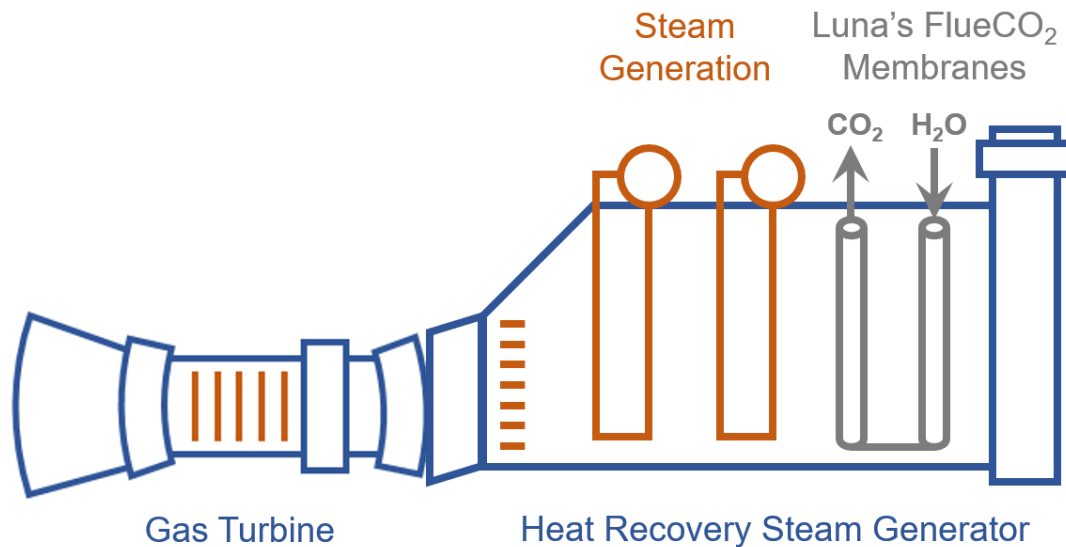


$$\text{CO}_2 \text{ Flux} > 0 \text{ if } \left(\frac{p_{\text{CO}_2^{\text{feed}}}}{p_{\text{CO}_2^{\text{sweep}}}} \right) > \left(\frac{p_{\text{H}_2\text{O}^{\text{feed}}}}{p_{\text{H}_2\text{O}^{\text{sweep}}}} \right)$$

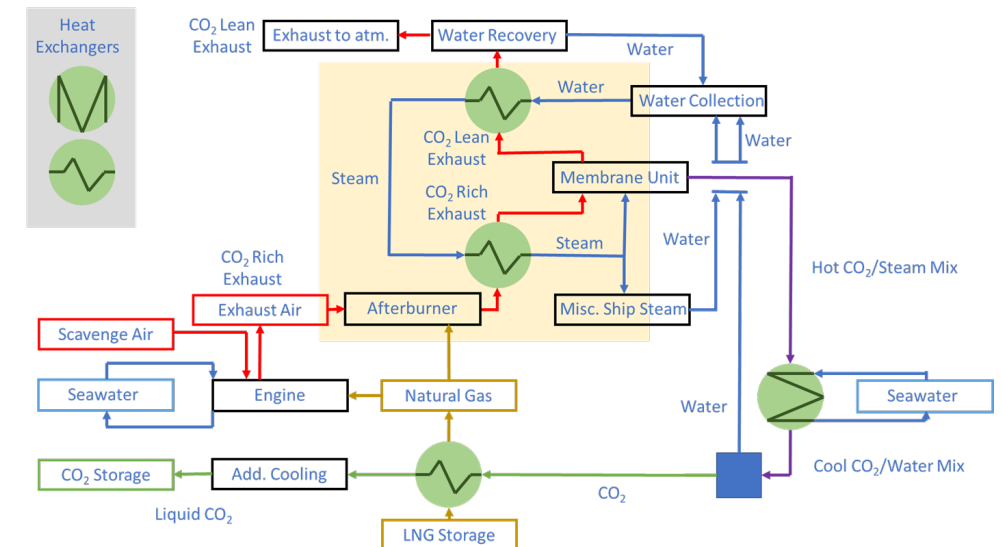
Maritime Carbon Capture

Integration

- FlueCO2 was developed for NGCCs, with integration directly in the heat recovery steam generator (HRSG)
- Phase I will evaluate application on ultra-large container ships burning heavy fuel oil (HFO)



*Membranes integrate directly into the NGCC HRSG
(hot exhaust gas path)*



Similar integration with reciprocating engine hot exhaust. LNG carrier example shown above.

Phase I Approach

Objectives

- Develop a detailed maritime FlueCO₂ process model for an ultra-large container reference ship
- Evaluate SO_x impact and water recovery concepts
- Optimize the CO₂ liquefaction, storage, and offtake process
- Determine the economic competitiveness
- Complete the New Technology Qualification (NTQ)
 - Completed for LNG carriers
 - Ongoing NTQ for Naval Surface Combatants

Future Efforts

- Demonstrate membrane stability during accelerated lifetime testing in the presence of high NO_x/SO_x
- Pilot testing under representative conditions
- Develop mass transfer models to optimize membrane sizing, reduce CAPEX, and demonstrate capture costs of <\$75/tonne