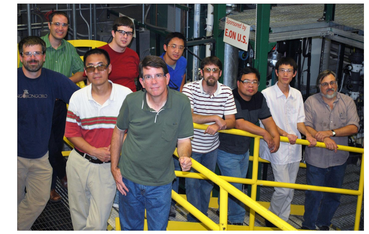
A Solvent/Membrane Hybrid Post-combustion CO_2 Capture Process for Existing Coal-Fired Power Plants

Xiansen Li, Joseph E. Remias, and Kunlei Liu
Center for Applied Energy Research, University of Kentucky



Motivation

- The primary disadvantage of concentrated aqueous ammonium solvents is ammonia volatility
  - One route to minimize scrubber ammonia loss is to operate with dilute NH_3 solutions at the cost of increasing more power for solvent regeneration
  - A solvent based membrane solution makes dilute solvent operation more feasible since higher heat of regeneration is negated
- To reduce the energy penalty associated with solvent-based post-combustion CO_2 capture system by incorporation of dual-function membrane prior to the regenerator
  - To Increase carbon loading
    - Water reduced in the solvent by physical separation
    - Catalytic reaction increases the concentration of bicarbonate over carbonate
  - To regenerate solvent catalytically
    - Regenerated by ammonium protons on the surface of membrane

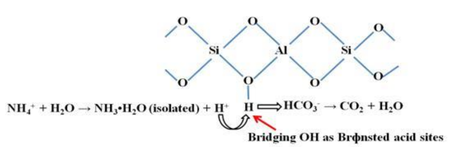


Figure 1. Schematic representation of proposed catalysis.

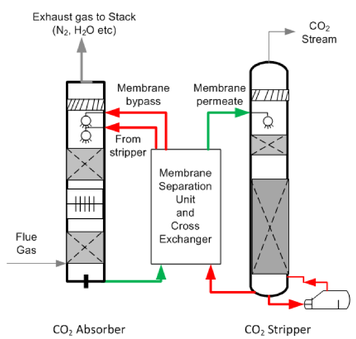


Figure 2. System integration

Project Goals and Milestones

- Year 1
  - Explore alternate commercial support materials.
  - Investigate hollow fiber supports and zeolite hollow fiber hybrids.
  - Develop ceramic support extrusion technology and ceramic supports.
- Year 2
  - Optimize membrane synthesis for optimal flux and rejection rate.
  - Determine best support and membrane structure for scale up.
- Year 3
  - Scale support and membrane synthesis to permit testing at pilot facility
  - Build and integrate pilot scale membrane separation unit.
  - Test process using the CAER's 0.1 MW_{th} pilot CO_2 capture facility including use of coal flue gas.

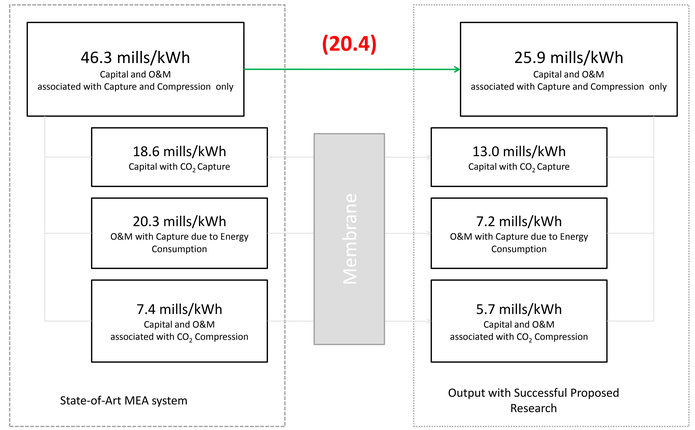


Figure 3. The Impact of Proposed Research on Incremental Cost of Electricity with Carbon Capture and Storage

Experimental Setup

- Inorganic support with zeolite membrane coating
- Ammonium carbonate solvent (currently)
- Other solvents (later on)
- $\Delta(pH) = pH_{permeation} - pH_{reject}$.
- Total flux = $m_{permeation}/(A * t)$, A: membrane area; t: permeation time; m: mass of permeate.
- Rejection rate $R_i = 1 - C_{i,p}/C_{i,f}$, $C_{i,p}$: i permeate concentration; $C_{i,f}$: i feed concentration.

Figure 4. Membrane evaluation apparatus and CAER pilot scrubber/ stripper.

Project Progress

1. Commercial supports obtained as alternates to current mullite.
   - Pall Membralox® ceramic coated asymmetric supports have adequate flux but lack cost effectiveness.
2. Ceramic extruder and ancillary equipment ordered to synthesize porous supports.
3. Work has started on hollow fiber separation option.
   - A polysulfone based commercial product was sourced
   - A bench scale synthesis and performance evaluation apparatus is being designed.
4. Work continues with membrane growth on existing mullite tubes.
   - Promising flux and catalytic activity obtained using existing mullite tubes.
   - Work is ongoing to explore novel methods to grow zeolite on various test supports.

Table 2. Performances for 0.55 m total-carbon-loading solutions for A and B type membranes vs. time.
* based on conductivity data.

Membr. Type and ID	Testing time (min)	Temp. (°C)	ΔP (psi)	Δ(pH)	Flux (kg/m²·h)	Total C Rejection (%)
A-1	107	60	30	0.02	19.3	-24.3
	163	60	30	0.02	23.7	-1.48*
A-2	74	60	30	0.01	24.4	-20.6
	105	60	30	-0.01	22.6	-3.64
B-1	156	98	100	-0.24	1.08	-69.7
	281	98	100	0.00	0.91	-42.4
	418	98	100	-0.01	1.47	-22.1

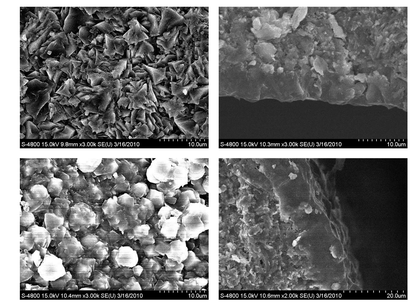
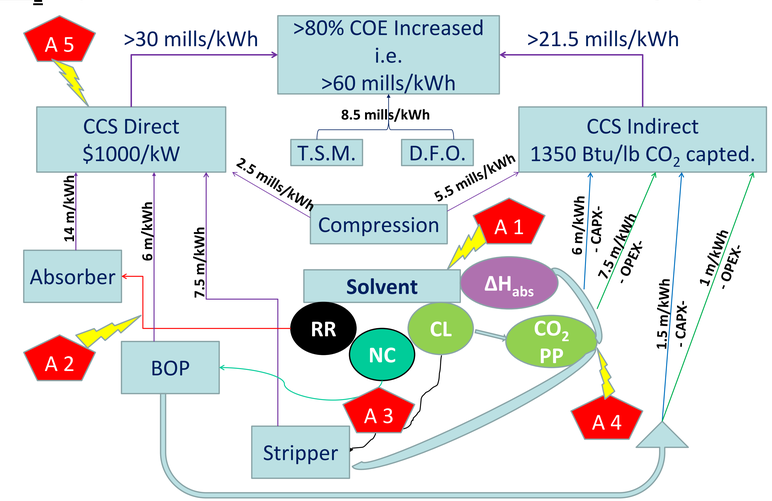


Figure 5. SEM pictures of A-type membranes.

CO_2 Capture Costs with 5 Active CAER Research Areas Highlighted



A1. New Solvent Development
A2. Solid/Liquid Catalyst Development
A3. Post-scrubbing Dewatering
A4. Enhance Stripping Investigation
A5-a. Material Development for Corrosion
A5-b. Fluid dynamic with Presence of Solid