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

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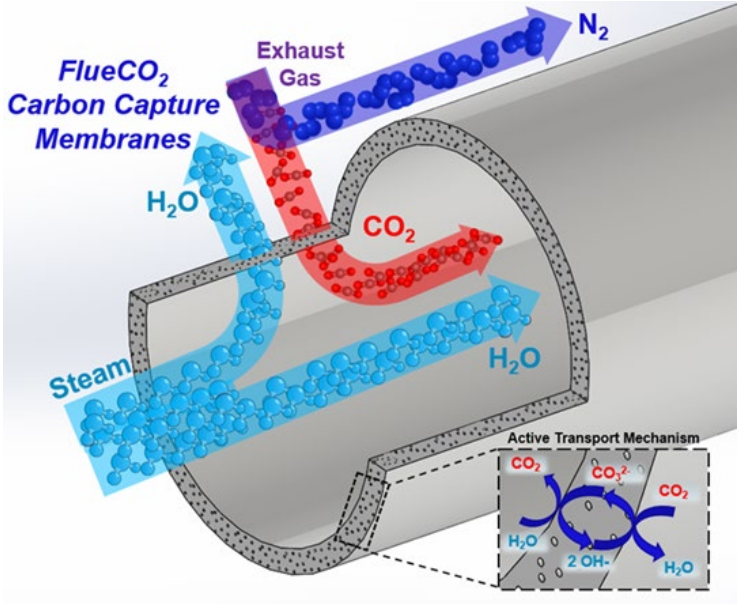
Technology Overview

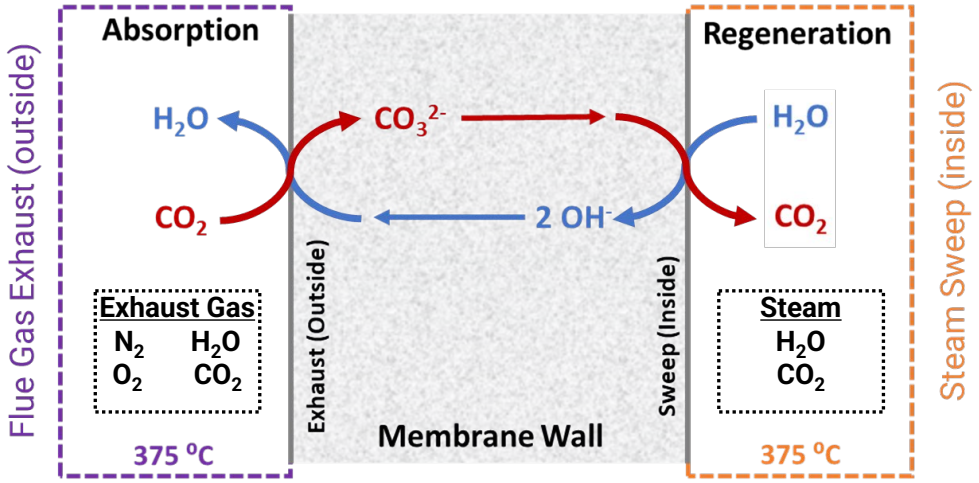
FlueCO$_2$ Membrane

- 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

$$M_2CO_3 + H_2O \leftrightarrow 2\ MOH + CO_2$$

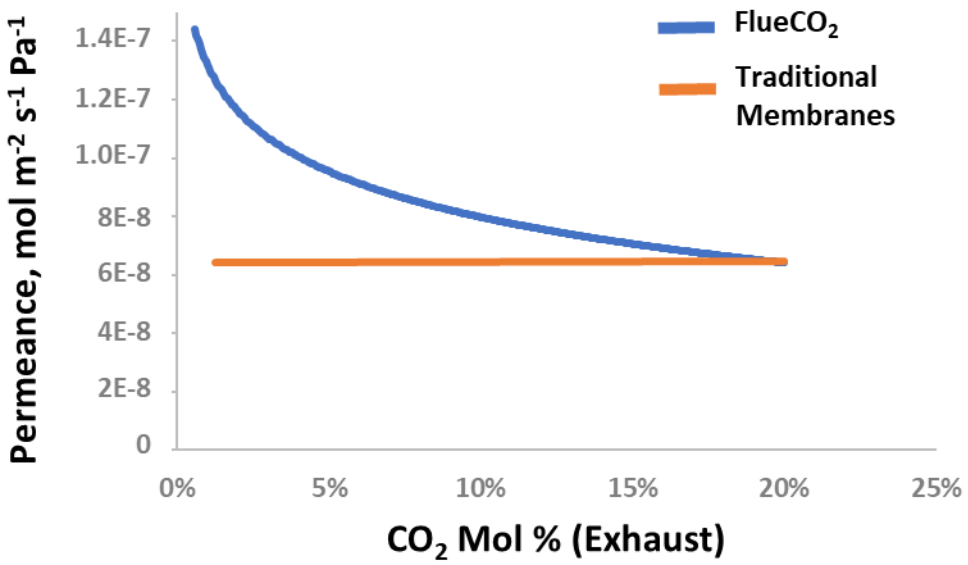


Continuous absorption and regeneration on each side of the membrane (~isothermal)

Technology Advantages

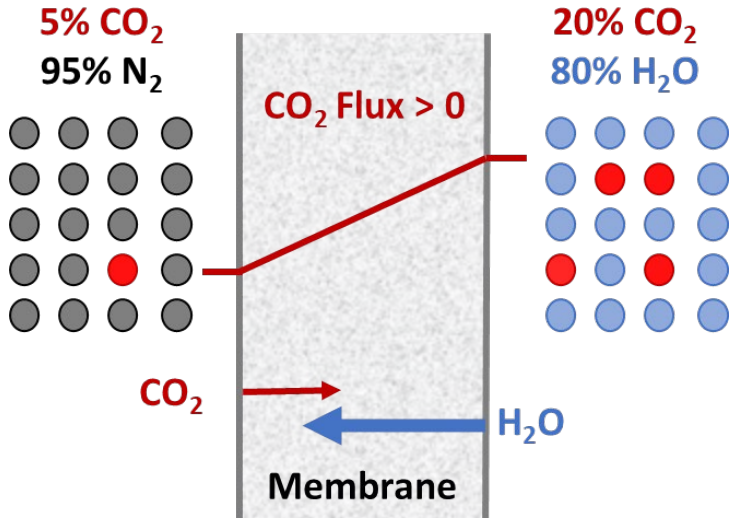
High Performance at Low CO_2 Concentrations

- Membranes typically show a stable permeance at low CO_2 concentrations
- FlueCO_2 permeance increases as the concentration of CO_2 decreases



Uphill Transport Capabilities

- Flux through a traditional membrane slows down as the sweep gas CO_2 concentration increases
- FlueCO_2 continues to transport CO_2 uphill to drastically reduce the steam sweep requirements

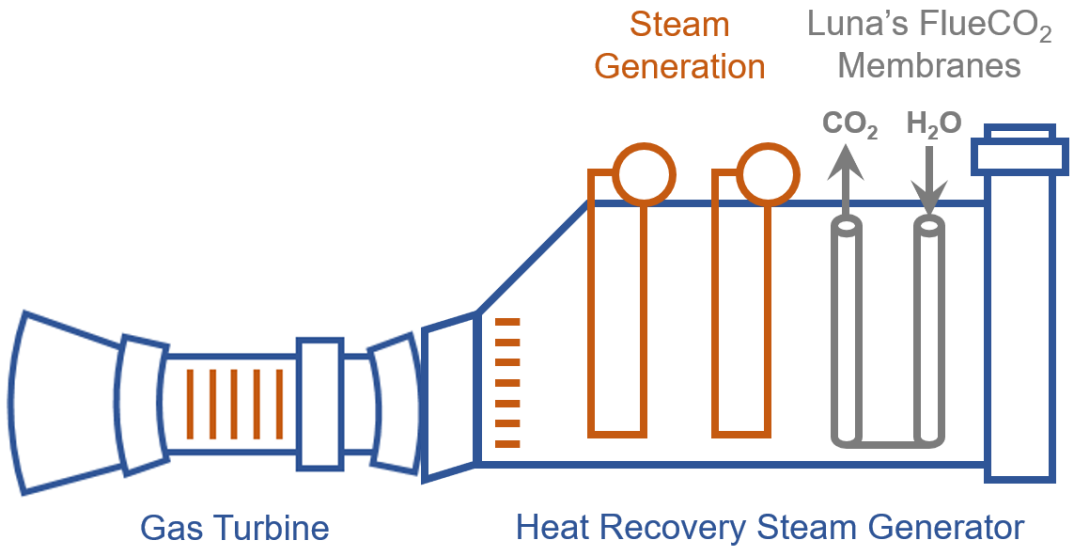


$$CO_2 \text{ Flux} > 0 \text{ if } \left(\frac{p_{CO_2}^{feed}}{p_{CO_2}^{sweep}}\right) > \left(\frac{p_{H_2O}^{feed}}{p_{H_2O}^{sweep}}\right)$$

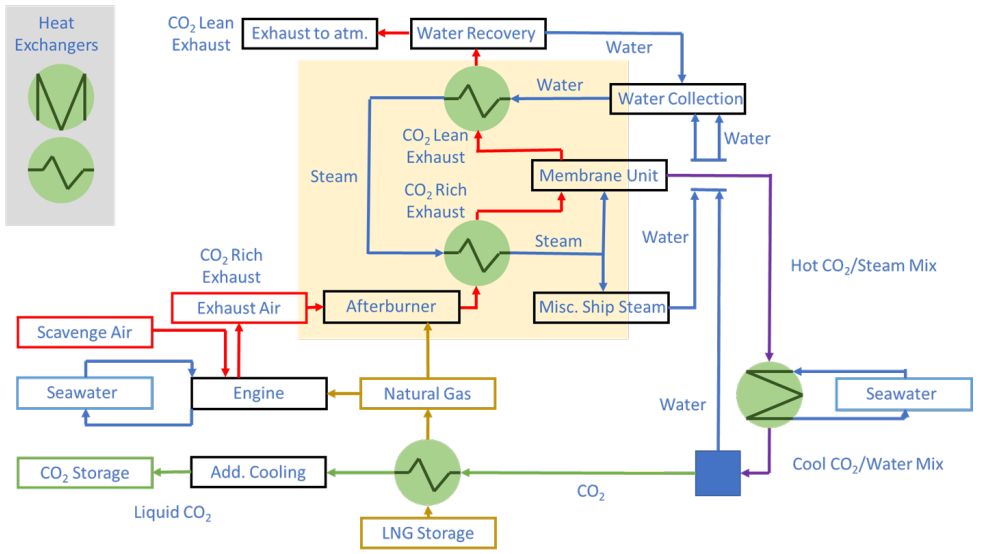
Maritime Carbon Capture

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 FlueCO_2 process model for an ultra-large container reference ship
- Evaluate SO_X impact and water recovery concepts
- Optimize the CO_2 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