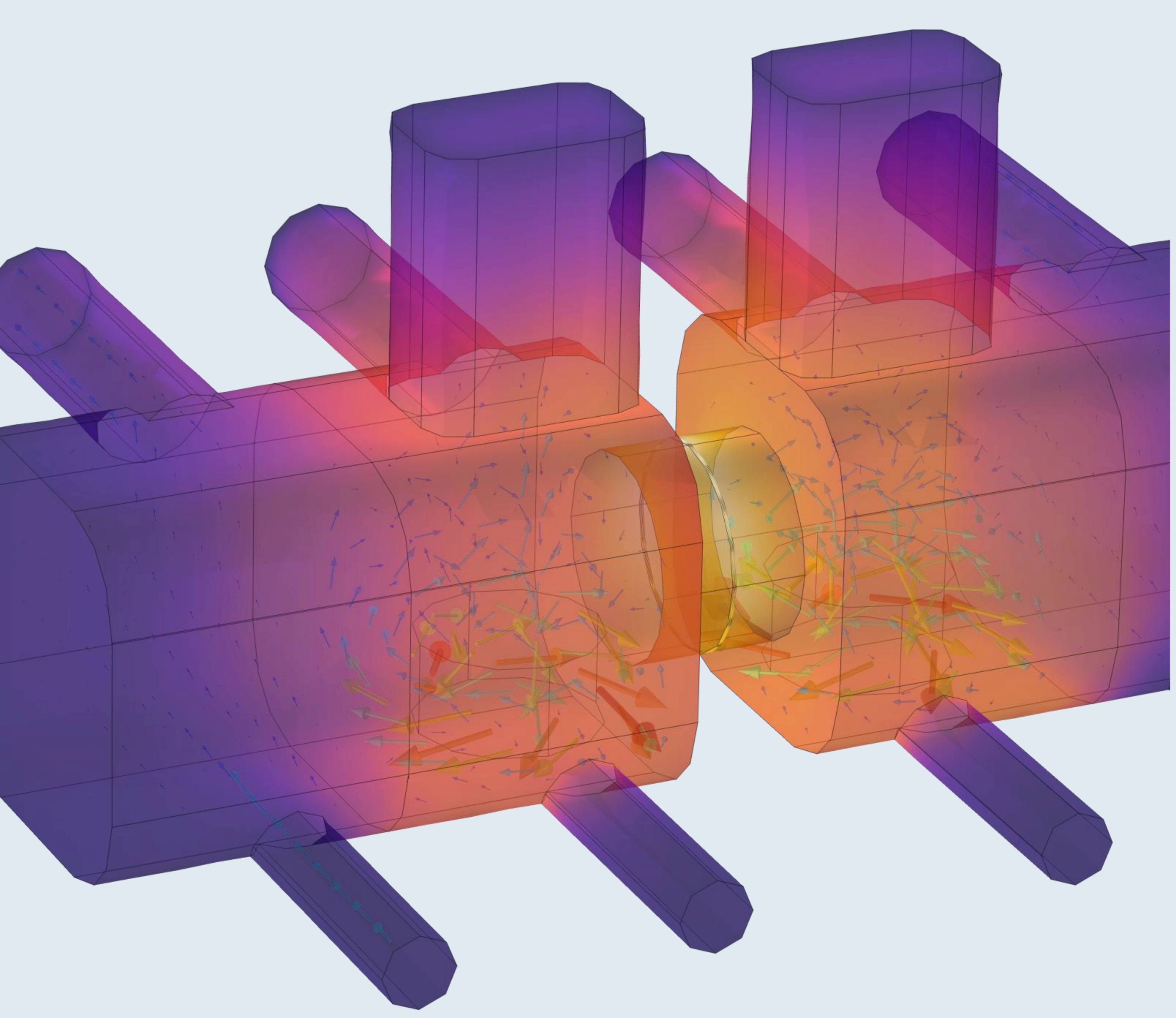

Development of a CO2 Direct Ocean Capture System Using Bipolar Membrane Electrodialysis

This work investigates the acid and base generation mechanism, efficiency and durability of bipolar membrane electrodialysis and its application in CO_2 direct ocean capture using pH swing. The system provides an efficient and cost-effective solution to reduce CO_2 level and ocean acidification.

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Introduction & Goals

Based on the pH-swing of the dissolved inorganic carbon species, a CO2 direct ocean capture system exploiting bipolar membrane (BPM) electrodialysis was designed. Models using CFD and tertiary current distribution are developed focusing on optimizing the cell structure to improve faradaic efficiency for acid and base generation and prevent over-heating for better durability even when operating at high current density. The environmental impact and CO_2 drawdown ability is also investigated with a mesoscale CFD and mass transport model on an ocean level.

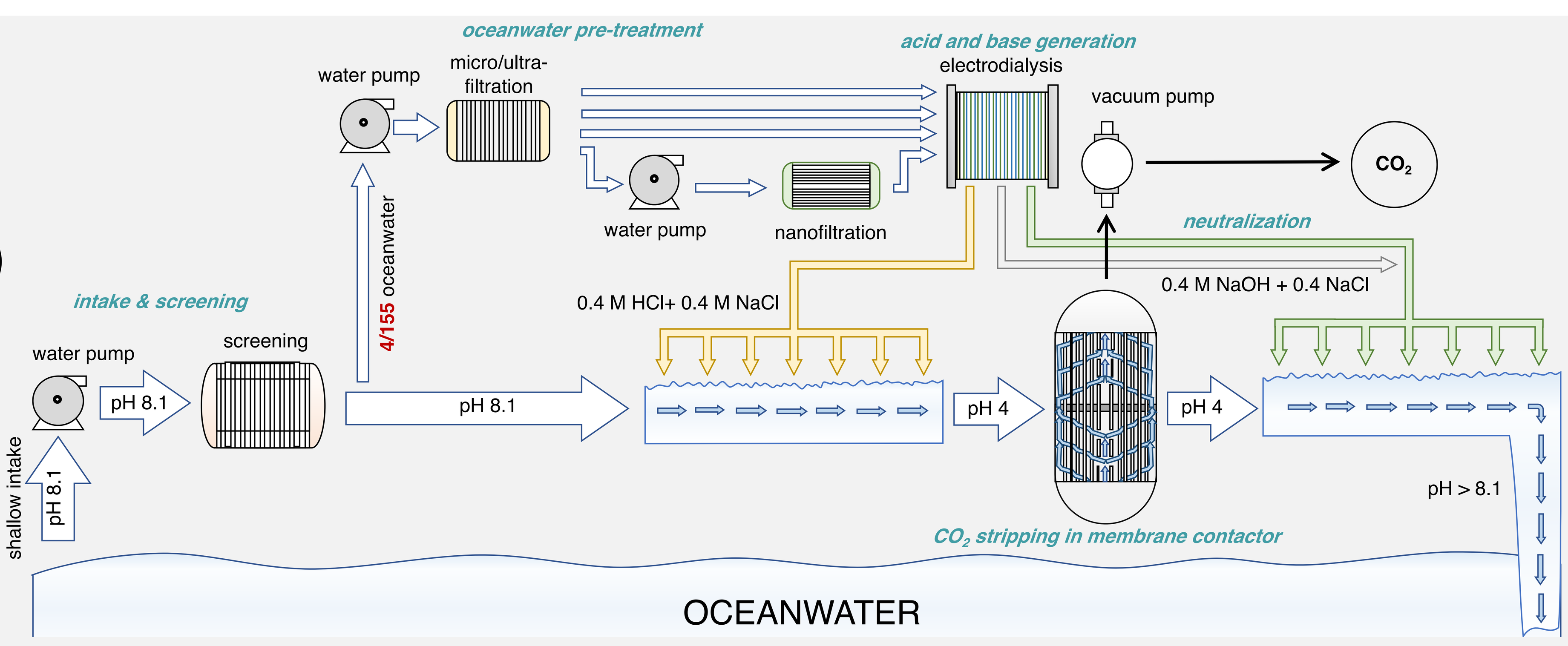
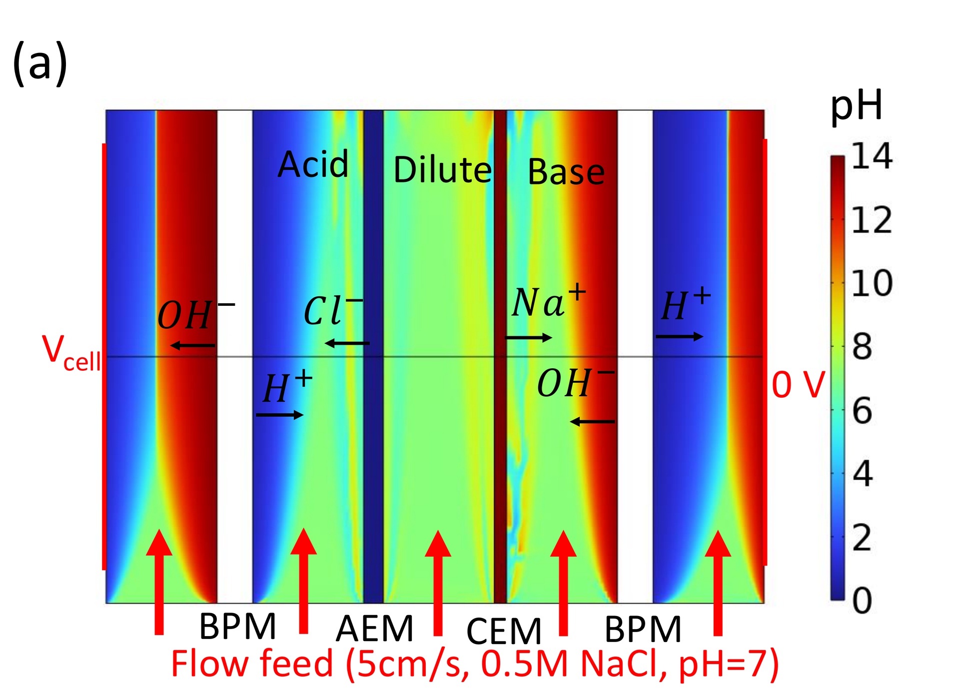


Figure 1. General schematic of the direct ocean capture CO2 removal system



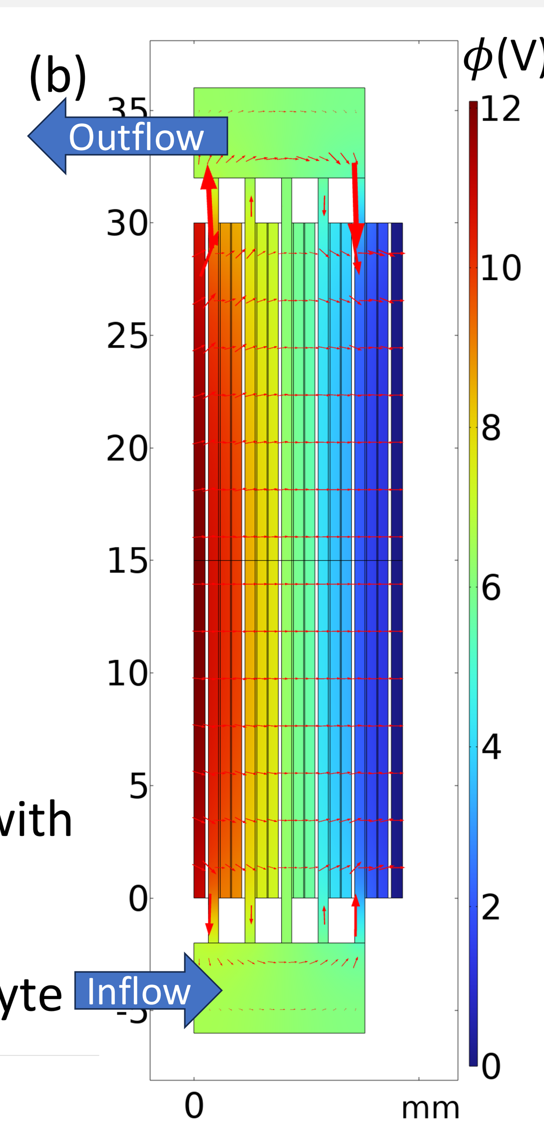


Figure 2. (a) 2D simulation for BPM-AEM-CEM stack cell generating acid and base with an applied potential. (b) Parasitic shunt current inside the manifold of a parallel multi-stack cell setup (Colormap: electrolyte potential. Arrows: current density vector)

Bipolar Membrane Electrodialysis

A BPM electrodialysis stack cell is modeled in 2D using the CFD and tertiary current distribution module. The selectivity of the anion exchange membrane (AEM) and cation exchange membrane (CEM) are simulated through a Donnan boundary condition at the membrane surface:

$$\phi_l - \phi_m = -\frac{RT}{zF}\ln\left(\frac{c_l}{c_m}\right)$$

BPM is a combination of the AEM and CEM with a very thin catalyst layer in between them, which promotes water dissociation ($H_2O \rightleftharpoons H^+ + OH^-$). Through applied potential and ion selectivity of the membranes, the electrodialysis cell can generate acid and base.

The model was used to improve the faradaic efficiency of the cell by optimizing geometry to reduce shunt current, which is the parasitic current flowing through the manifold when multiple cell are setup in parallel.

CO_2 Ocean Drawdown

To ensure efficient CO_2 capture while not causing too aggressive disturbance to the marine ecosystem, an area with slightly higher pH needs to be established as an enhanced CO_2 drawdown site. This ocean mesoscale model studies the turbulent flow and its influence on the mixing and drawdown of CO_2.

A flux boundary condition was assigned to the top of the seawater domain depending on the gas transfer velocity [2]:

$$J_{CO_2} = k(Hp_{CO_2,air} - c_{CO_2,water})$$

Inside the domain, an enhanced diffusivity ($D_T = \nu_T / Sc_T$) was used to address the turbulent mixing. And reactions between dissolved inorganic carbon species were applied: $CO_2 + H_2O \underset{k_1^b}{\overset{k_1^f}{\rightleftharpoons}} H^+ + HCO_3^-$, $HCO_3^- \underset{k_2^b}{\overset{k_2^f}{\rightleftharpoons}} H^+ + CO_3^{2-}$. [3]

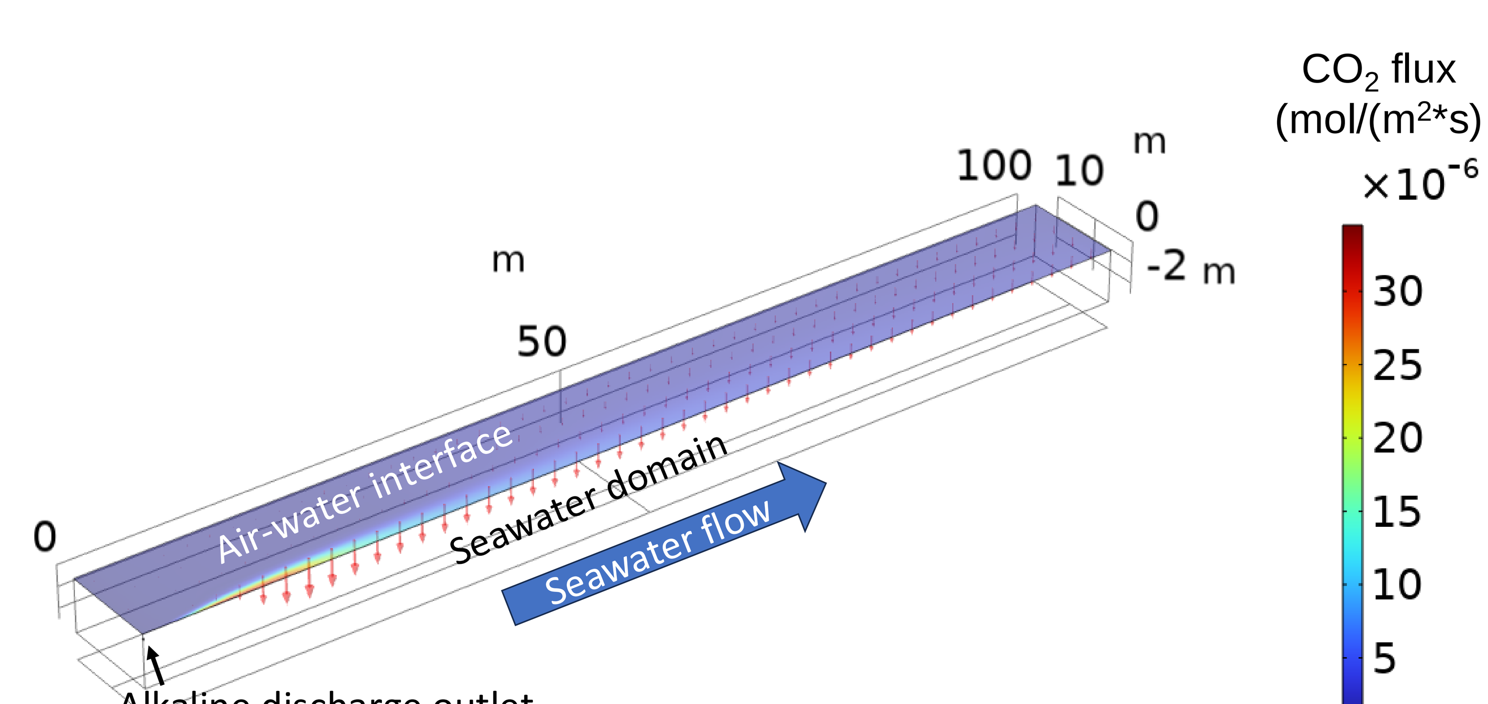


Figure 3. CO_2 drawdown rate at the alkaline discharge.

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