Molten Carbonate Fuel Cell based Power and Propulsion System with integrated carbon capture

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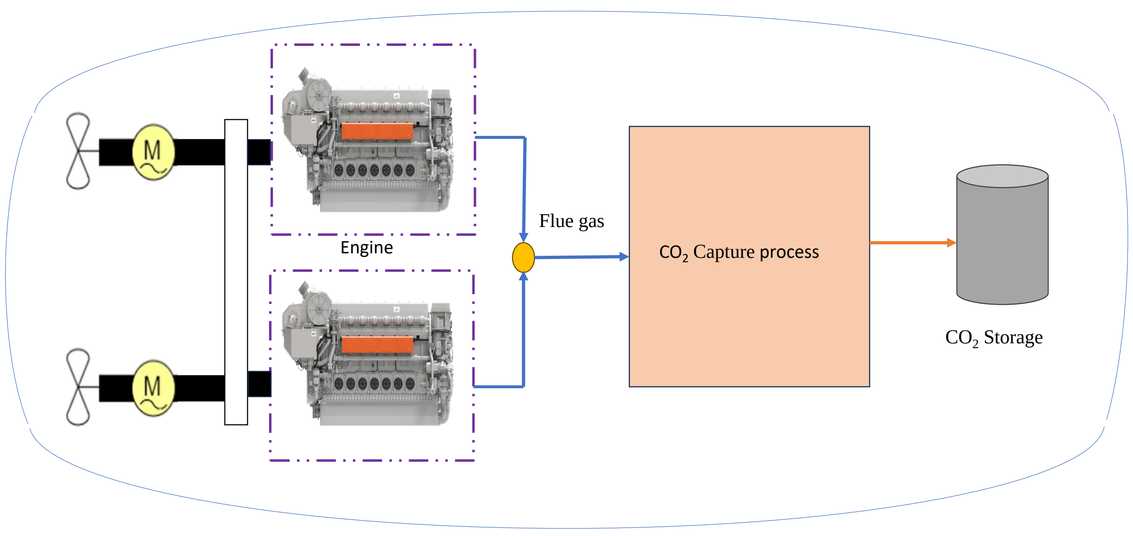
Background

The 2023 IMO GHG Strategy targets a 40% reduction in CO_2 emissions by 2030, aligning with the Paris Agreement's 2°C limit [1]. The IMO outlines two key strategies to cut shipping GHG emissions: a) adopting low- and zero-carbon fuels like methanol, ammonia, biofuel, and hydrogen, despite regulatory, safety, cost, and supply challenges; and b) implementing new technologies and operational strategies. One promising technology is the molten carbonate fuel cell (MCFC), which operates at high temperatures to generate additional electricity while concentrating CO_2-rich mixtures at the anode outlet. These capabilities make MCFCs well-suited for integration with onboard internal combustion engines (ICE) and carbon capture systems (CCS) on carrier vessels.

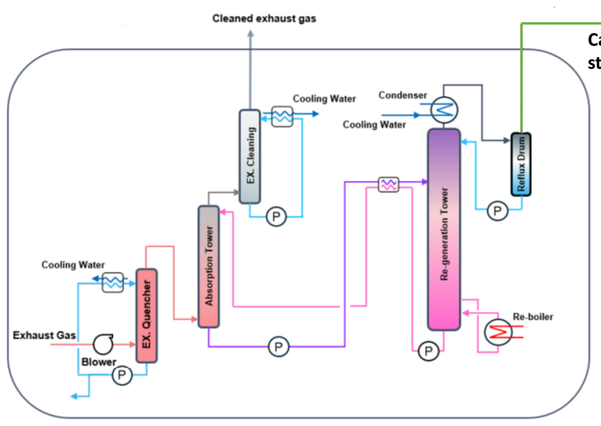
Aim and objectives

- Conceptualisation of a novel energy system integrated with a methanol fuelled internal combustion engine (ICE), molten carbonate fuel cell (MCFC), organic Rankine cycle (ORC) and CCS sub-components.
- Designing of MCFC based CO_2 capture unit for different ship size.
- To perform thermodynamic analysis of the integrated energy system.
- To perform economic analysis to estimate the levelised cost of energy.
- Comparison with traditional amine-based CO_2 capture systems.

Concept of onboard CO_2 capture process

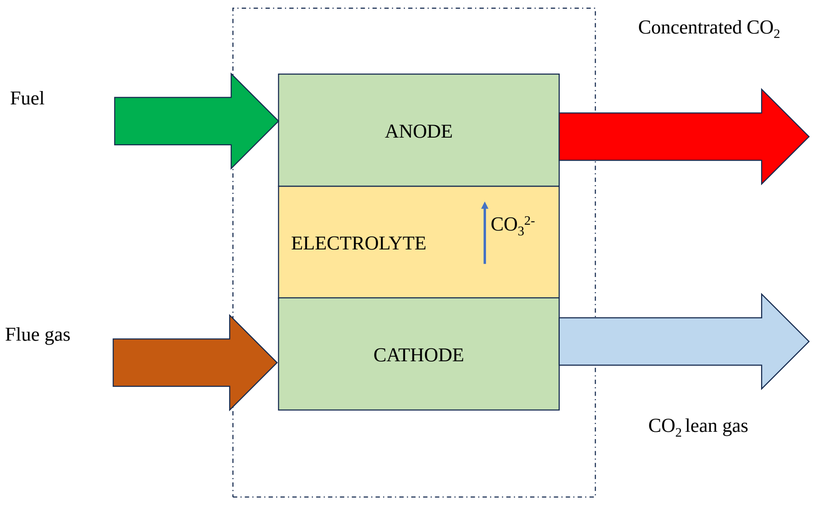


Amine based CO_2 capture process



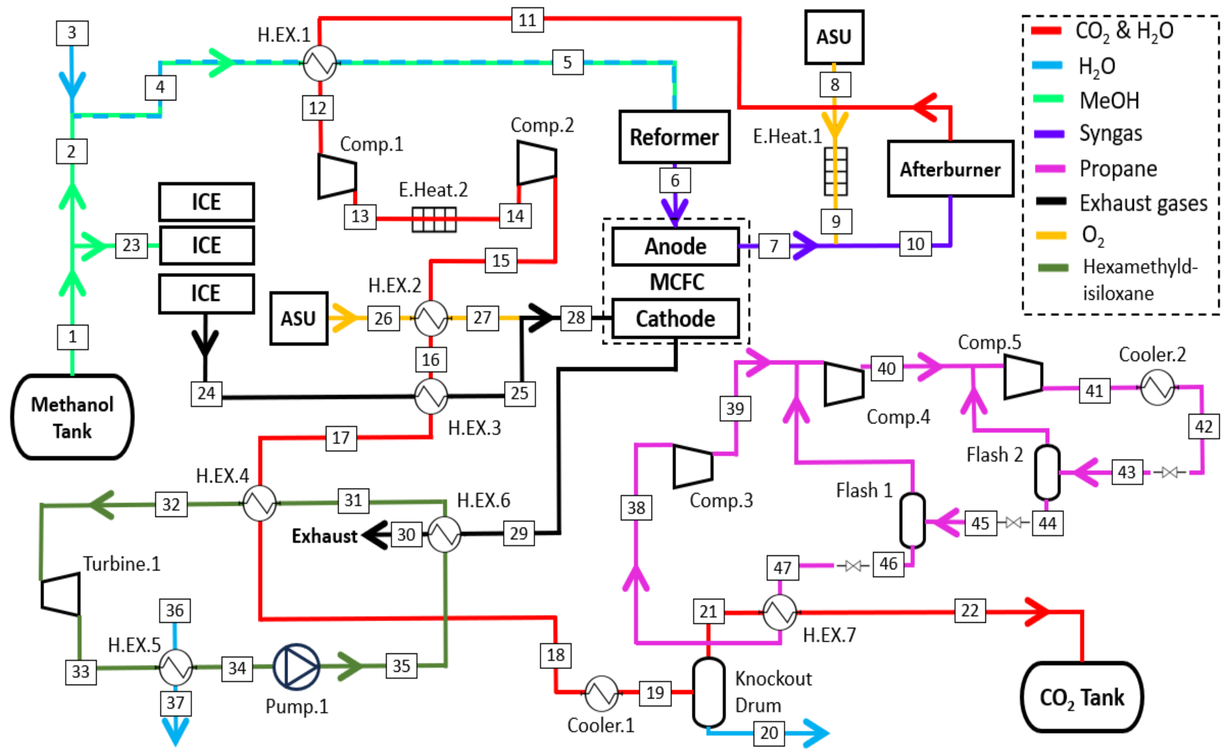
This method captures CO_2 from the ship's exhaust gas after combustion. Amine scrubbing is a popular method that utilises chemical solvents (amines) to react with and separate CO_2. The captured CO_2 is then desorbed for onboard storage.

MCFC based CO_2 capture process

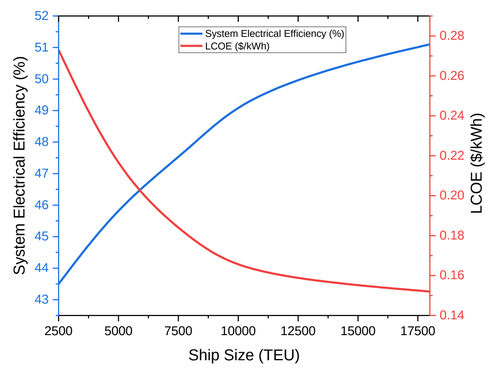


MCFC serves as a CO_2 concentrator, concentrating CO_2-rich flue gas from the engine exhausted.

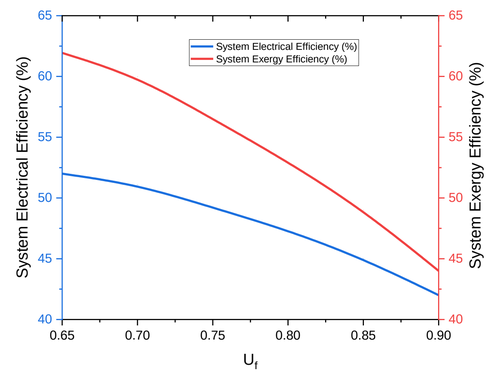
Proposed system configuration



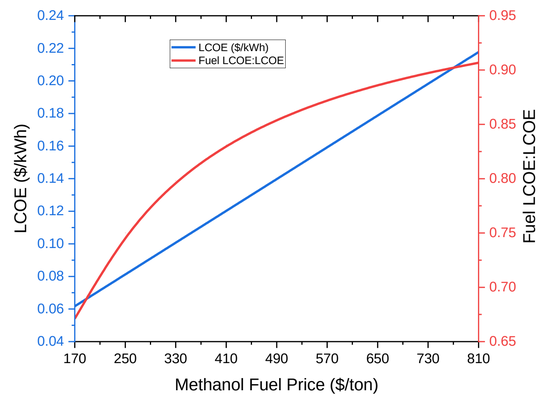
Results and summary



Effect of ship TEU number on electrical efficiency and LCOE of the system



Effect of U_f on electrical efficiency and exergy efficiency of the system



LCOE and Fuel LCOE : LCOE as a function of methanol fuel price

- The integrated ICE- MCFC-ORC system yields electrical and exergy efficiencies of 49% and year ; respectively.
- Integration of the MCFC and CCS system can capture 93.2% of CO_2 from the engine exhaust, however, their incorporation decreases the system's electrical efficiency by 8.4%.
- The economic analysis revealed a minimum levelised cost of energy (LCOE) of 0.16 $/kWh and it is comparable with traditional amine-based CO_2 capture system.
- The freight reduction cost is $11.55 million per year; however, this is offset by the additional revenue of $12.35 million generated from selling the captured CO_2 and carbon credits.
- For a singular retrofit onboard a 10,000 TEU container vessel, $46.4 million is required for the initial CAPEX investment. The MCFC accounts for 49% of this initial investment which may pose as a barrier for financing the retrofit.

Acknowledgement

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References:

[1] IMO. 2023 IMO Strategy on Reduction of GHG Emissions from Ships (2023).

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