Compact and high throughput modular unit for carbon capture on ships

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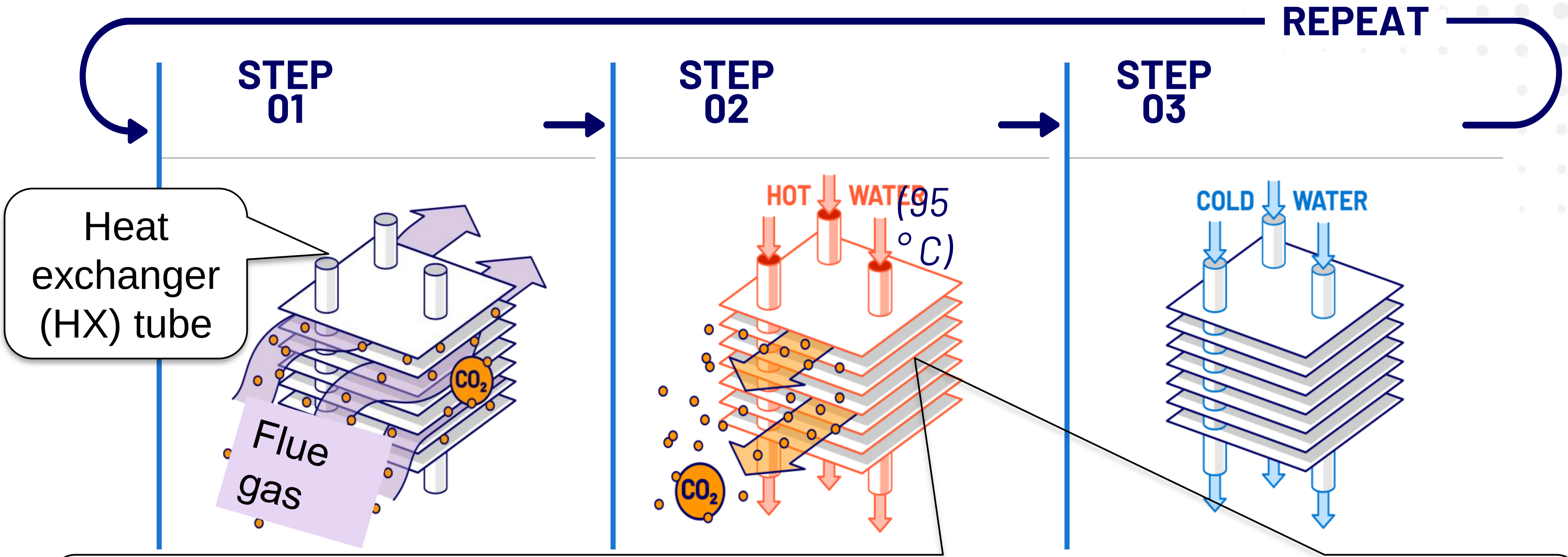
The phase I objective

Develop basic process design and conduct feasibility study of the adsorption and heat exchange (AHX) capture unit for CO_2 capture on ships at flue gas exhaust rate of 700 kg/min with two CO_2 disposal methods:

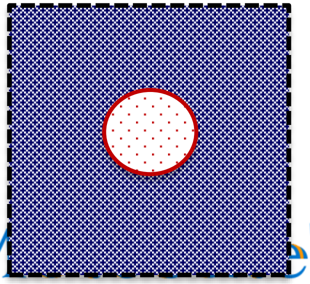
- Onboard storage of liquified CO_2
- Onboard electrochemical conversion of CO_2 back to oxygenated fuels with onboard electricity.

Molecule Works' proprietary adsorption and heat exchange (AHX) contactor for low-cost CO_2 capture



Adsorption and heat exchange (AHX) plate of **high adsorbent loading (g/cm^2) and high thermal conductivity**

Scaleup by increasing number of unit AHX cells in 3 dimensions



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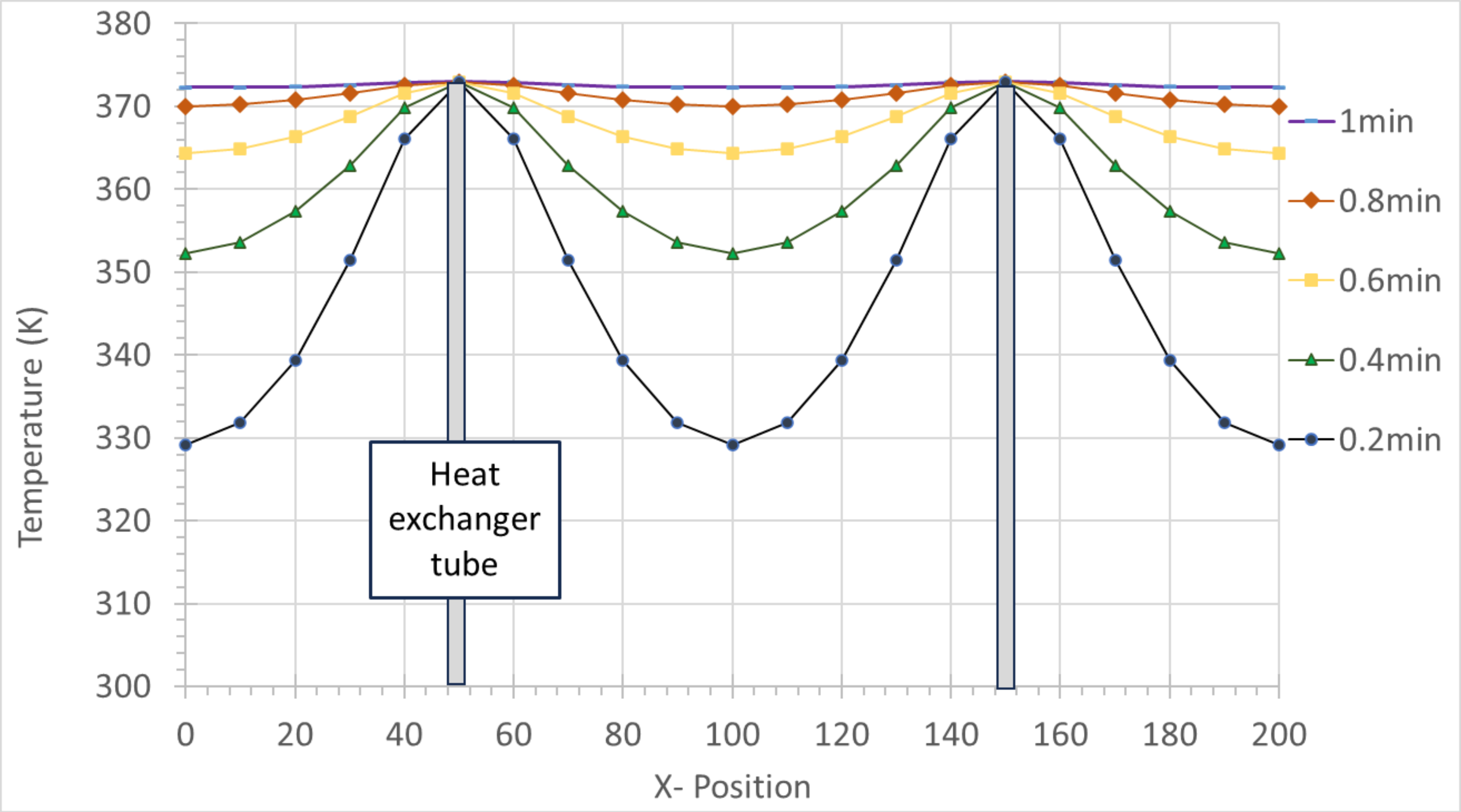
Rapid heating of the AHX plate from 293 to 373K by hot thermal fluid in the heat exchange tube



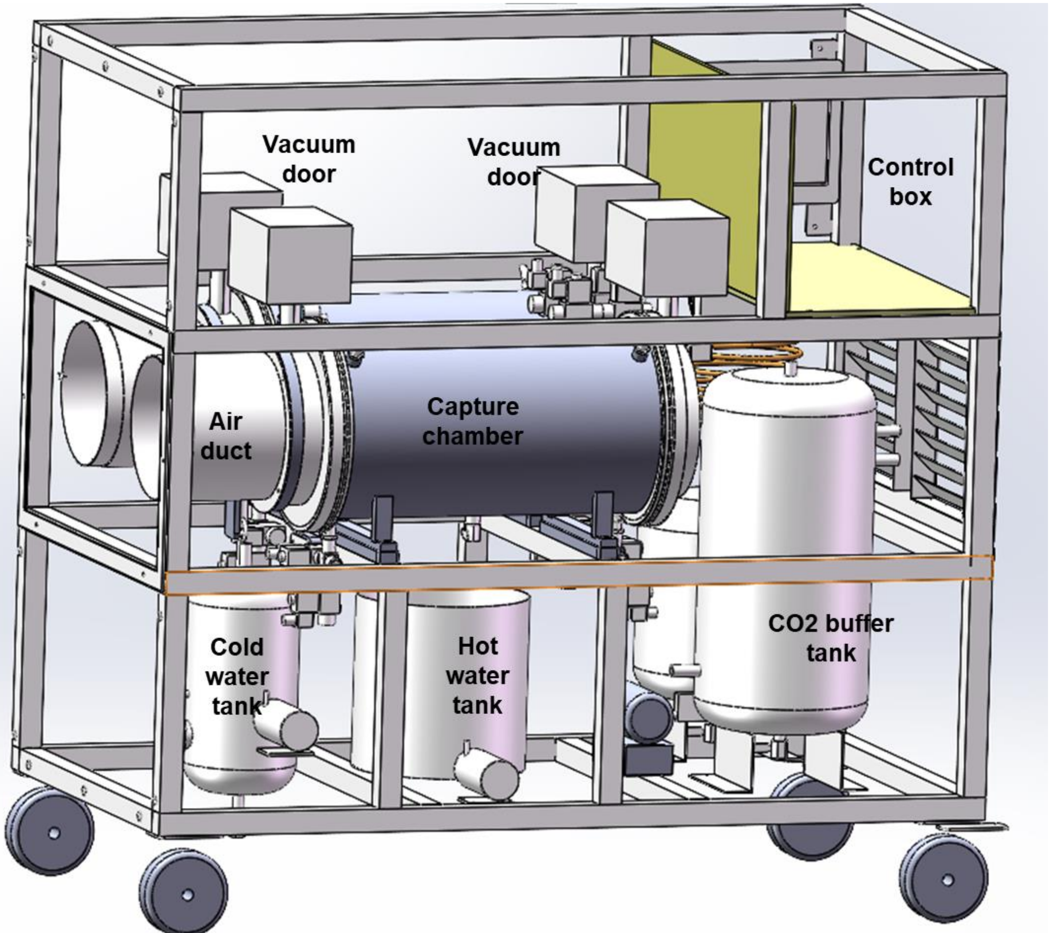
Molecule Works' prototype units employing AHX contactor

Single-vessel unit for screening of adsorbent performances (capacity, stability) and design parameters

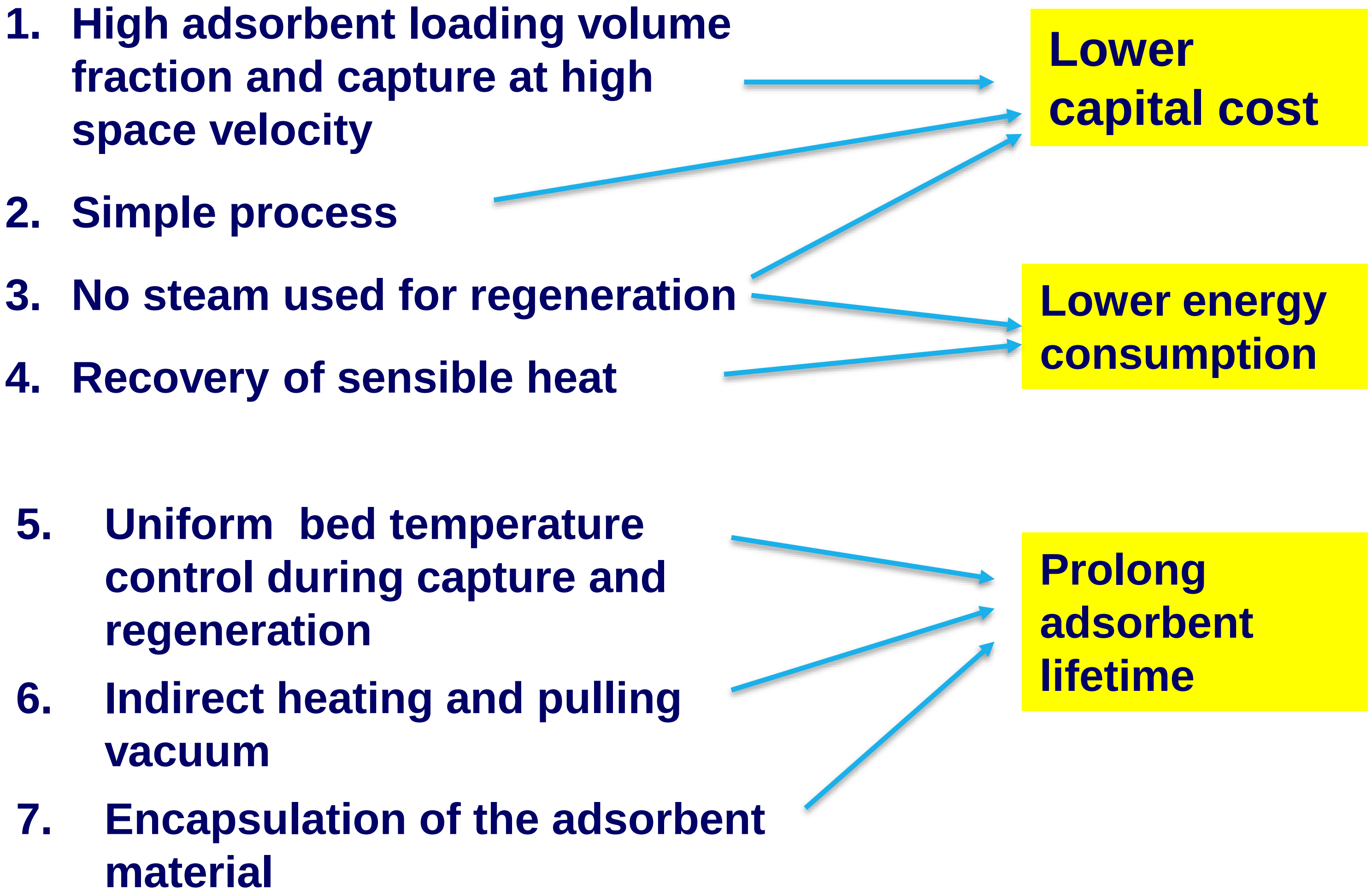
~3 m^2 gas/solid mass transfer area

Two-vessel prototype unit to simulate scaleup capture processes

~8 m^2gas/solid mass transfer area /vessel



Performance features of the AHX contactor addressing capital cost, energy consumption, adsorbent lifetime issues



1. **High adsorbent loading volume fraction and capture at high space velocity**
2. **Simple process**
3. **No steam used for regeneration**
4. **Recovery of sensible heat**

Lower capital cost

Lower energy consumption

5. **Uniform bed temperature control during capture and regeneration**
6. **Indirect heating and pulling vacuum**
7. **Encapsulation of the adsorbent material**

Prolong adsorbent lifetime

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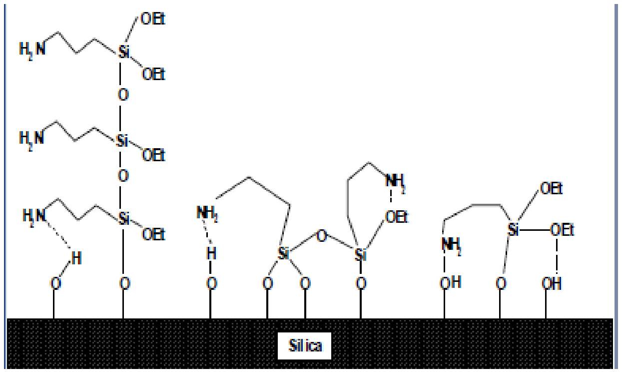
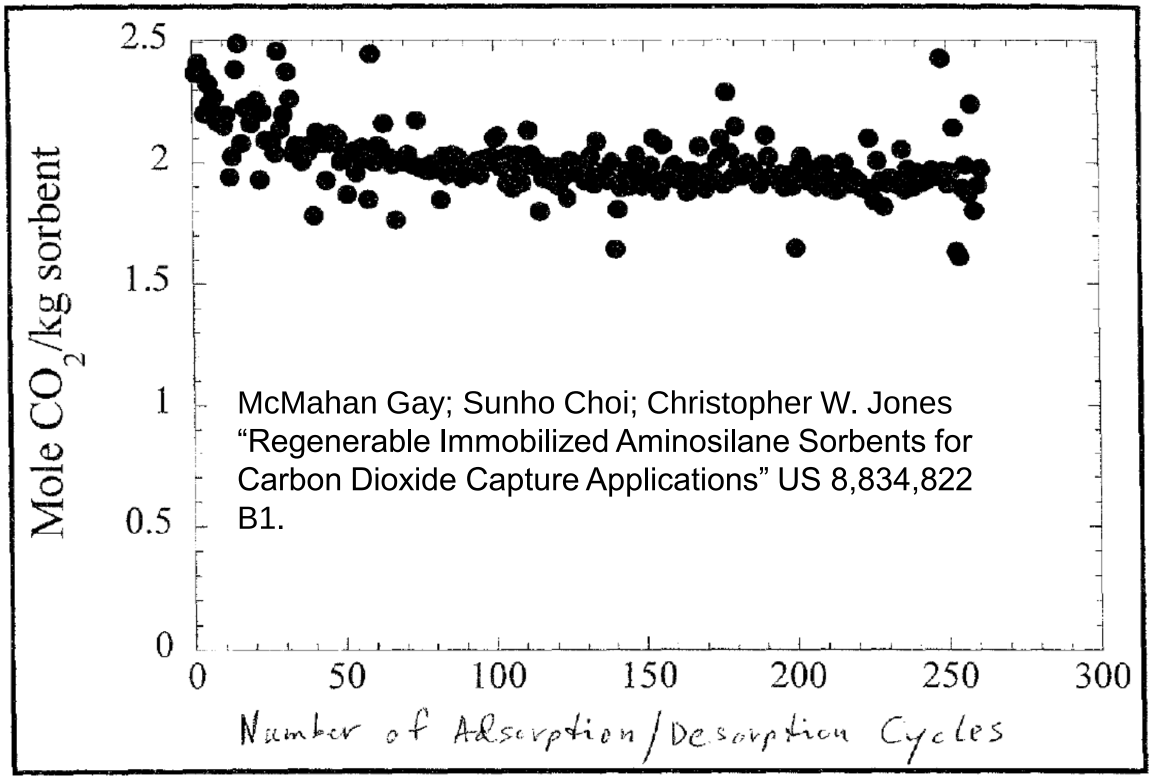
Candidate adsorbent material: stabilized solid amine

The adsorption chemistry invented by Dr. McMahan Gray's team at NETL

- Excellent working capacity and CO2 selectivity over a broad range of humidity and CO2 concentration were confirmed through repeated tests at MWI.
- Stability shown cyclic tests by Gray's team: CO_2 capture capacity stabilized after about 250 cycles of capture/regeneration cycles, (60°C, 8% RH)/ (90% RH, 105°C).





McMahan Gay; Sunho Choi; Christopher W. Jones "Regenerable Immobilized Aminosilane Sorbents for Carbon Dioxide Capture Applications" US 8,834,822 B1.

Adsorption breakthrough simulation of the AHX contactor

Simplified one-dimensional model for variation of CO_2 concentration in gas channel along the reactor length (z):

$$-\frac{\partial C_{i,g}}{\partial t} = V_g \cdot \frac{\partial C_{i,g}}{\partial z} + \boldsymbol{SA_v} \cdot \boldsymbol{h_{gs}} \cdot \left(C_{i,g} - C_{i,s}\right)$$

Variation of CO_2 concentration in the AHX plate (solid phase):

$$\frac{\partial \omega_{i,s}}{\partial t} = \frac{1}{\boldsymbol{l_s}} \cdot \boldsymbol{h_{gs}} \cdot (C_{i,g} - C_{i,s})$$

$$\frac{w_{i,s}}{w_{max}} = \frac{K_i \cdot p_{i,s}}{1 + K_i \cdot p_{i,s}} = \frac{K_i \cdot C_{i,s} \cdot RT}{1 + K_i \cdot C_{i,s} \cdot RT}$$

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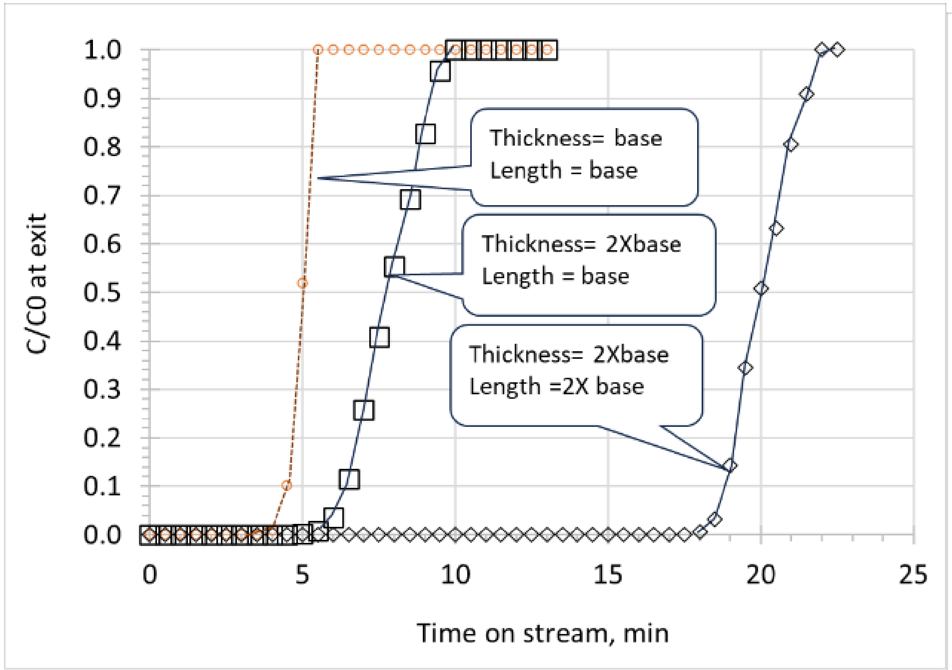
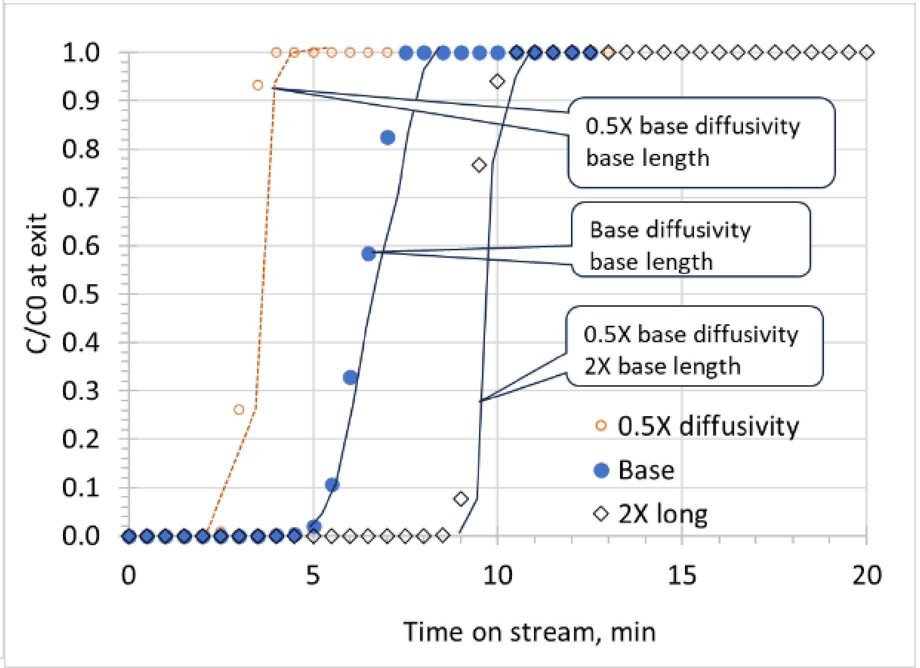
Impacts of the AHX design parameters on CO_2 adsorption breakthrough curve

(a) Impact of AHX plate thickness



- Adsorption capacity of the reactor can be increased proportionally by increasing both plate thickness and reactor length

(b). Impact of CO_2 diffusivity and reactor length.



- Adsorption capacity of the reactor can be decreased by lowering CO_2 diffusivity in the plate
- The decrease can be mitigated by increasing reactor length

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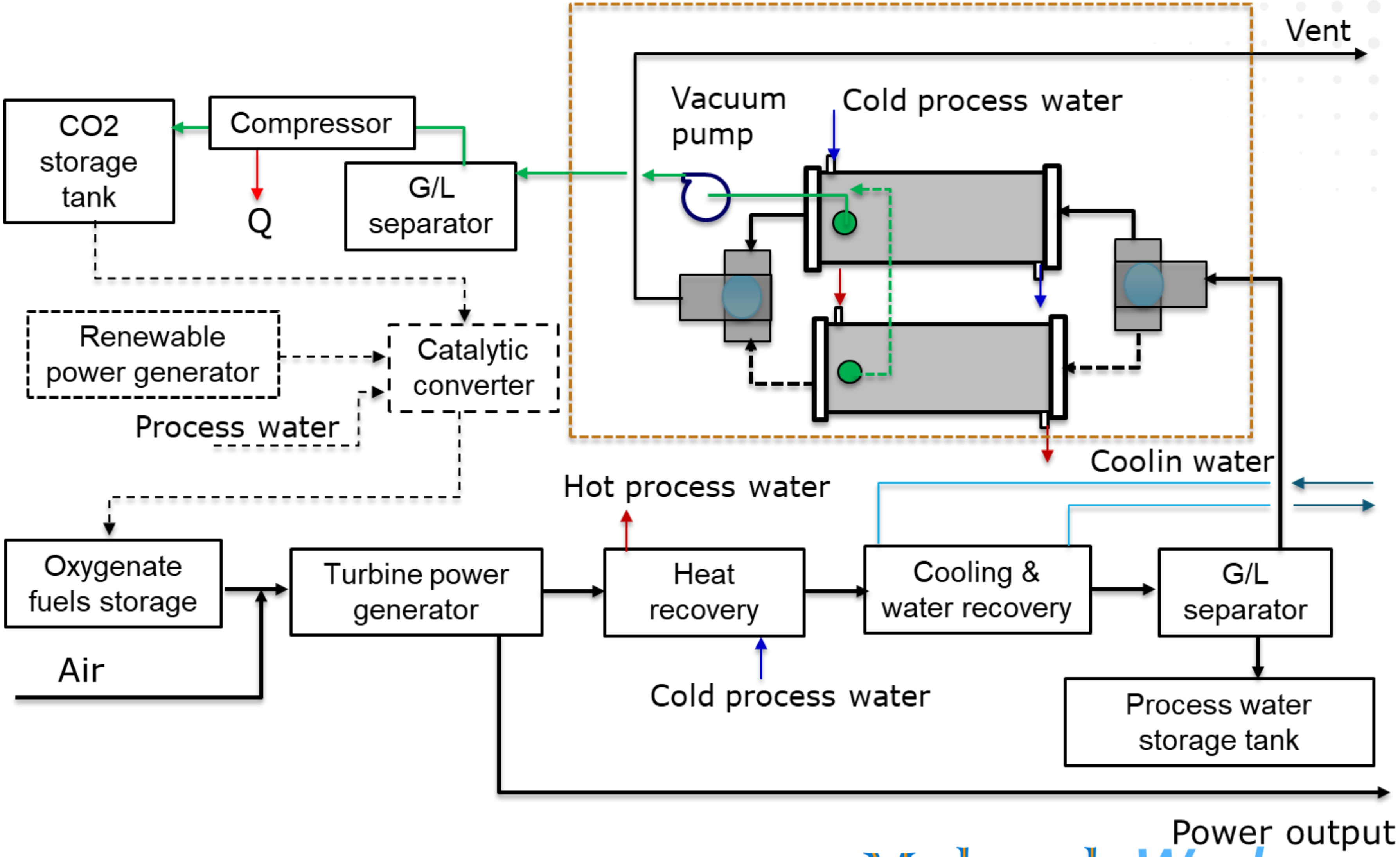
Process flow diagram proposed for reduction of CO_2 emissions on ships



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Expected outcomes of phase I work

- Overall material and energy balances
- Specifications and cost of major pieces of equipment
- Process designs and performance targets of the capture and/or conversion units to make the onboard capture process be a new potential opportunity for commercialization pursuit.

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