Development of An Off-Shore, Stand-Alone System For Efficient CO_2 Removal from Oceanwater

ARPA E TINA Program

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U.S. Department of Energy

National Energy Technology Laboratory

Direct Air Capture Kickoff Meeting

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Program Overview

a. Funding: DOE ARPA-E $850k

b. Overall Project Performance Dates: 24 months, beginning est. March 2021

c. Project Participants: Caltech and U.C. Irvine

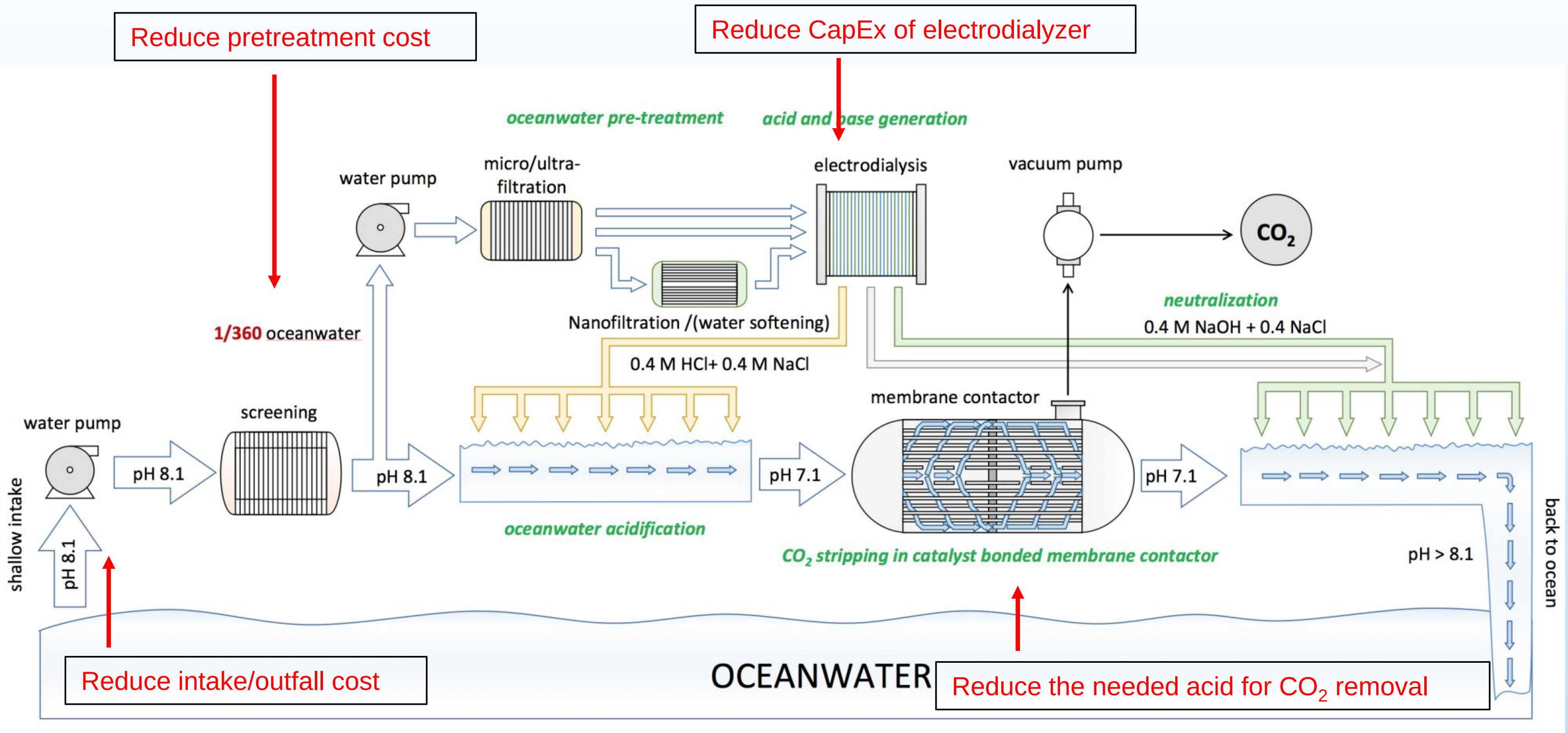
d. Overall Project Objectives: Develop an off-shore, stand-alone system for efficient and cost-competitive removal of CO_2 from oceanwater. The two main objectives of this project are to demonstrate

   a. a multi-cell electrodialyzer that operates at high current densities (>1 A cm^2), and

   b. a novel membrane contactor that exhibits unprecedented rates for CO_2 removal from only slightly acidified oceanwater (pH ≈ 7).

At the end of the project, we will deliver a power-matched and flux-matched electrodialyzer and membrane contactor prototype for continuous operation at a CO_2 capture rate of 2.1 L min-1 (≥24 h, ≤0.5 MWh/t-CO_2 efficiency). The aim is to provide a proof-of-concept that device-level innovations can be coupled into a system that can meet the FOA cost target of $100/t-$CO_2$ at the Gt-CO_2/yr scale.

Technology Background



Oceanwater vs Direct Air Capture

- CO_2 concentration (~130 times better per volume, and ~6 times worse per weight)
  Air: 0.775 mg L^{-1}
  Seawater: 99.1 mg L^{-1}
- Ocean capture represents a direct reversal of ocean acidification caused by anthropogenic CO_2 emissions
- Ocean capture has the potential to operate offshore, which limits competitive land use for useful land and allows easy access to CO_2 storage sites.

Oceanwater Capture Challenges

- Oceanwater intake and pre-treatment dominate the cost of land-based oceanic CO_2 removal systems.

  $1.4M/million gallon-day (from desalination plants)= $1839/ton-$CO_2$

- Co-location of oceanic CO_2 removal systems with desalination plants is not scalable.

  Oceanwater feed from the largest desalination plants = 83 k-ton/year
  All potable water currently consumed worldwide (4.3 trillion m^3/yr) = 0.95 Gt-CO_2/yr

- Electrodialyzers to produce acid/base have a high CapEx and associated BOS costs

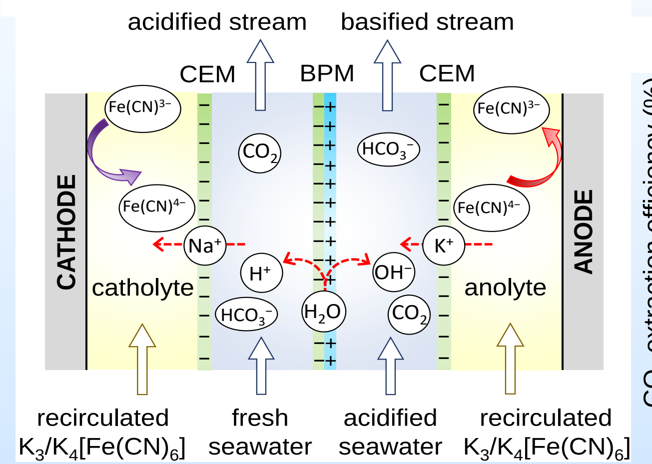
  Operating current density limited to < 200 mA cm^{-2}

- Acidified oceanwater is required to help drive gaseous CO_2 removal

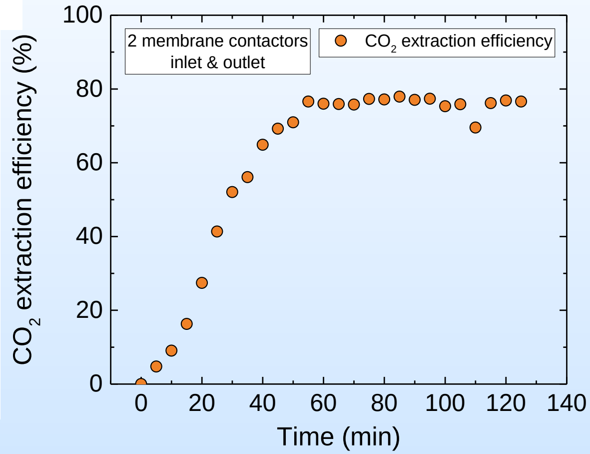
  Liquid-gas contactor requires acidified oceanwater at pH~4

Technical Approach/Project Scope

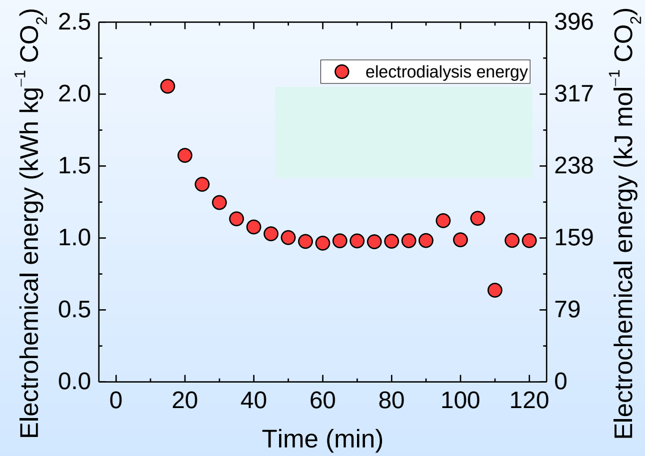
A schematic illustration of the electrodialyzer design



High CO_2 capture efficiency



Low energy consumption



- A record-low electrochemical energy consumption of 0.98 kWh/kg CO_2 was demonstrated at lab-scale (0.23 kWh/kg is the thermodynamic limit).

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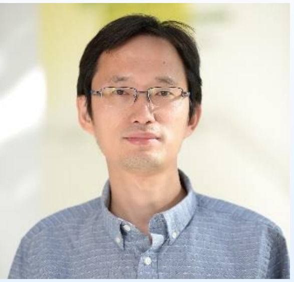
- Design and model optimal electrodialyzer cell architecture
- Synthesis and characterization of bipolar membranes for high current density operation
- Development of custom membrane contactor for CO_2 removal from high pH water
- Demonstration of a proof-of-concept system using oceanwater

Team and Facilities

Caltech:

Harry Atwater

CX Xiang



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UC-Irvine:

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Custom-made 8 cm x 8 cm, single cell electrodialzyer unit

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Opportunities for Collaboration

a. Seeking collaborators with experience and understanding of oceanic environment
b. Interest in application of electrochemical pH swing concepts in direct air capture systems
c. Potential common ground in scale and technoeconomic analysis