High-Performance, Hybrid Polymer Membrane for Carbon Dioxide Separation from Ambient Air

Project Number: DE-FE0031968

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U.S. Department of Energy

National Energy Technology Laboratory

Direct Air Capture Kickoff Meeting

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Outline

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Program Overview

a. Funding: DOE $799,985 and Cost Share $200,001

b. Overall Project Performance Dates: 01/01/2021 – 06/30/2022

c. Project Participants: InnoSense LLC (Torrance, CA) and University of Utah (Salt Lake City, UT)

d. Overall Project Objectives: Develop hybrid polymer membrane capable of direct air capture (DAC) CO_2 separating from ambient air at a low cost (low hundreds in $) per metric tonne by 2030

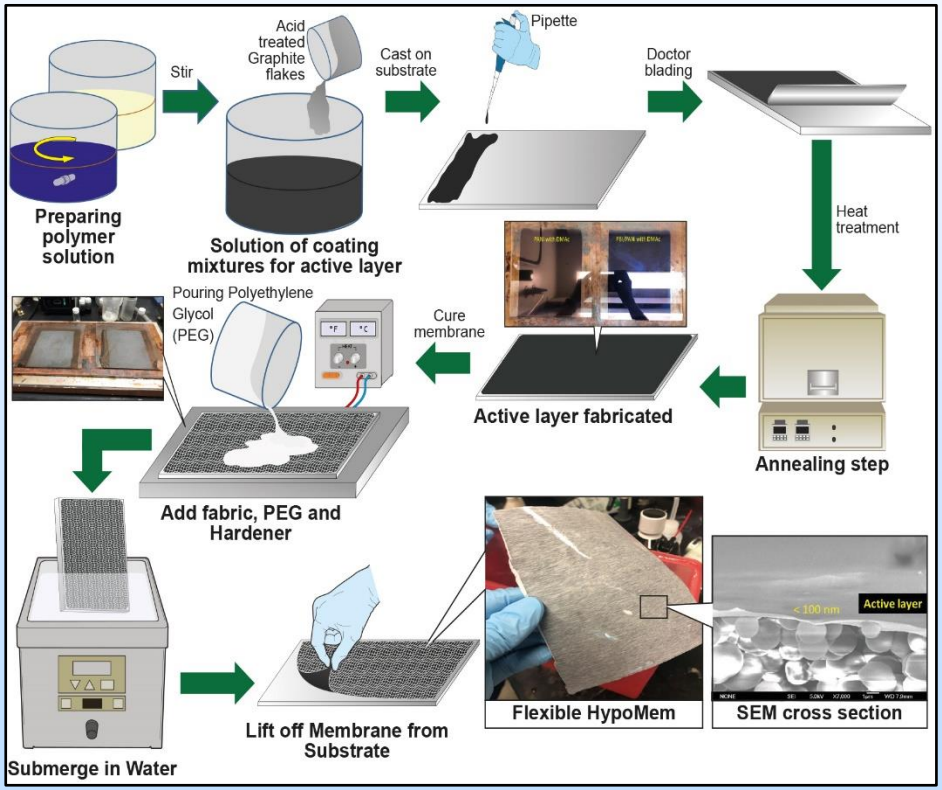
Technology Background

- Carbon dioxide (CO_2), captured directly from ambient air, is a leading method for reducing greenhouse gas emissions.
- A recent study estimates that primary processes envisioned for large-scale CO_2 capture from ambient air can cost $94–$232 per metric tonne.
- Current methods of DAC CO_2 separation from ambient air (~0.04%) are intrinsically inefficient due to:
  - Thermal energy losses,
  - Large footprint,
  - Degradation of sorbent materials.
- Sorbents and solvents used in the DAC process have many disadvantages:
  - Need to build a very large structure,
  - High cost and complexity of regenerative systems,
  - Loss of moisture in dry environments.

Project Objectives

The overall objective of this project is to develop a disruptive DAC CO_2 separation system using a hybrid polymer membrane (HypoMem) from ambient air to reduce CO_2 separation costs and energy penalties.

Step-by-step processes for developing HypoMem



Technical Objectives

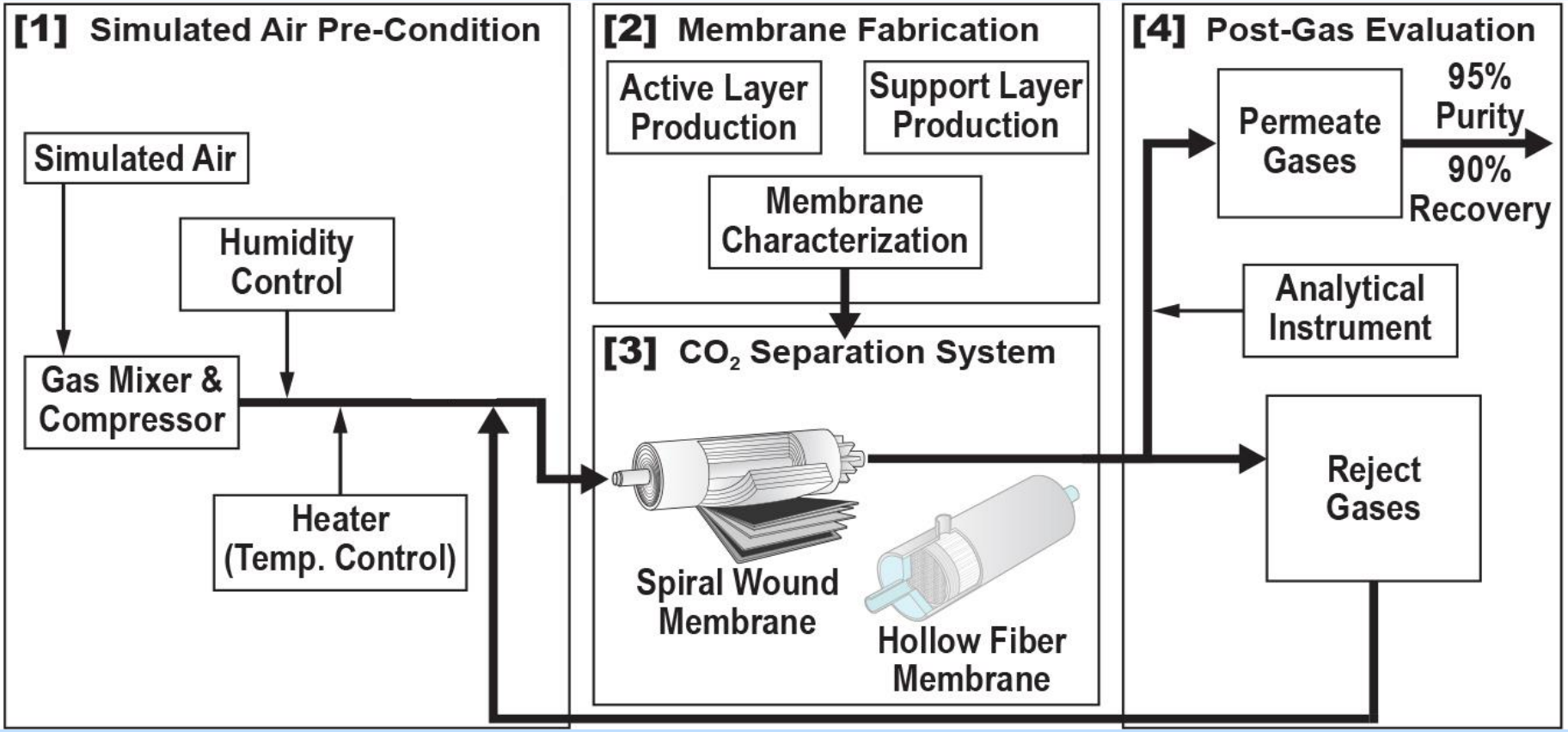
Objective 1. Developing highly CO_2 selective HypoMem. Fabricate ultra-thin functionalized polymer membrane, HypoMem.

Objective 2. Demonstrating lab-scale system for DAC CO_2 separation from simulated air. Construct a lab-scale DAC system, and test and evaluate HypoMem performance.

Objective 3. Demonstrating a cost-effective DAC CO_2 separation system from ambient air.

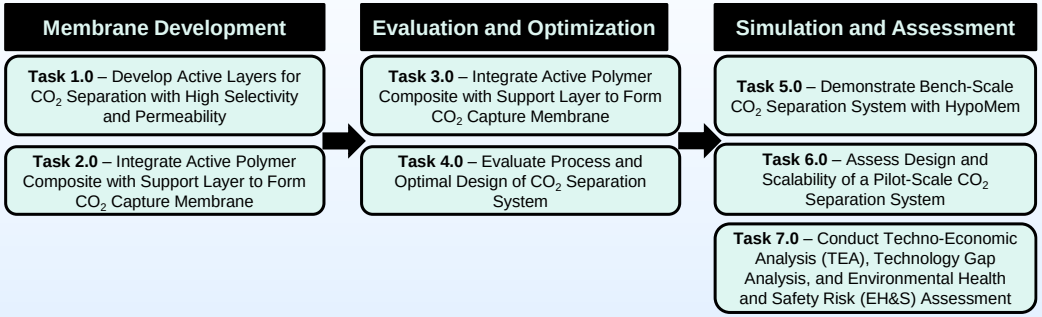
Technical Approach/Project Scope

An overall process of HypoMem based DAC CO_2 separation system



Technical Approach/Project Scope

a. Experimental design and work plan



b. Project schedule:

Milestone 1: Fabricated and characterized ultra-thin robust HypoMem with ≥80% reproducibility for the CO_2 separation system. Completion date: 11/30/2021

Milestone 2: Constructed Phase I CO_2 separation system and demonstrated mass transfer and CO_2 separation. Completion date: 04/30/2022

Milestone 3: 100% process simulation and design documents, design for commercial scale facility system, and performance data compiled and completed. Completion date: 06/30/2022

c. Project success criteria:

(1) Developed ultra-thin robust polymeric composite active layers (10–50 μm thickness and ≥80% reproducibility), and (2) HypoMem achieves CO_2 permeability of 1500 barrers and ideal CO_2/N_2 selectivity of ~100.

Team and Facilities

InnoSense LLC Team

Maksudul M. Alam, PhD
Principal Investigator

Adrien Hosking, MS
Design & Formulation Scientist

Marquise Bartholomew, BS
Research Engineer

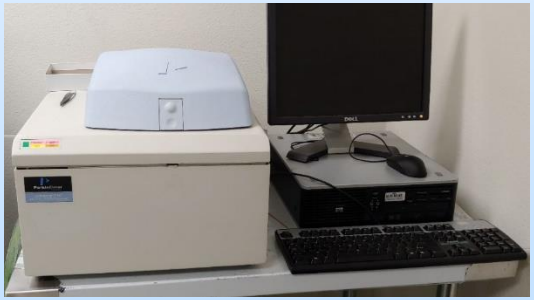
University of Utah Team

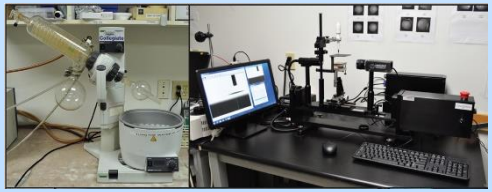
Professor Milind Deo, PhD
Subaward Project Director

Cleanroom Certified ISO-7

Scanning Electron Microscope (SEM)

Differential Scanning Calorimetry (DSC)

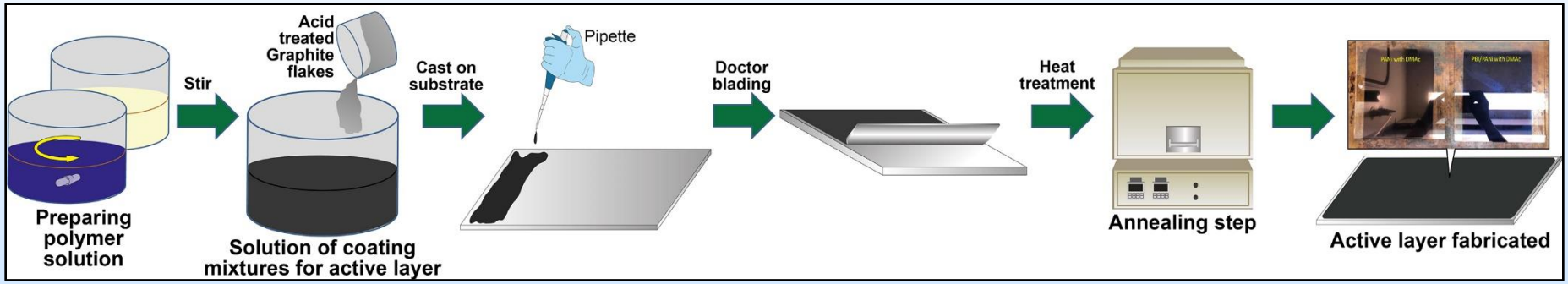




Progress and Current Status of Project

- Procured component polymers for fabricating polymer active layers
- Procured carbon support materials to fabricate HypoMem samples

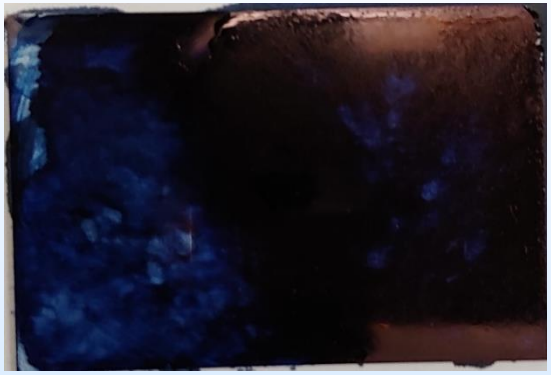
Steps to fabricate polymer active layers



1. Disperse and dissolve polymer(s) in a suitable solvent (common solvents such as tetrahydrofuran, chloroform, dichloromethane, dichloroethane, *N*-methylpyrrolidone, etc.
2. Add functionalized nanomaterials to increase permeability and selectivity of CO_2.
3. Cast onto substrate and dry under heat (~60 °C) to remove solvent.

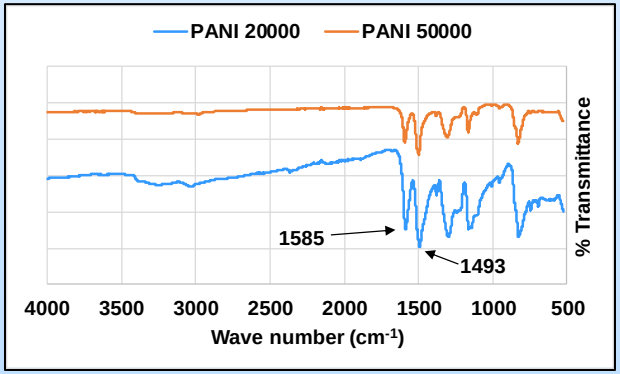
Progress and Current Status of Project (Cont'd)

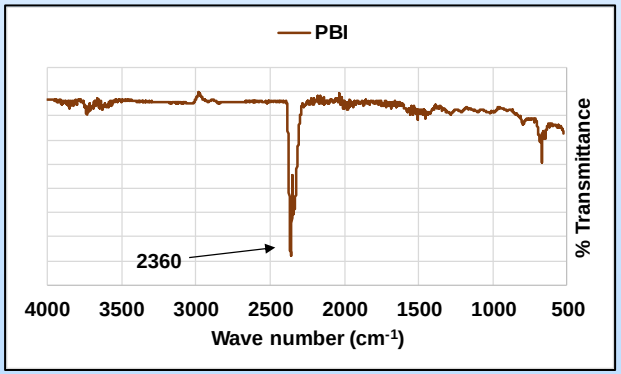
Polymer thin films



Fourier Transform Infrared (FTIR) Instrument

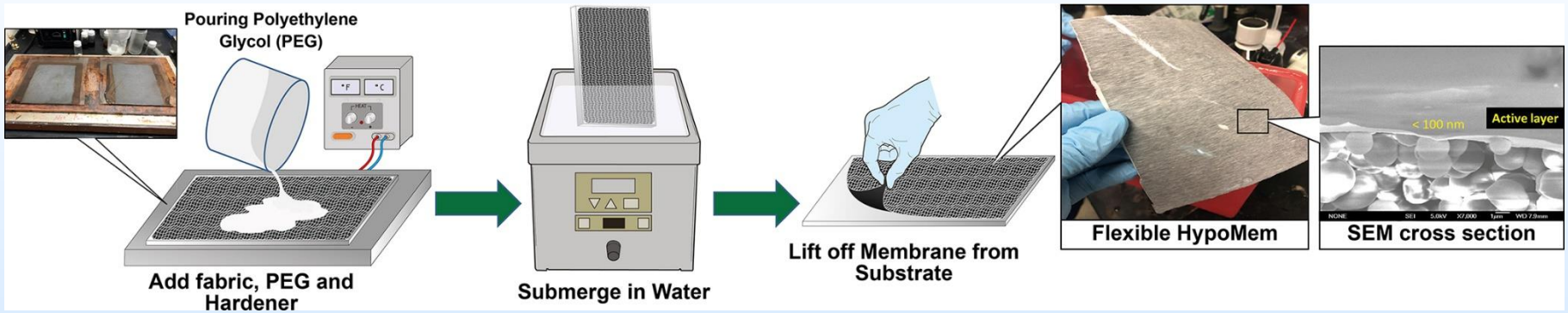
FTIR spectra of component polymers





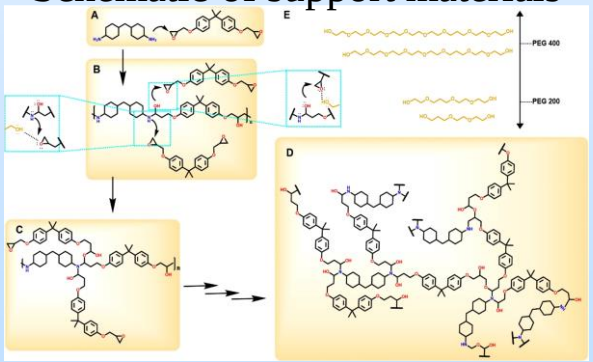
Progress and Current Status of Project (Cont'd)

Steps to fabricate HypoMem samples for DAC CO_2 separation



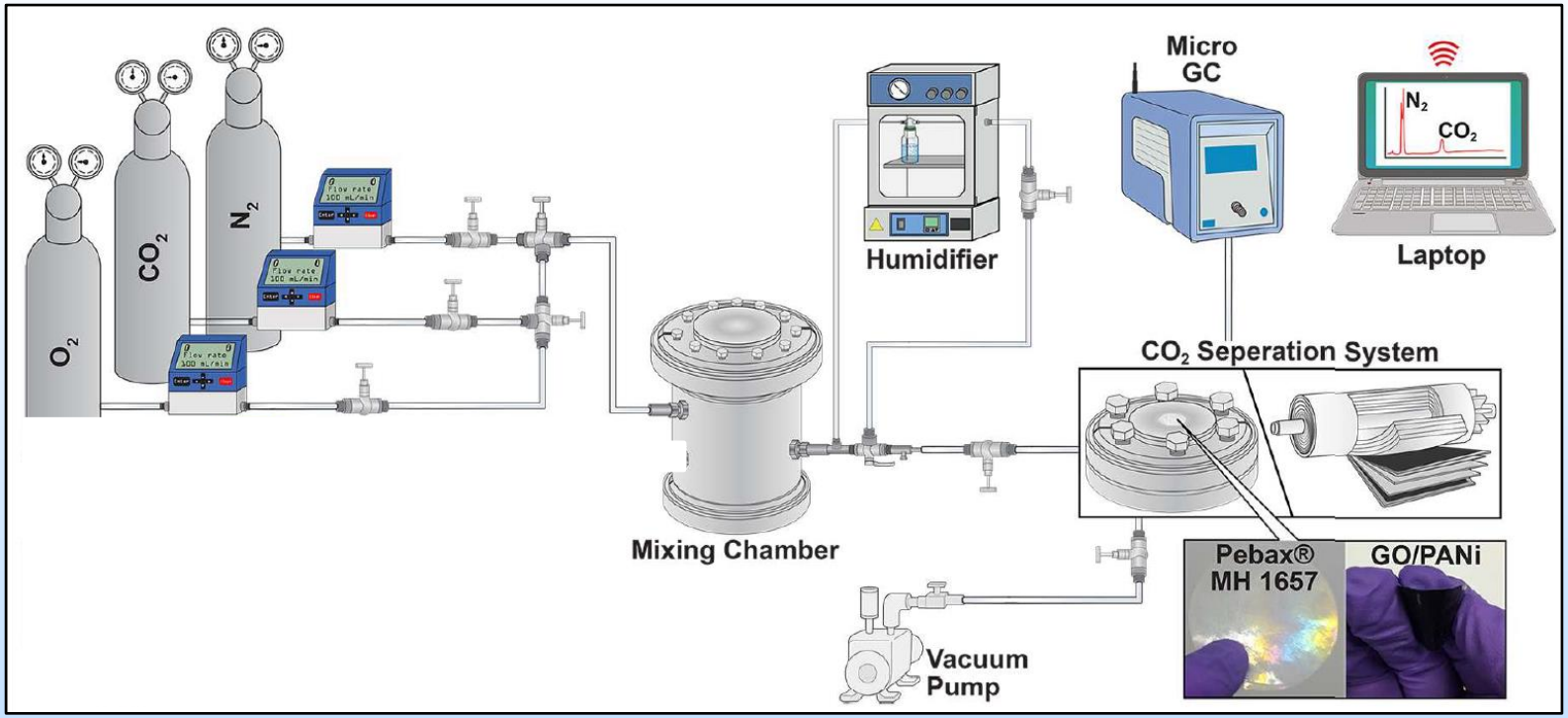
1. Create support layers of different pore sizes.
2. Cast support layer onto active layer fabricated.
3. Characterization will be performed with FT-IR, Raman spectroscopy, SEM, TGA, DSC, etc. to determine change in chemical structure, thermal decomposition and degradation and cross-linking density.

Schematic of support materials



Progress and Current Status of Project (Cont'd)

Schematic of a lab setup for testing HypoMem samples



- Use simulated air to perform permeation experiments under dry (RH <30%) and wet conditions (RH >70%).
- Correlate membrane performance with active layer thickness, composition, casting wt.% and gas kinetic diameter.

Progress and Current Status of Project (Cont'd)

Conduct Techno-Economic Analysis (TEA), Technology Gap Analysis, and Environmental Health and Safety Risk (EH&S) Assessment

- TEA: Cost estimates will be determined based on the energy and mass balance (EMB) requirements derived from bench-scale experiments.
  - Direct byproduct of process simulation
  - Bare module costs for individual units
  - Approximate plant costs
  - Preliminary economics
  - Net present value and internal rate of return calculations using simple assumptions
- Technology Gap Analysis: Analyze strengths and weakness for CO_2 separation system and determine if the system can be improved by existing technologies.
- EH&S: Perform an assessment of environmental health and safety risk to ensure protection of employees, the public and the environment.

Plans for Future Development

- In this project
  - Project just started, we will focus on project work, tasks, and meetings to achieve stated milestones and success criteria.

- After this project
  - Prototype development and field level testing for DAC CO_2 separation from ambient air.

Summary

- We are developing a DAC CO_2 separation system using HypoMem to reduce CO_2 separation costs and energy penalties
- Revised and updated project management related documents
- Began procuring required chemicals and reagents (≥20% done)
- Began preparing thin films of polymer active layers

Opportunities for Collaboration

a. Collaboration will facilitate development of functional membrane materials, design and develop robust membrane, system development, understanding parameters to optimize, process feasibility, economic viability, scale-up and commercialization.

b. Potential areas of complementary work that others may contribute to this technology:

- Design and develop functional materials,
- Analyze membrane's properties,
- Design and setup large-volume air capture and flow (modeling and experimental setup), and
- Design and integration of analytical instrument for accurate determination of CO_2 separation, concentration, and efficiency.

Acknowledgements

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NATIONAL ENERGY TECHNOLOGY LABORATORY

- DOE Office of Fossil Energy Project Manager Dustin Brown and Relevant Scientists/Personnel