Electrochemically-Mediated Sorbent Regeneration in CO_2 Scrubbing Processes (FE0026489)

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Project Overview

Award Name: Electrochemically-Mediated Sorbent Regeneration in CO_2 Scrubbing Processes (FE0026489)

Funding:

- DOE $1,202,052
- Cost Share $ 310,601
- Total $1,512,653

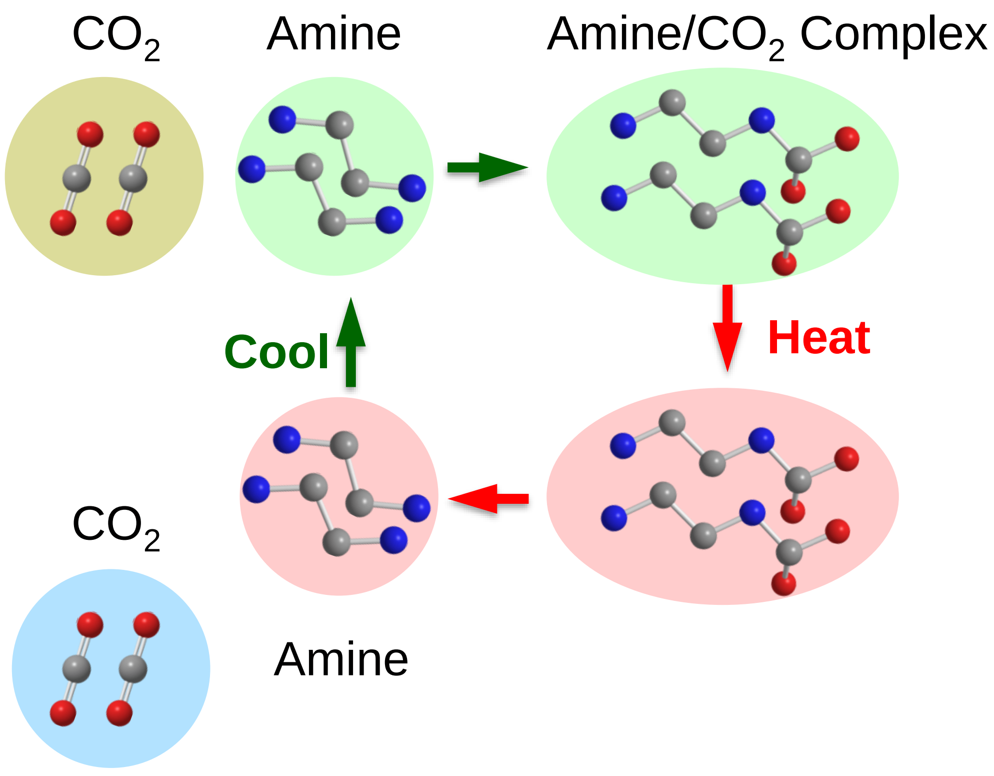
Project Period: August 1, 2017 – July 31, 2020

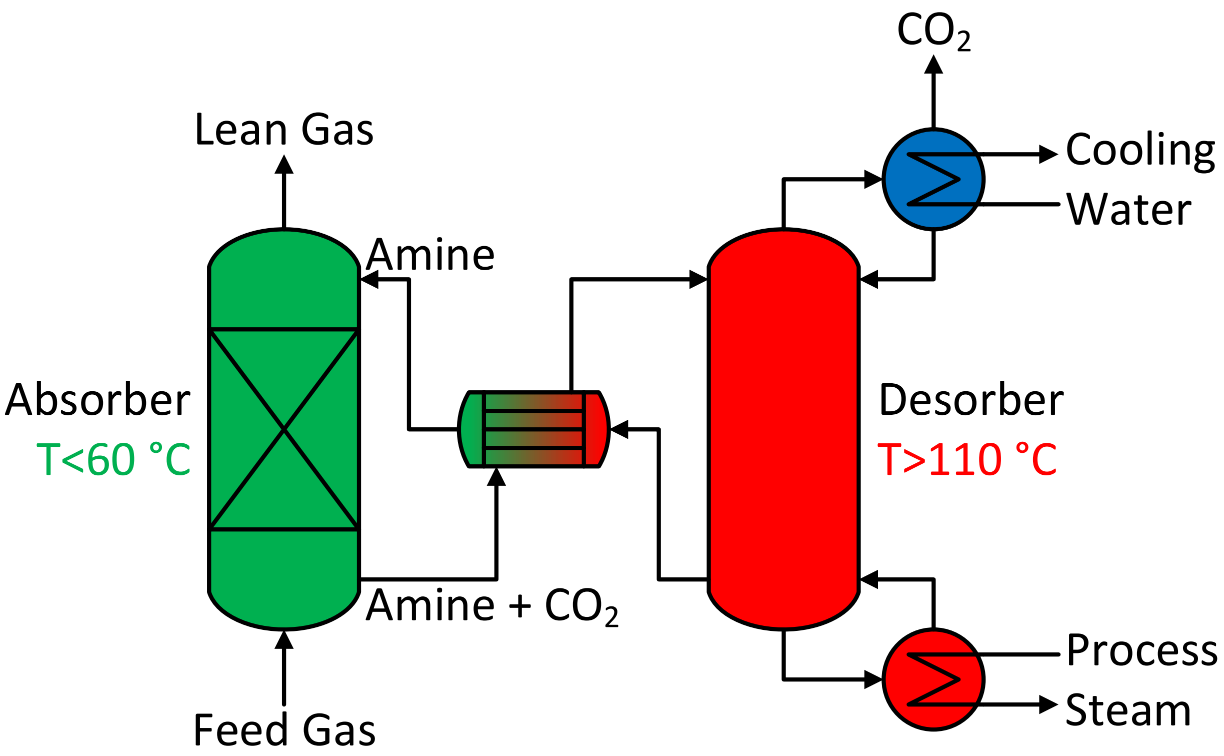
Project PIs: T. Alan Hatton, Howard Herzog

DOE Project Manager: Ted McMahon

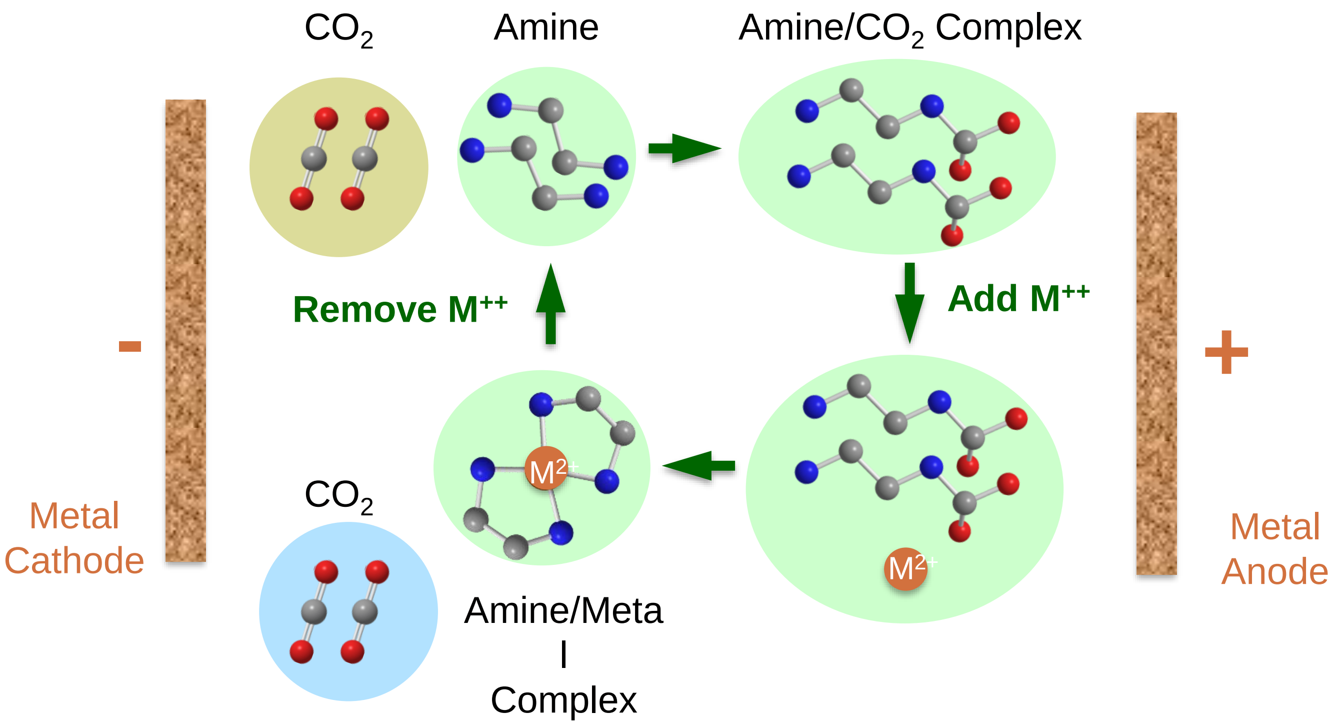
Overall Project Objectives: Develop, characterize and implement electrochemically mediated sorbent regeneration and CO_2 release in amine scrubbing processes

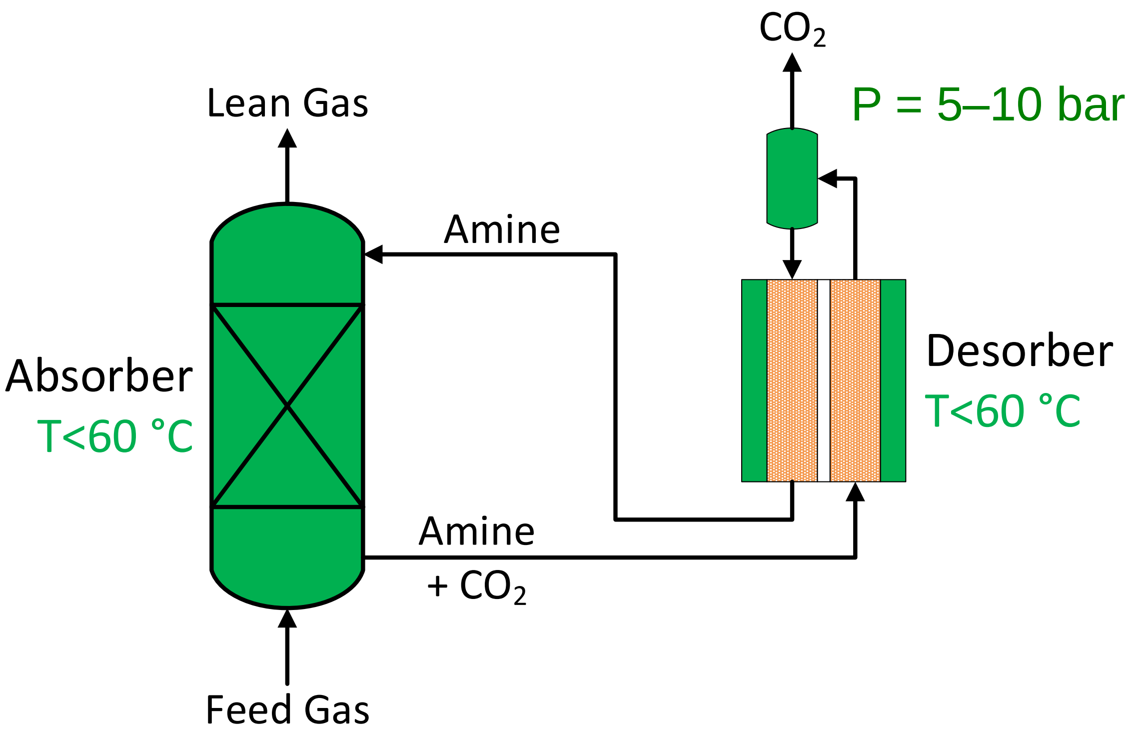
Benchmark CO_2 Capture Technology: Thermal Amine





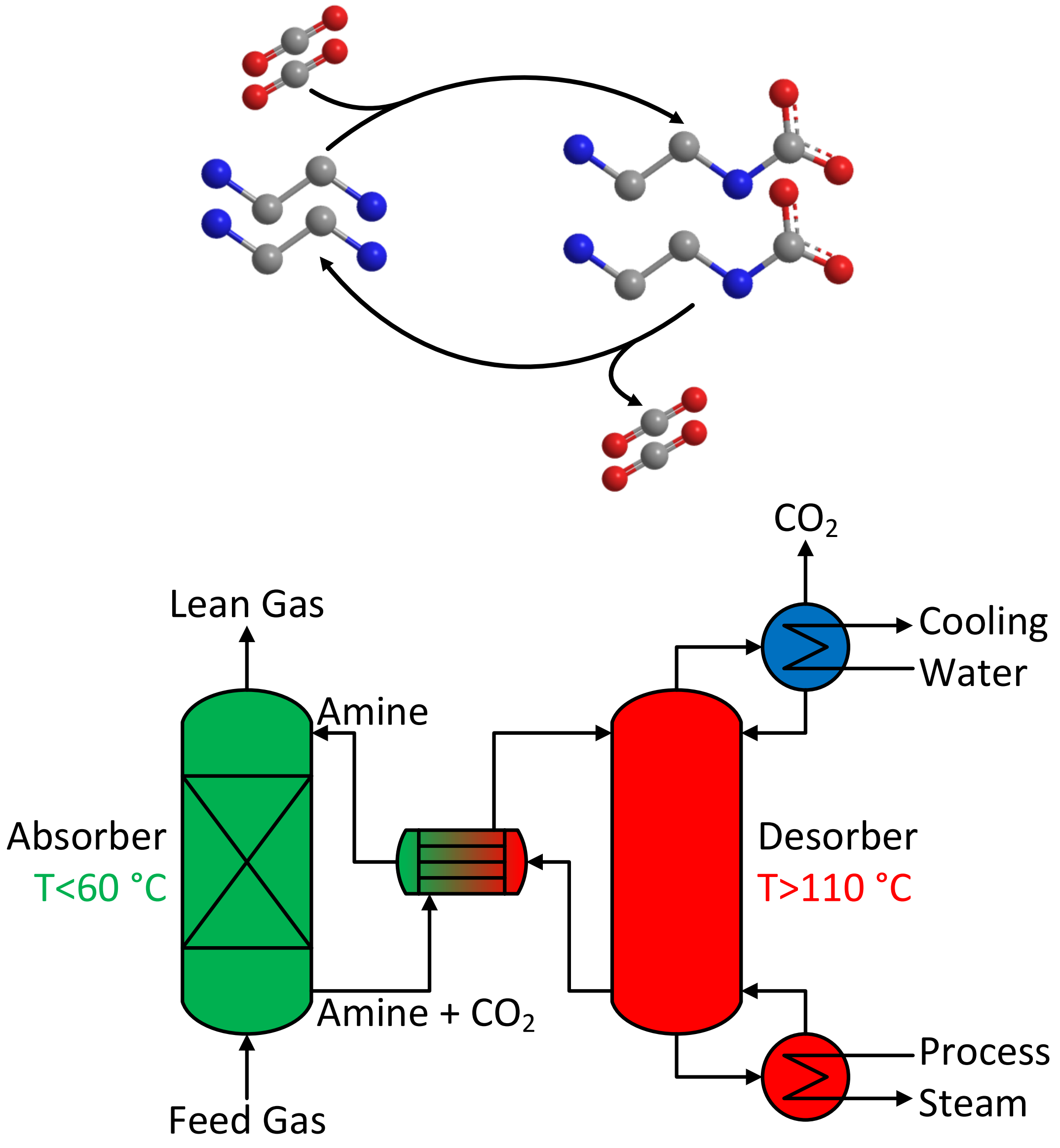
Electrochemically Mediated Amine Regeneration (EMAR)

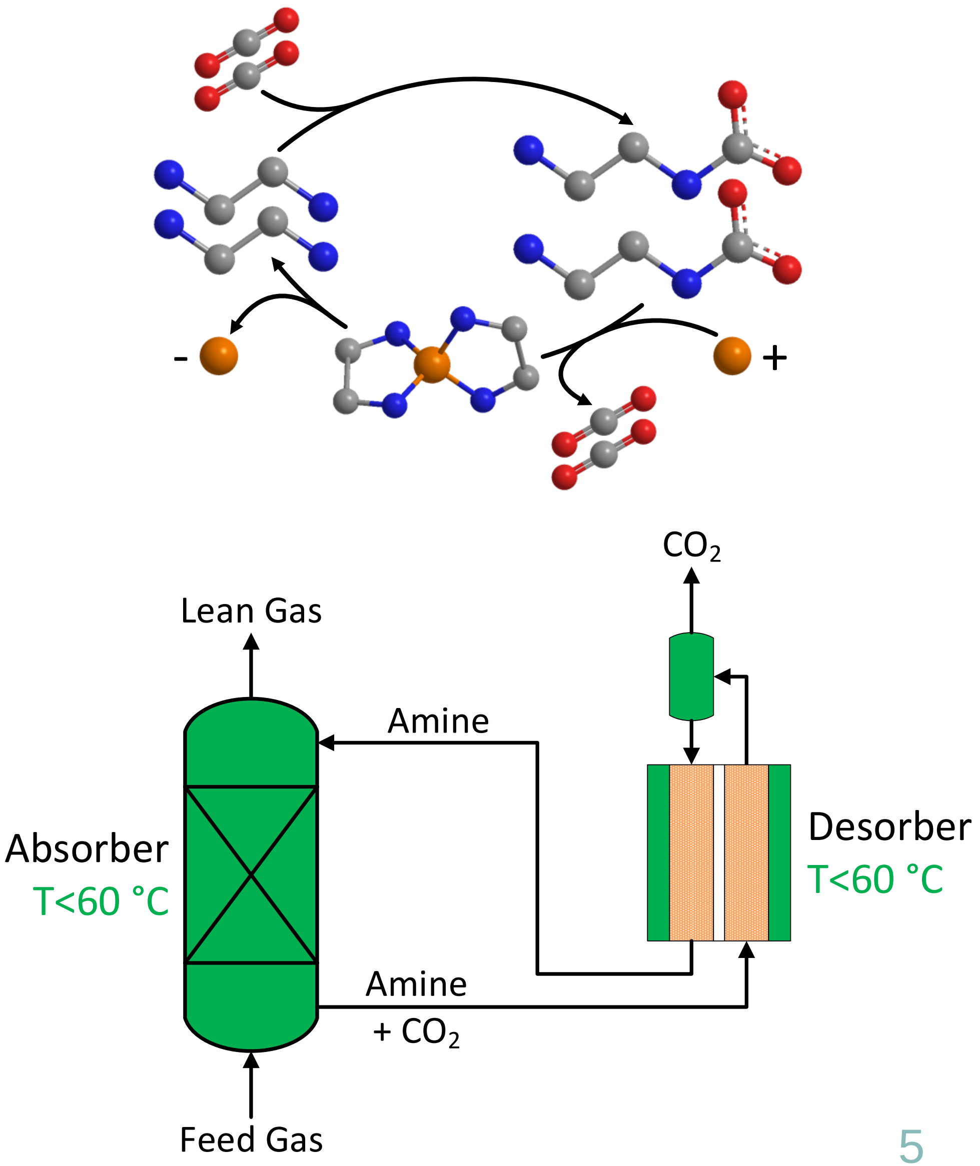




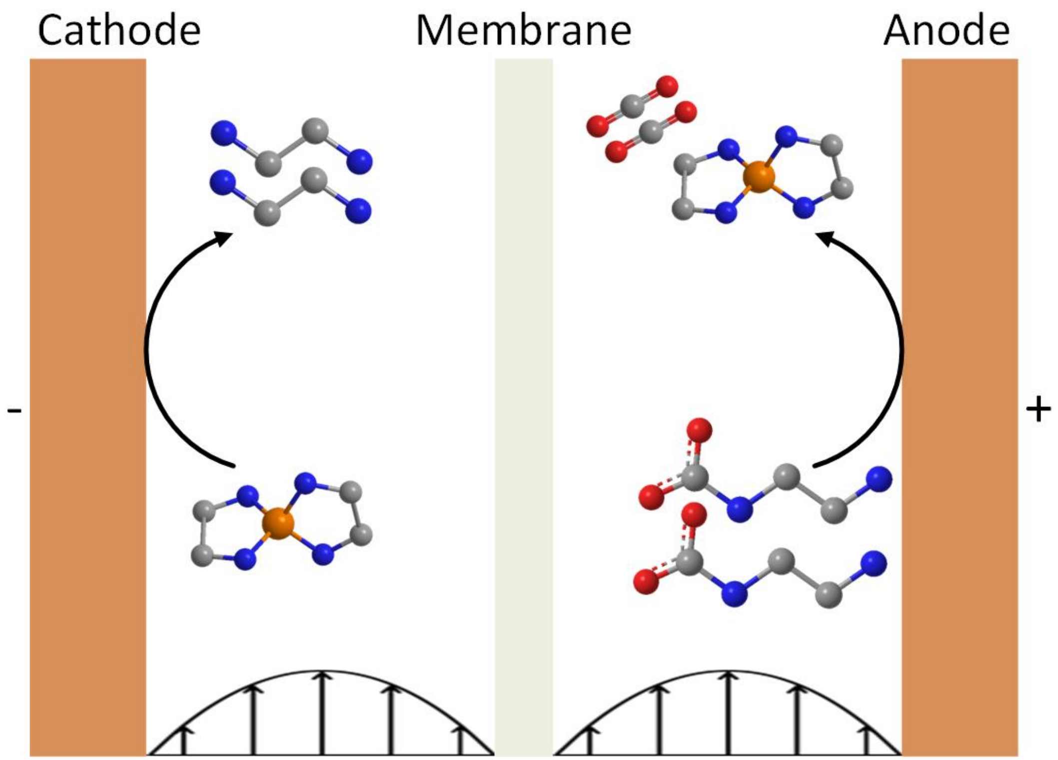
✓ Plug and Play ✓ Efficient ✓ High Pressure Release

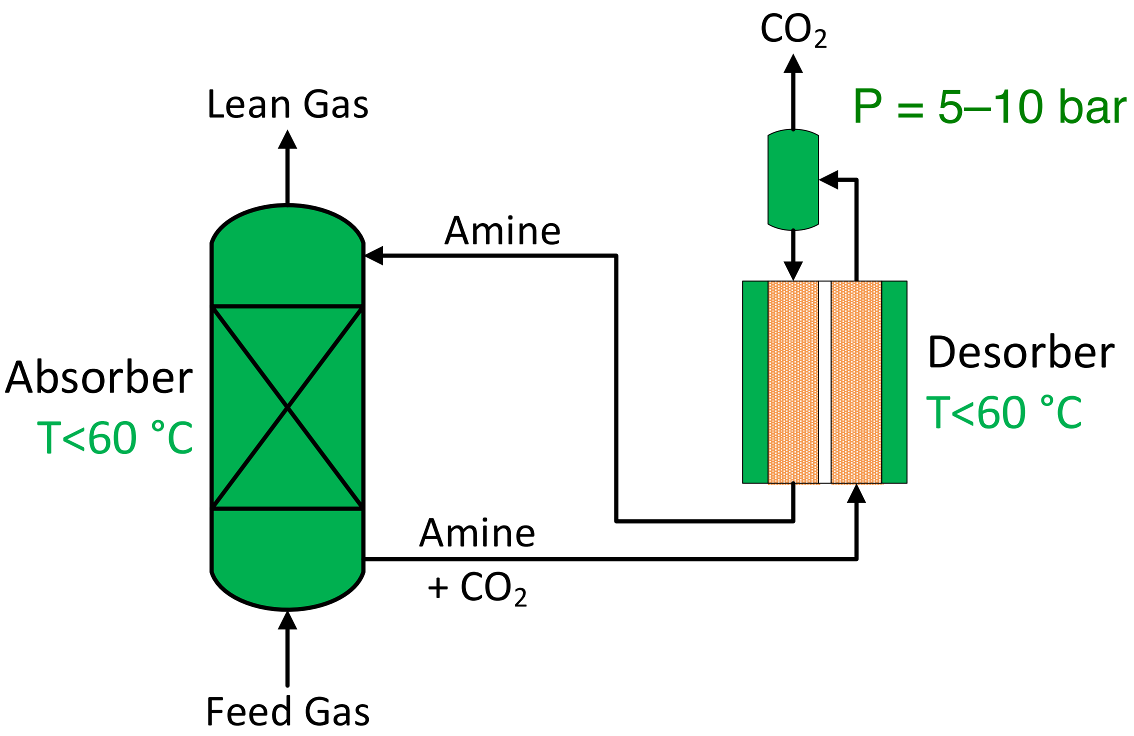
Electrochemically Mediated Amine Regeneration (EMAR)





EMAR Anatomy



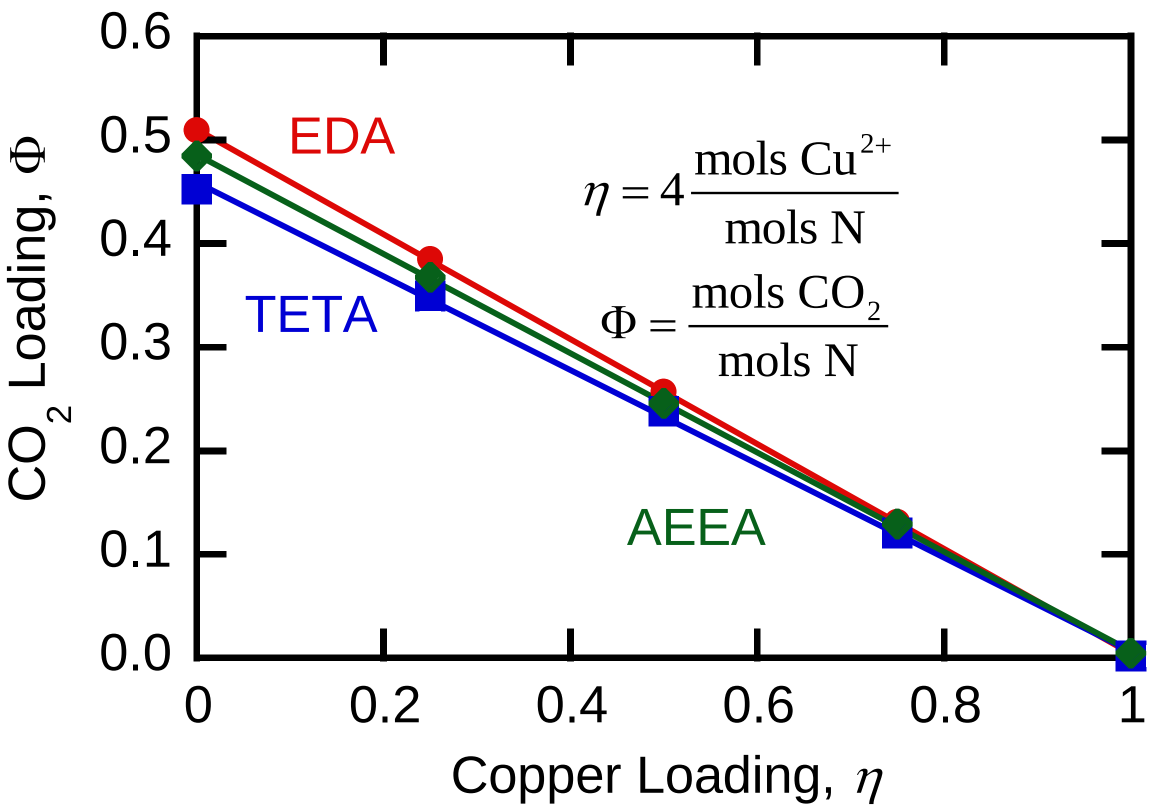


Selection Criteria

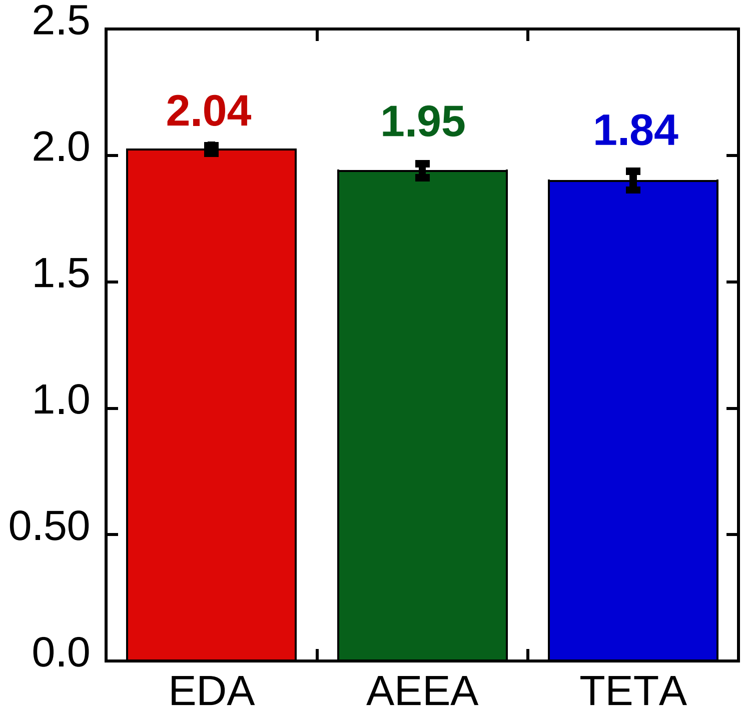
- Cost
- Electrochemical transition happens within the aqueous stability window
- Metal ion has sufficiently strong binding to displace CO_2 (amine specific!)
- Solubility
- Electrochemical kinetics

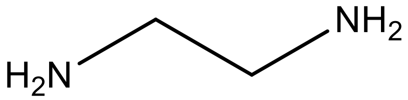
Effect of Copper on CO_2 Loading

T = 50°C , [Am] = 2N , 1M KNO_3 , y_{CO2} = 0.15

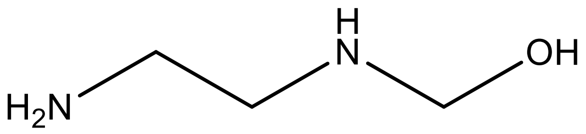


Moles of CO_2 Released per Moles of Copper Added

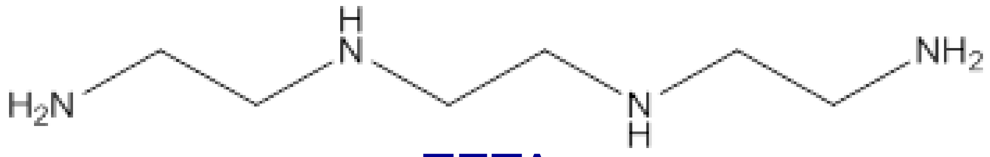




EDA



AEEA

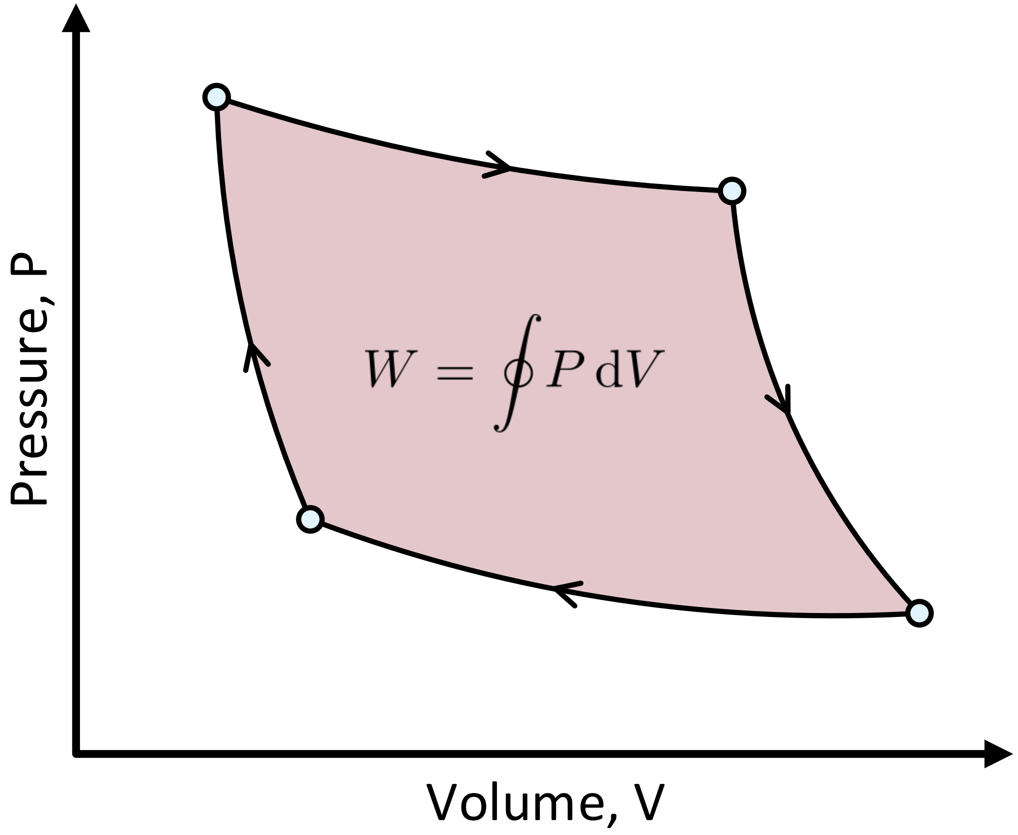


TETA

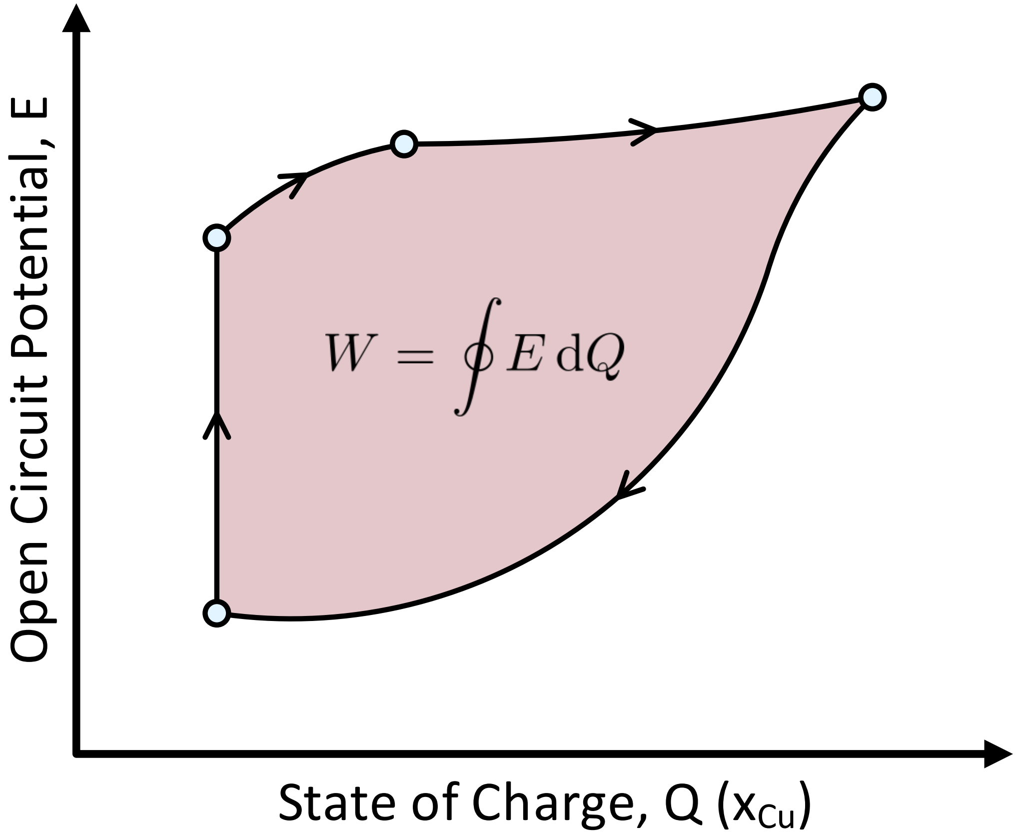
M.C. Stern, F. Simeon, H. Herzog, T.A. Hatton, ***Energy and Environmental Science.*** 2013

Thermodynamic Cycle

Carnot Cycle

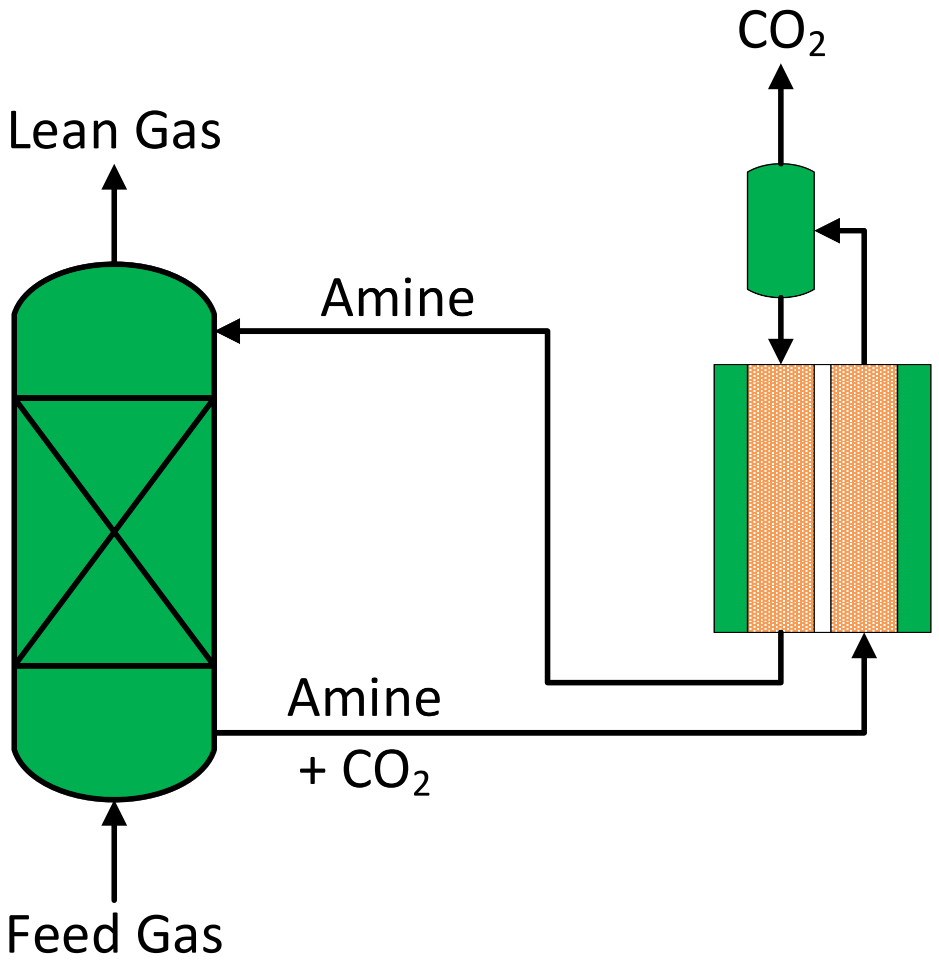


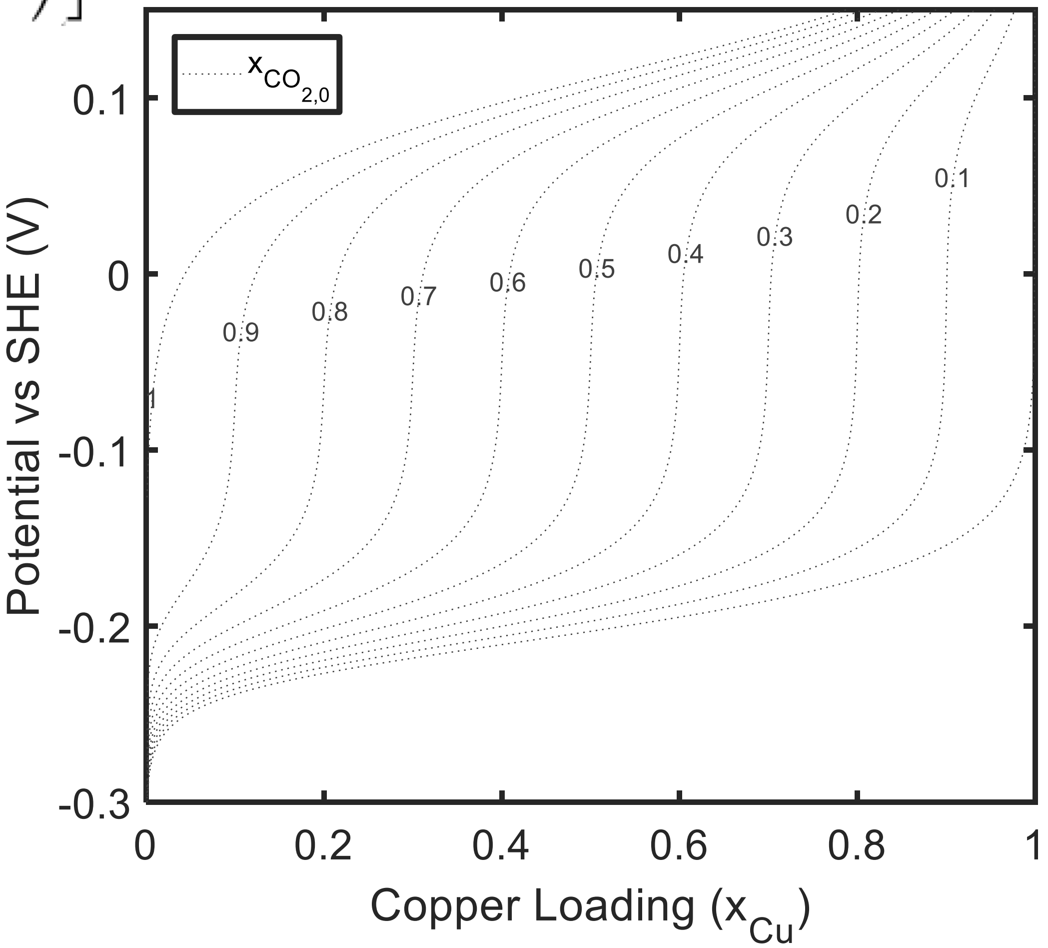
EMAR Cycle



Thermodynamic Cycle

$$E = E^{\circ} + \frac{RT}{2F}\left[\ln\left(x_{cu}\right) + \ln\left(\frac{m\tilde{Am}_0}{2}\right) - \ln\left(1 + \beta\left[\frac{\tilde{Am}_0\left(1 - x_{Cu}\right)}{1 + K_{CO_2}\tilde{P}^m_{CO_2}}\right]^{2/m}\right)\right]$$





Thermodynamic Cycle

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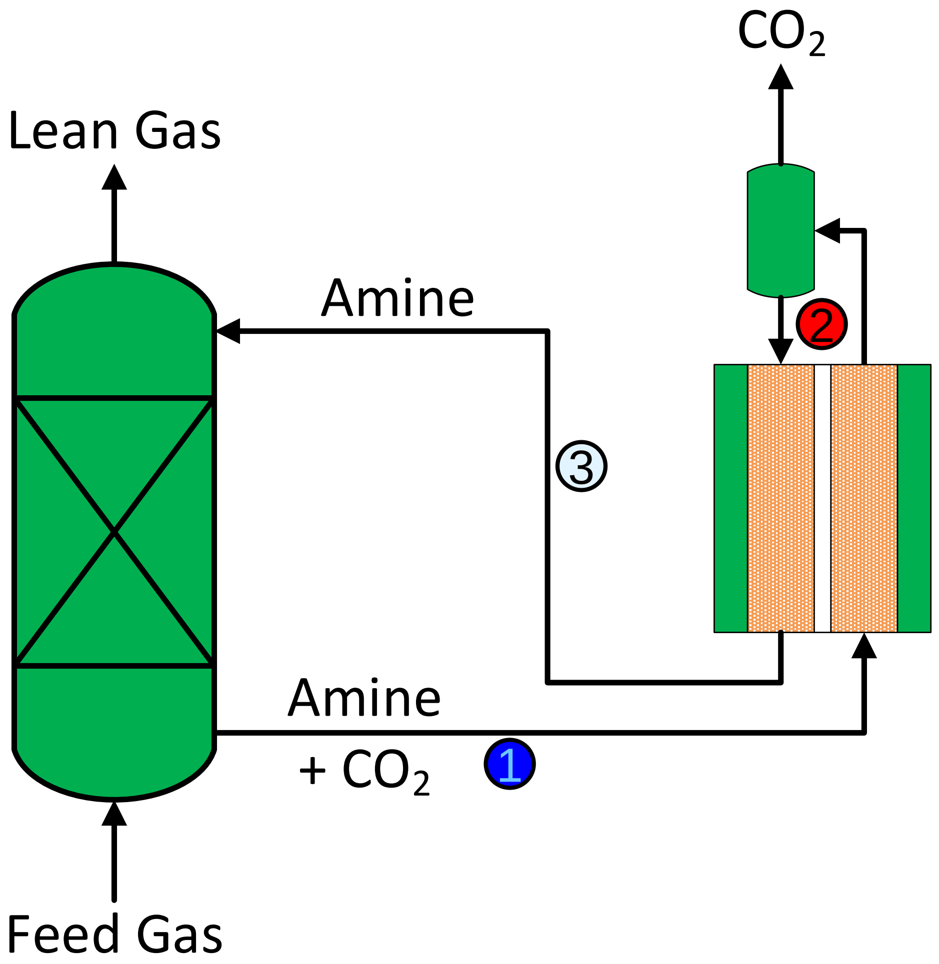

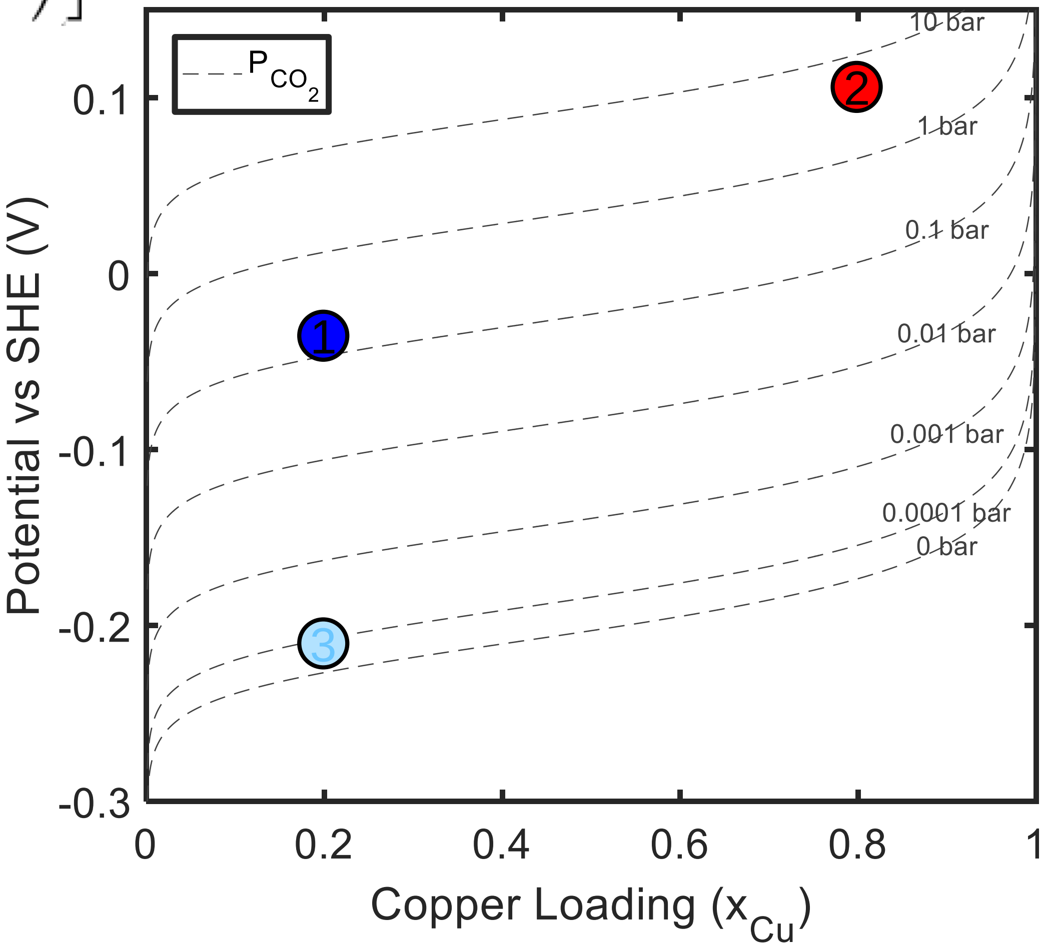

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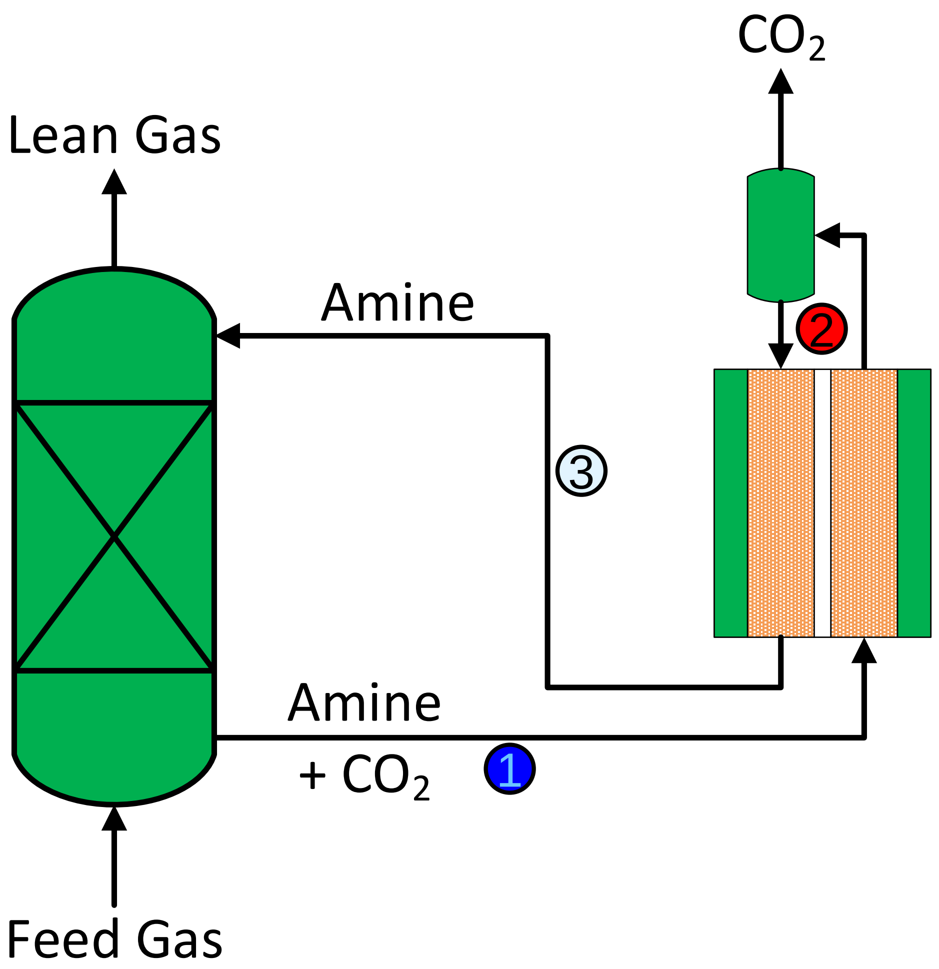
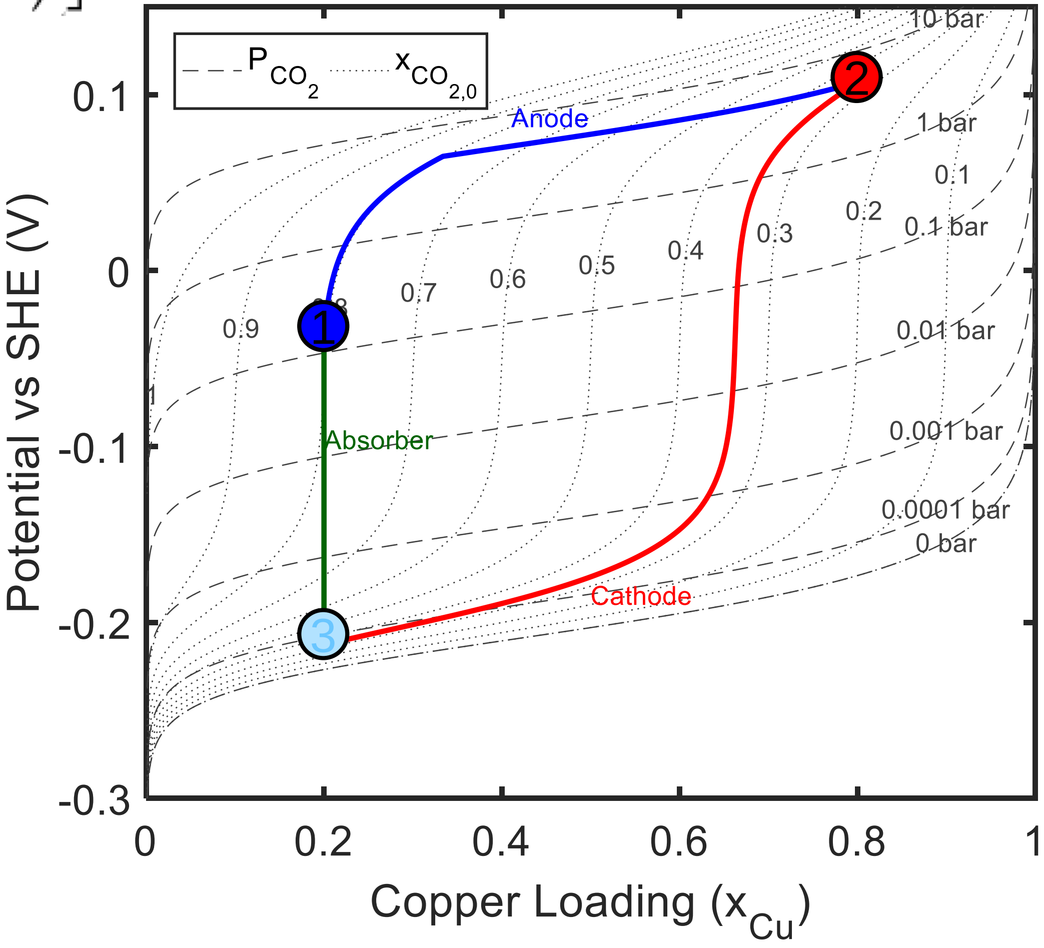
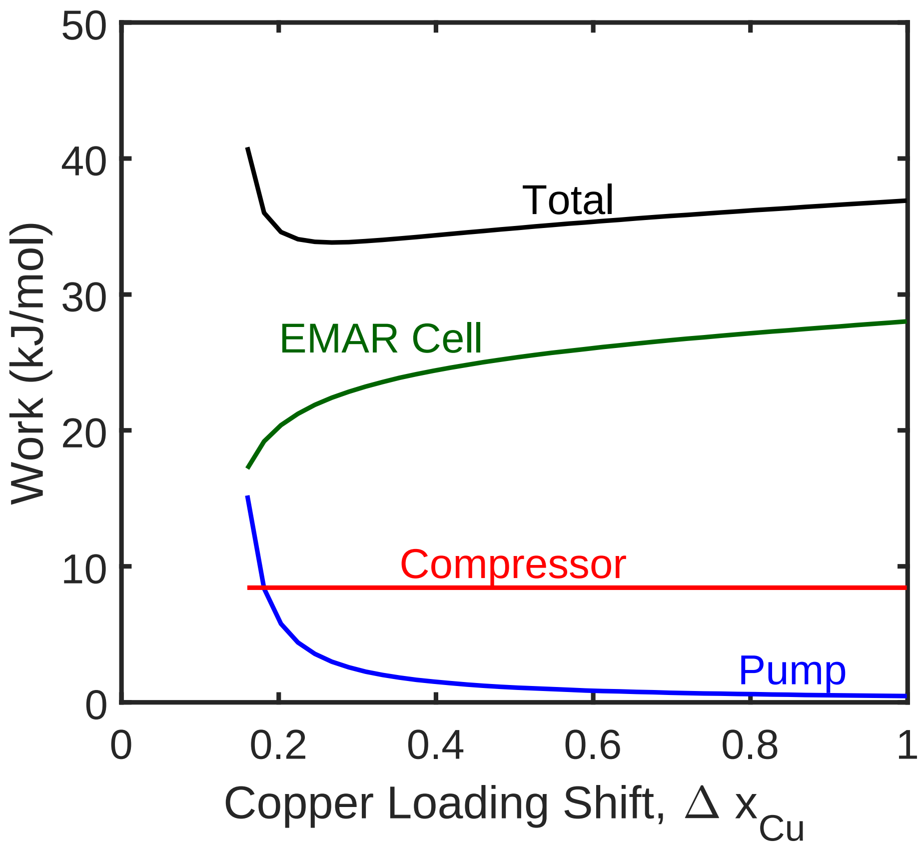
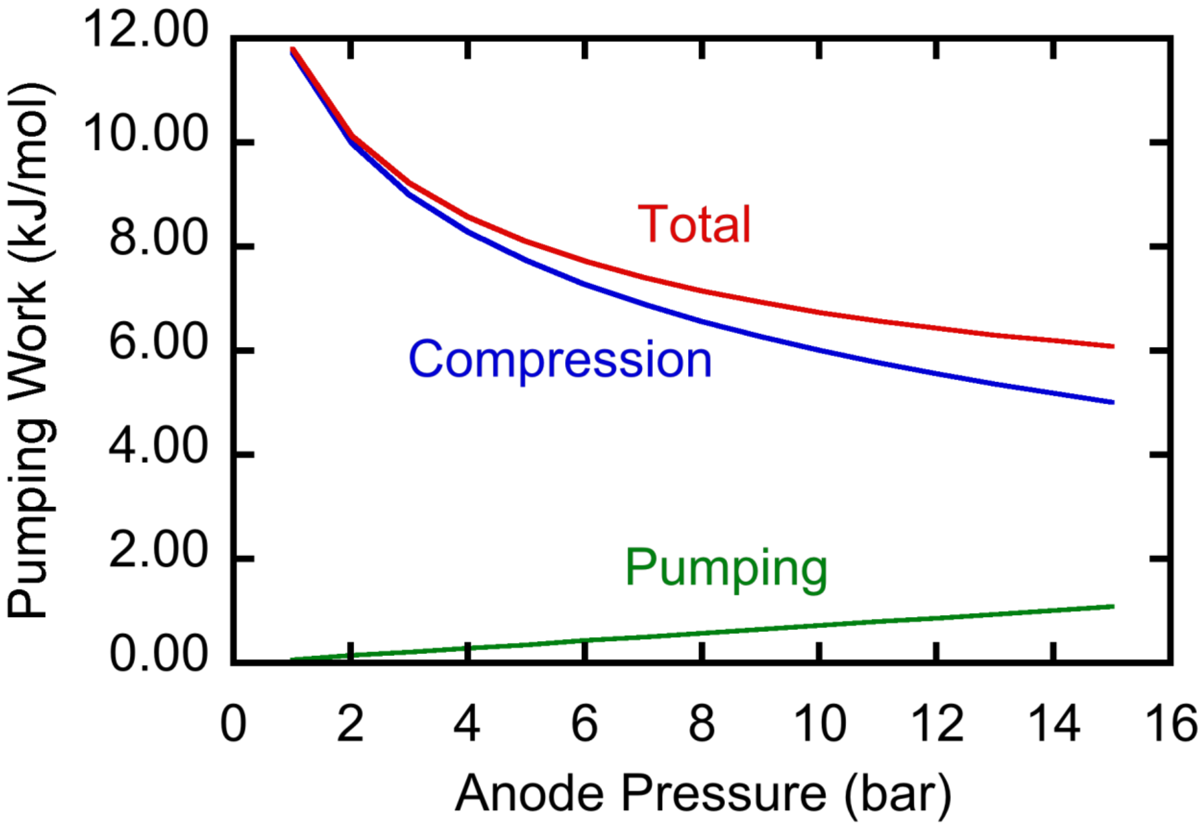


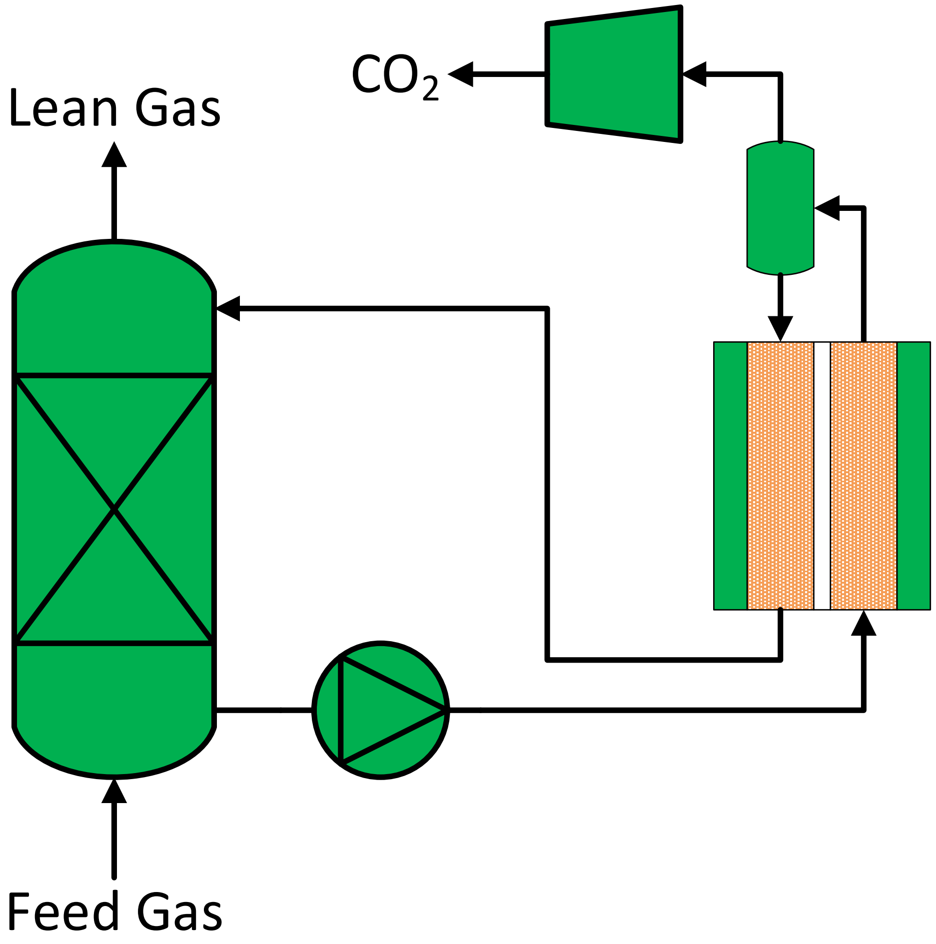


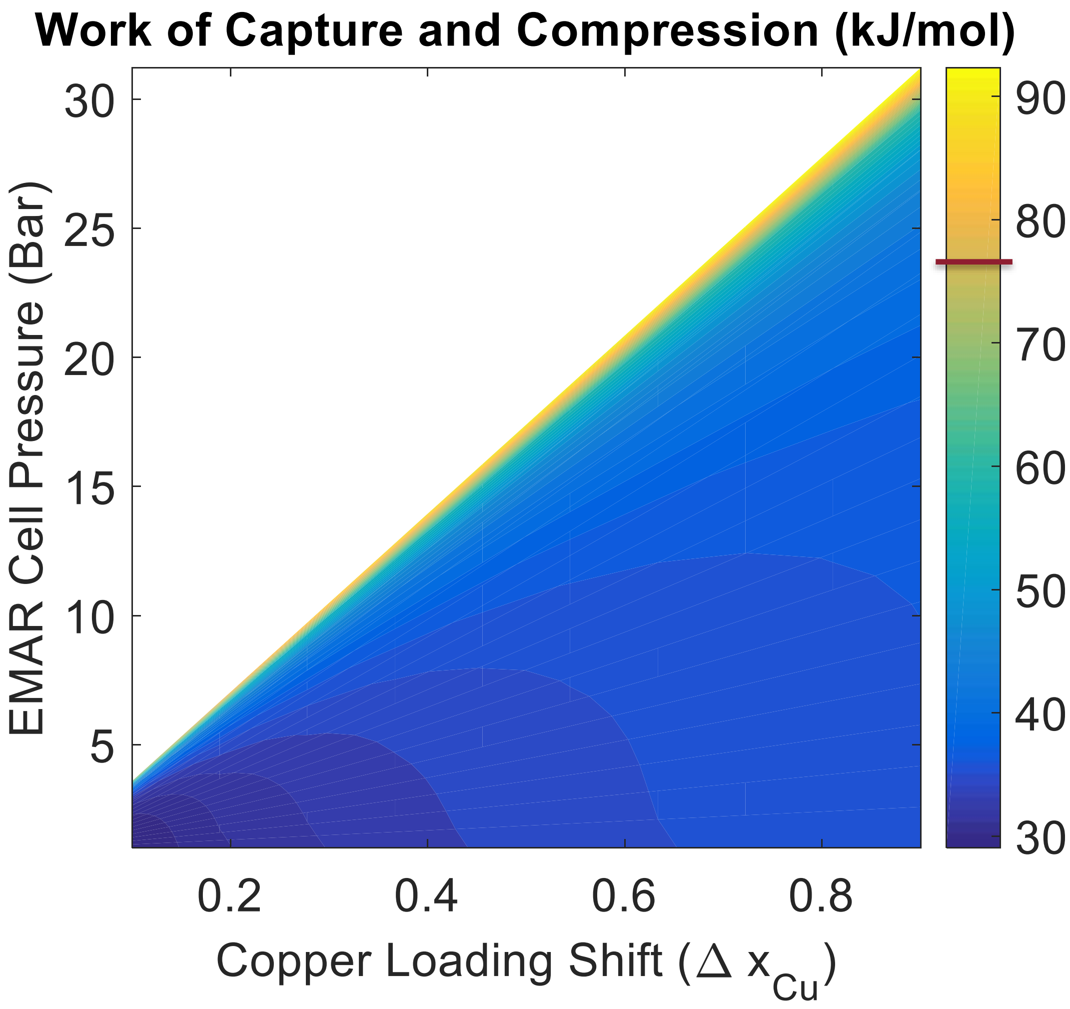
Total Work for EMAR Cell





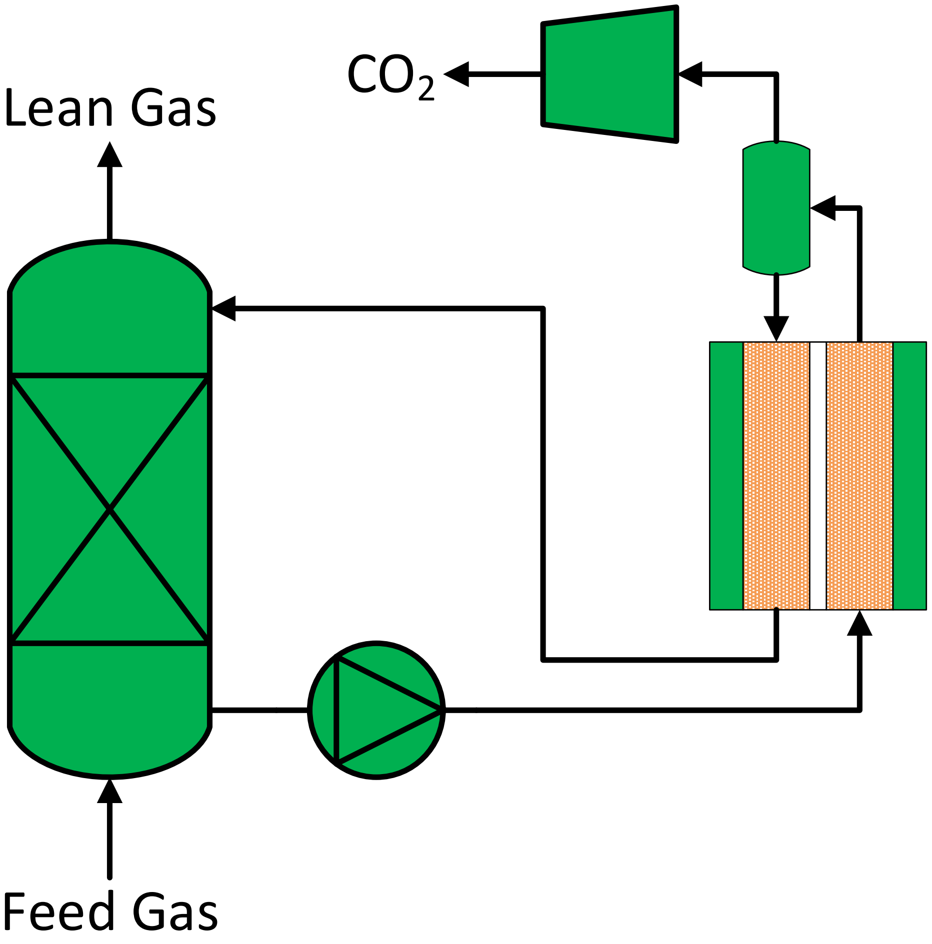
Thermodynamic Results

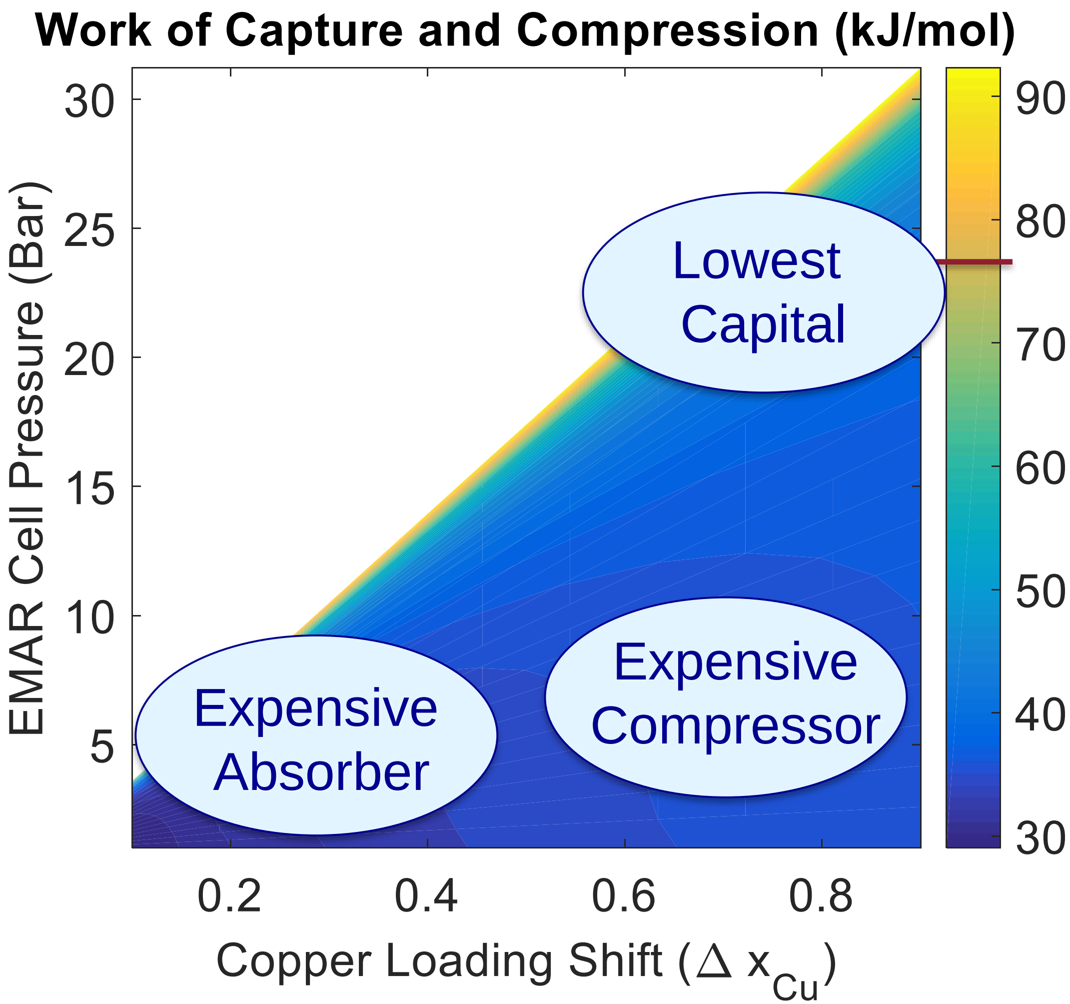




Thermodynamic minimum work of CO_2 capture and compression to 150 bar of a 15% CO_2 stream

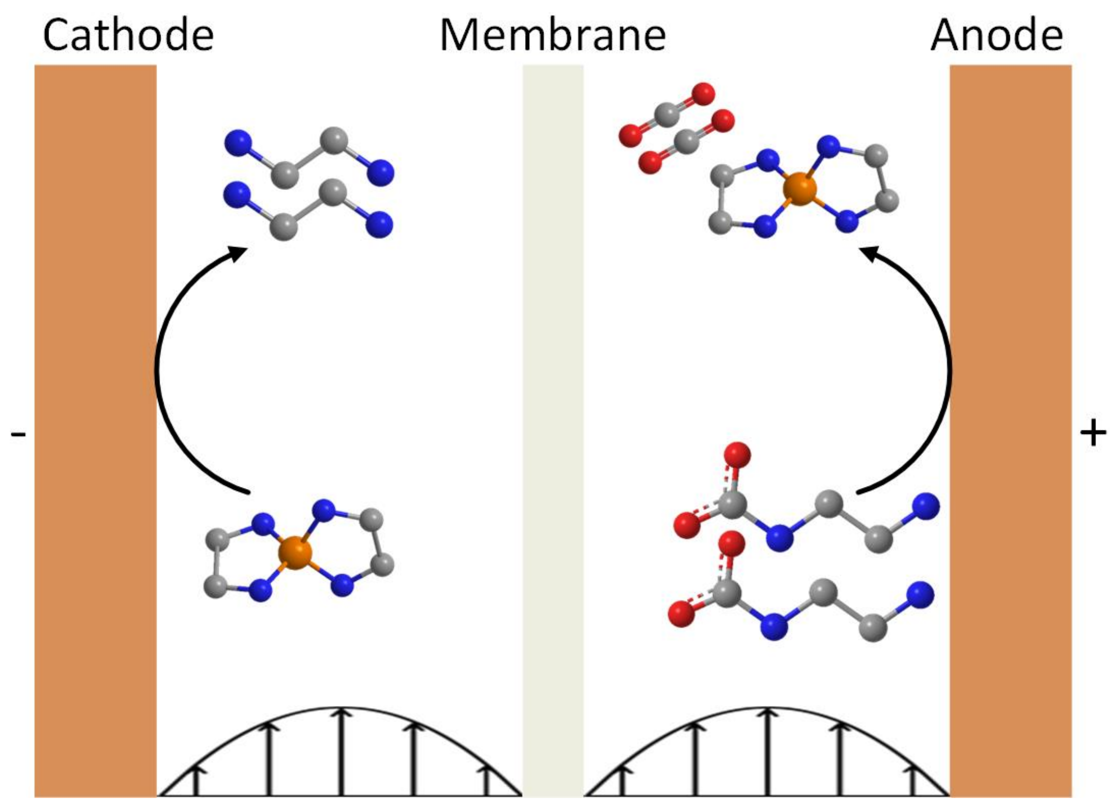
Thermodynamic Results

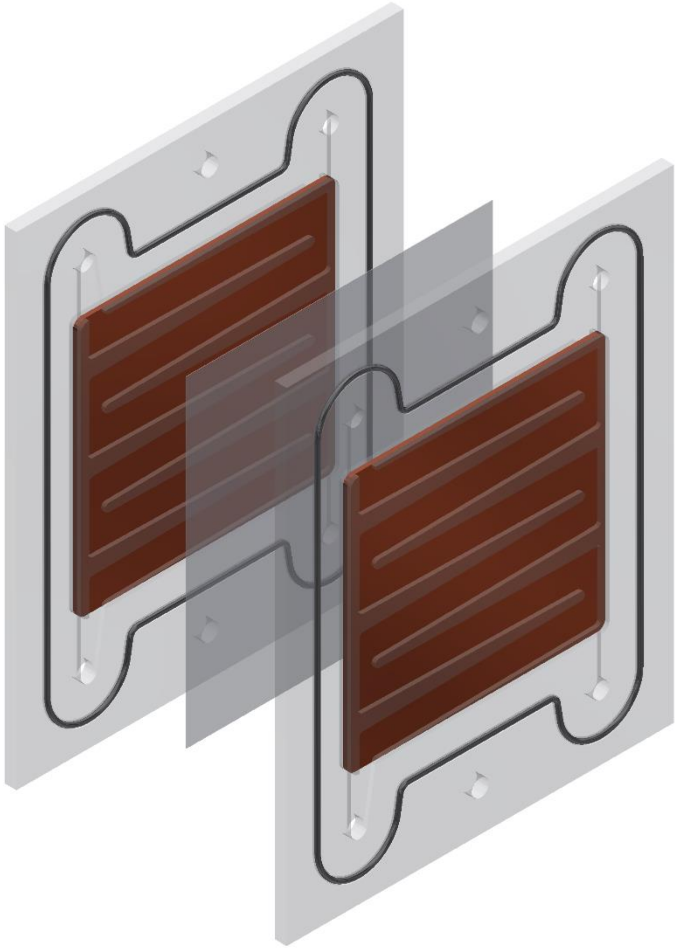




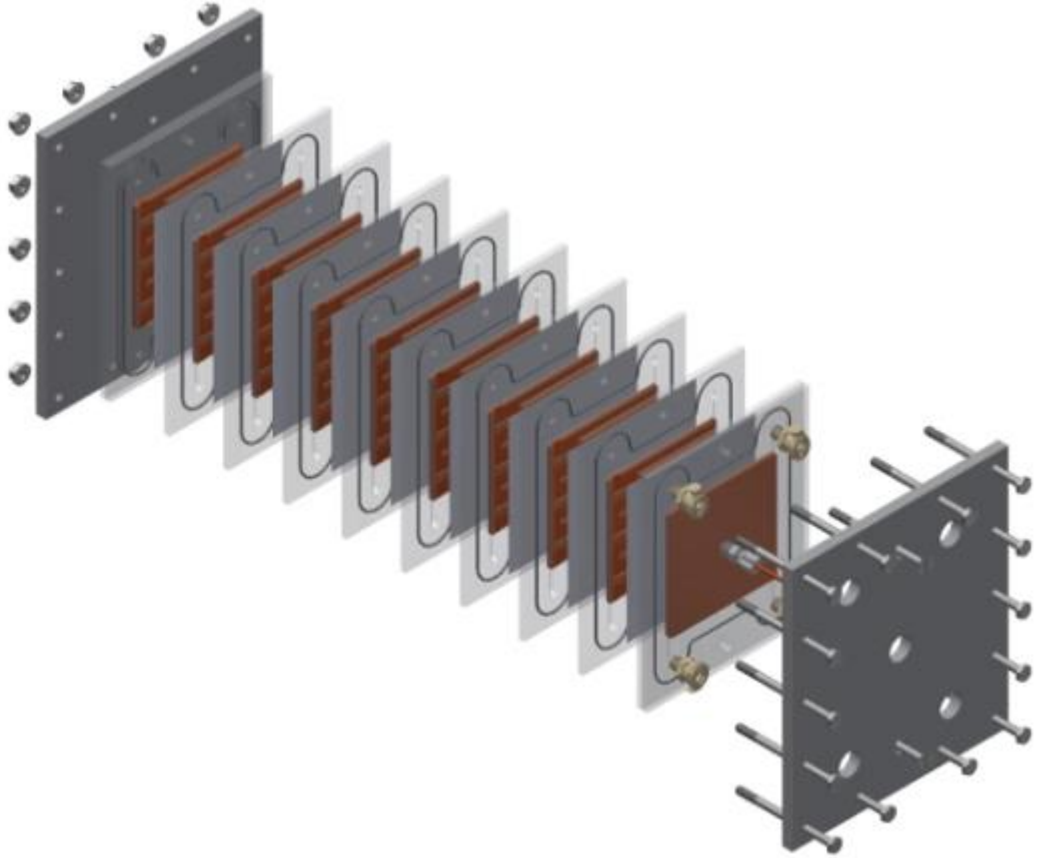
Thermodynamic minimum work of CO_2 capture and compression to 150 bar of a 15% CO_2 stream

Anatomy of EMAR Cell

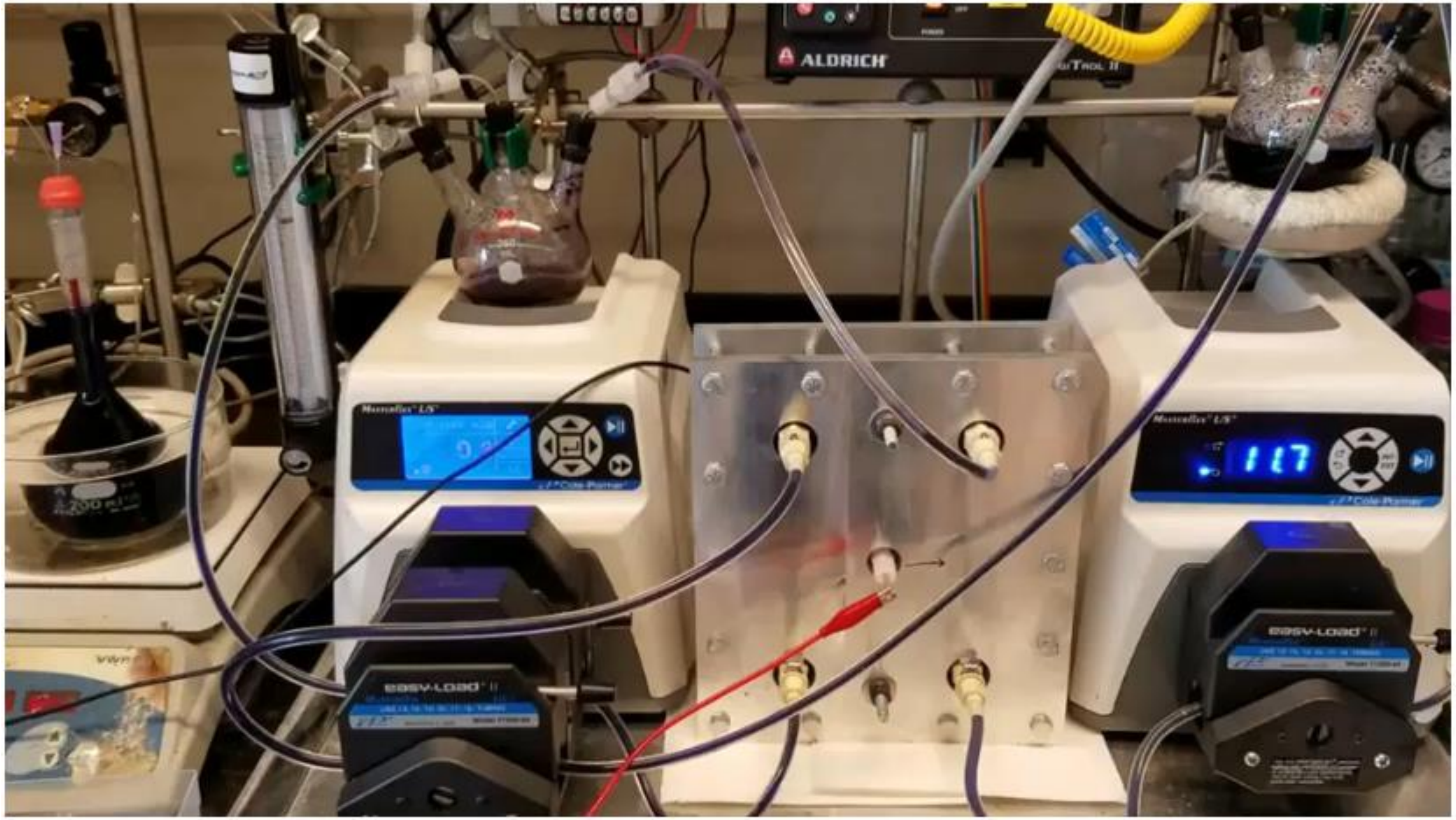


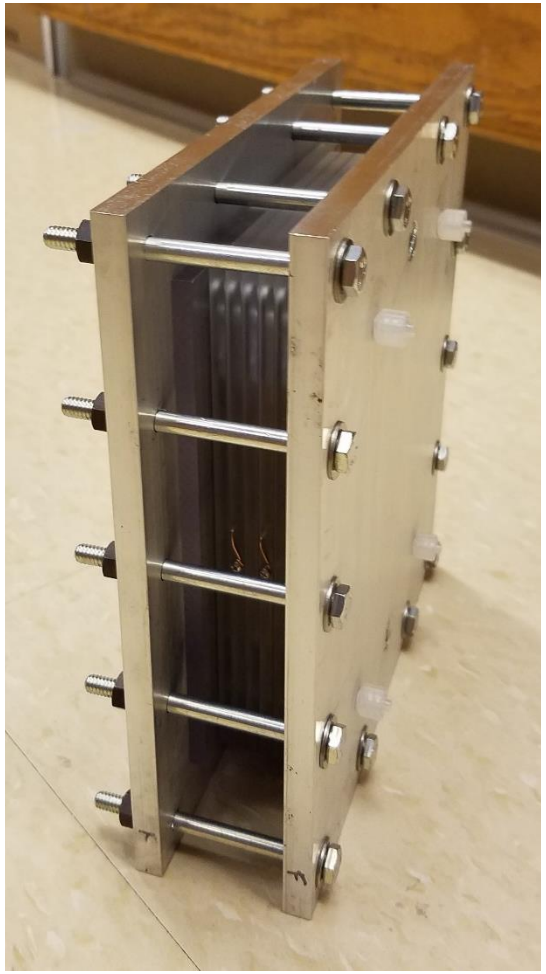


Scaling Up Electrochemical Systems



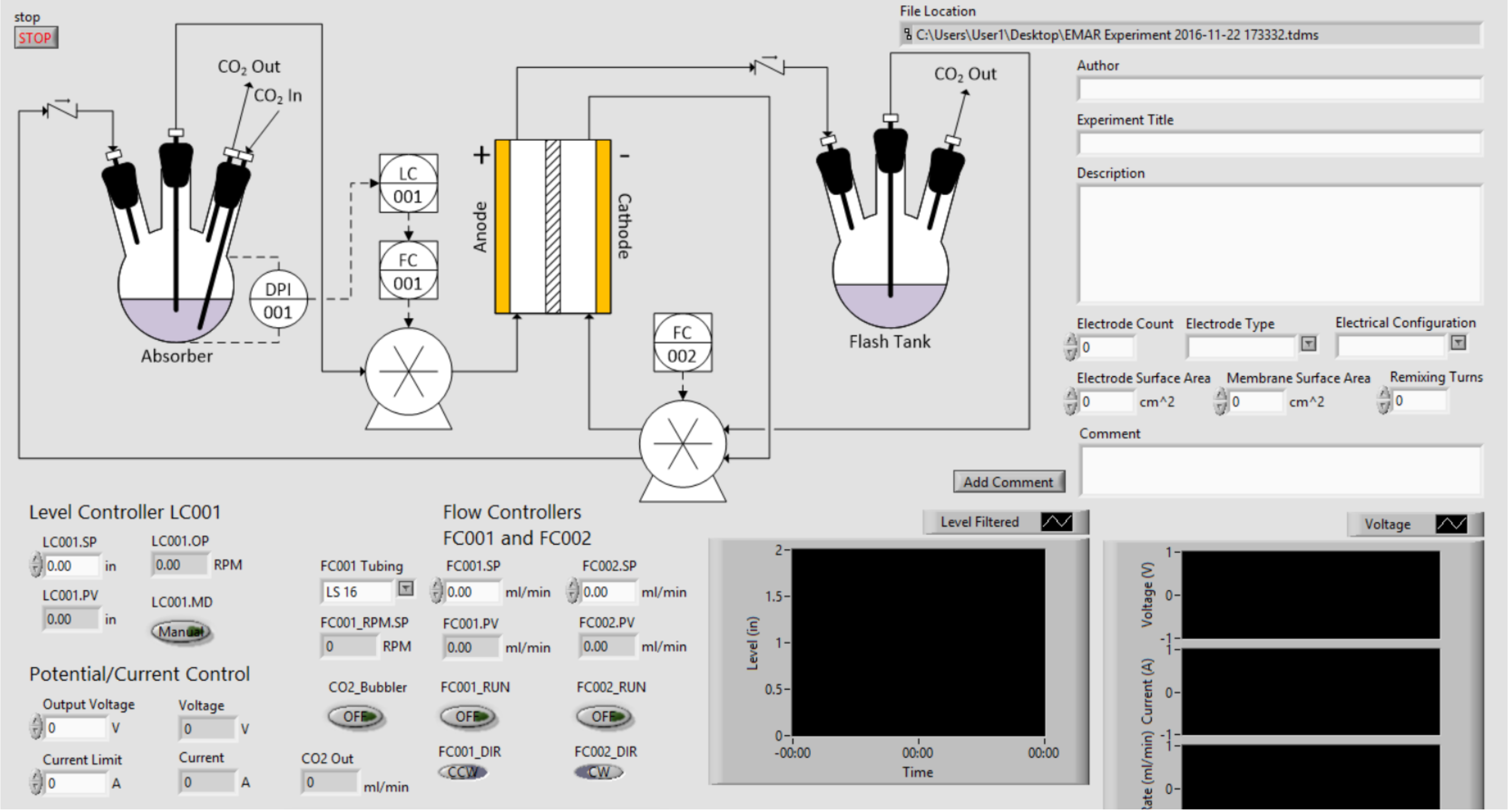
Experimental Demonstration of CO_2 Release

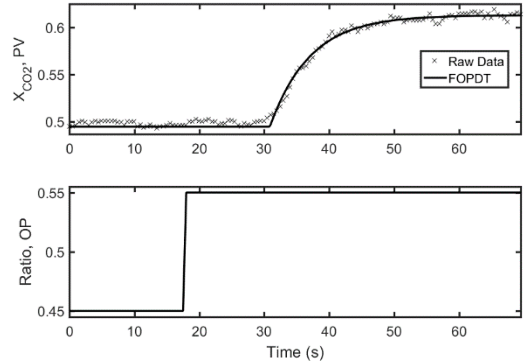


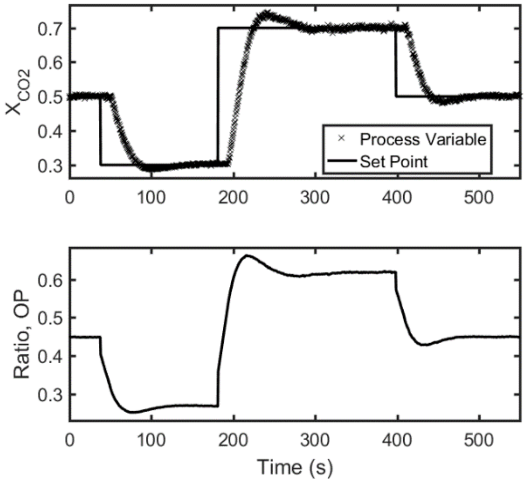


Liquid flow rate = 10mL/min

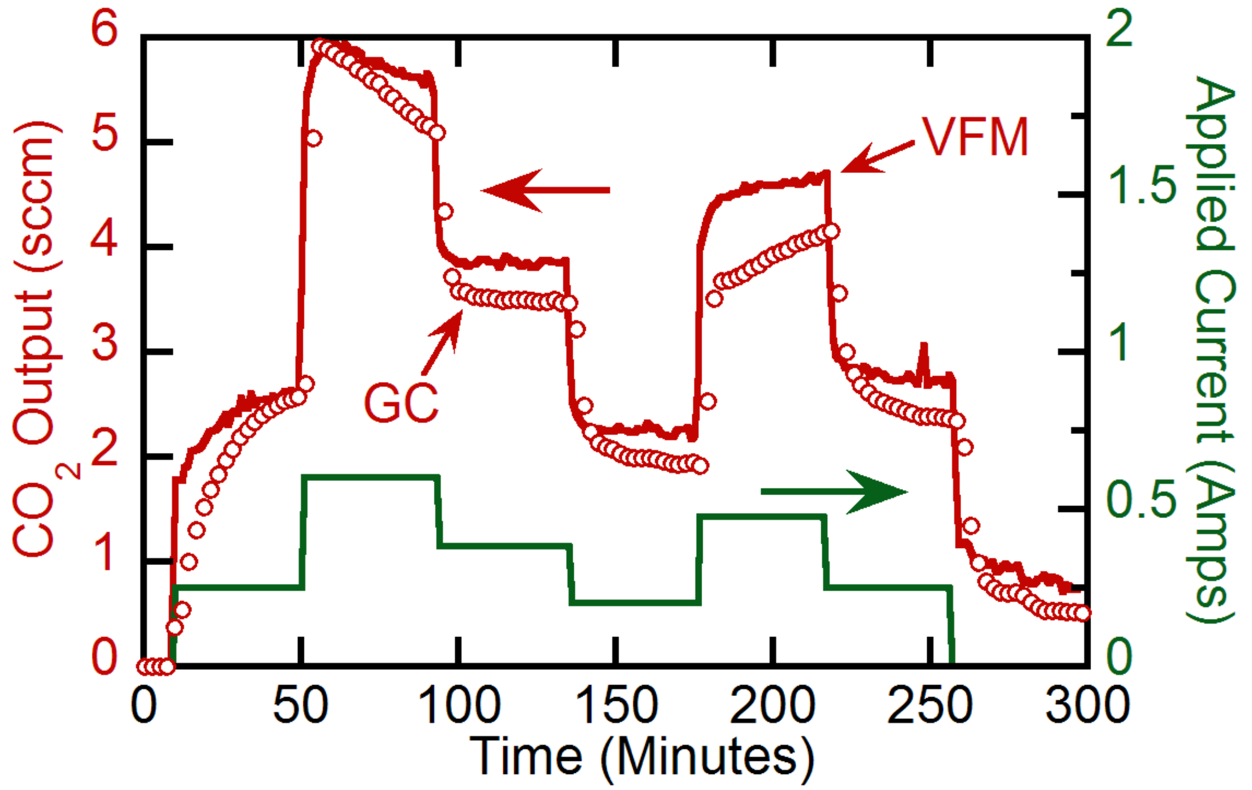
Process Automation

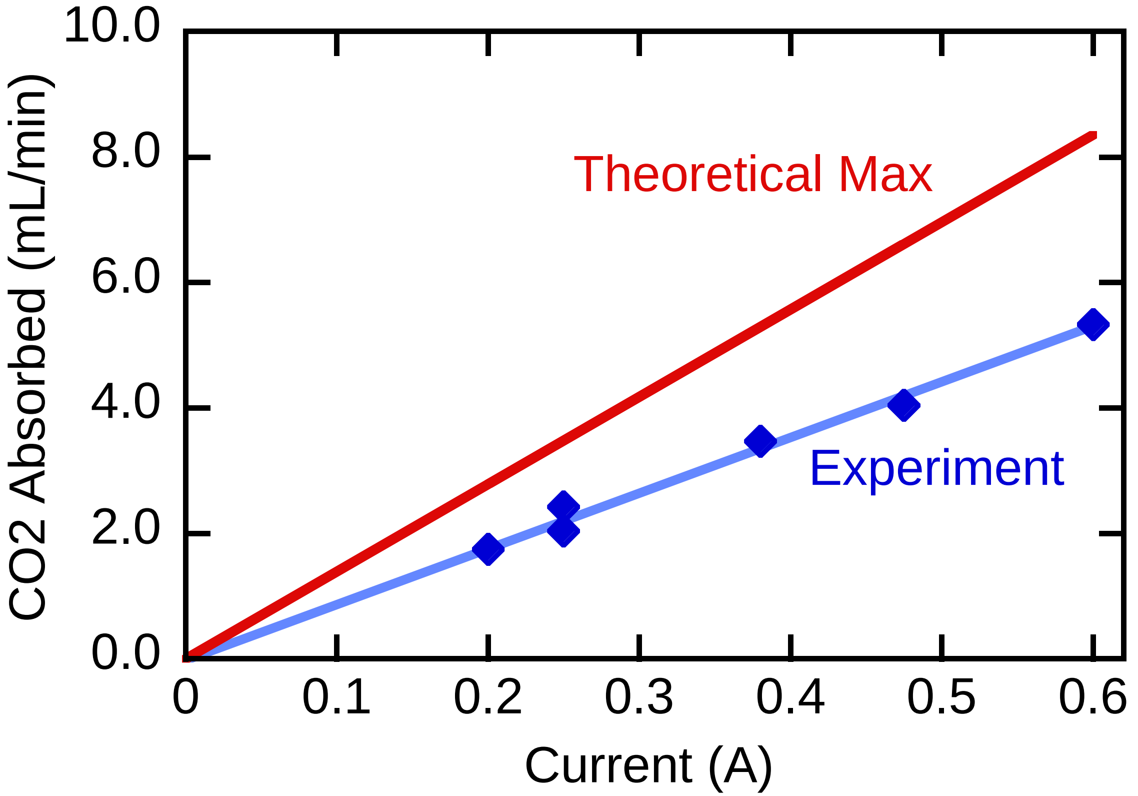




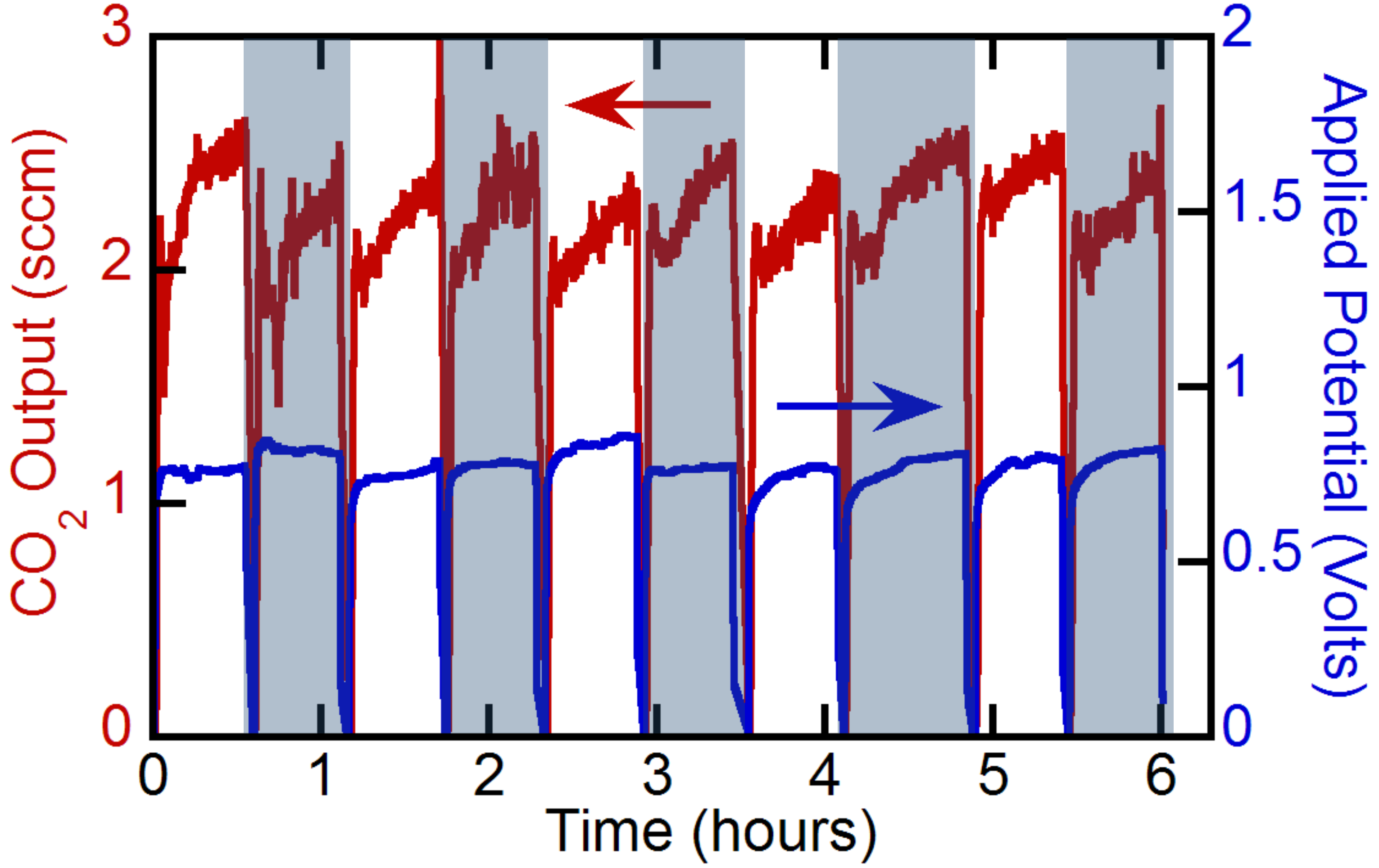


CO_2 Release in Response to Applied Current

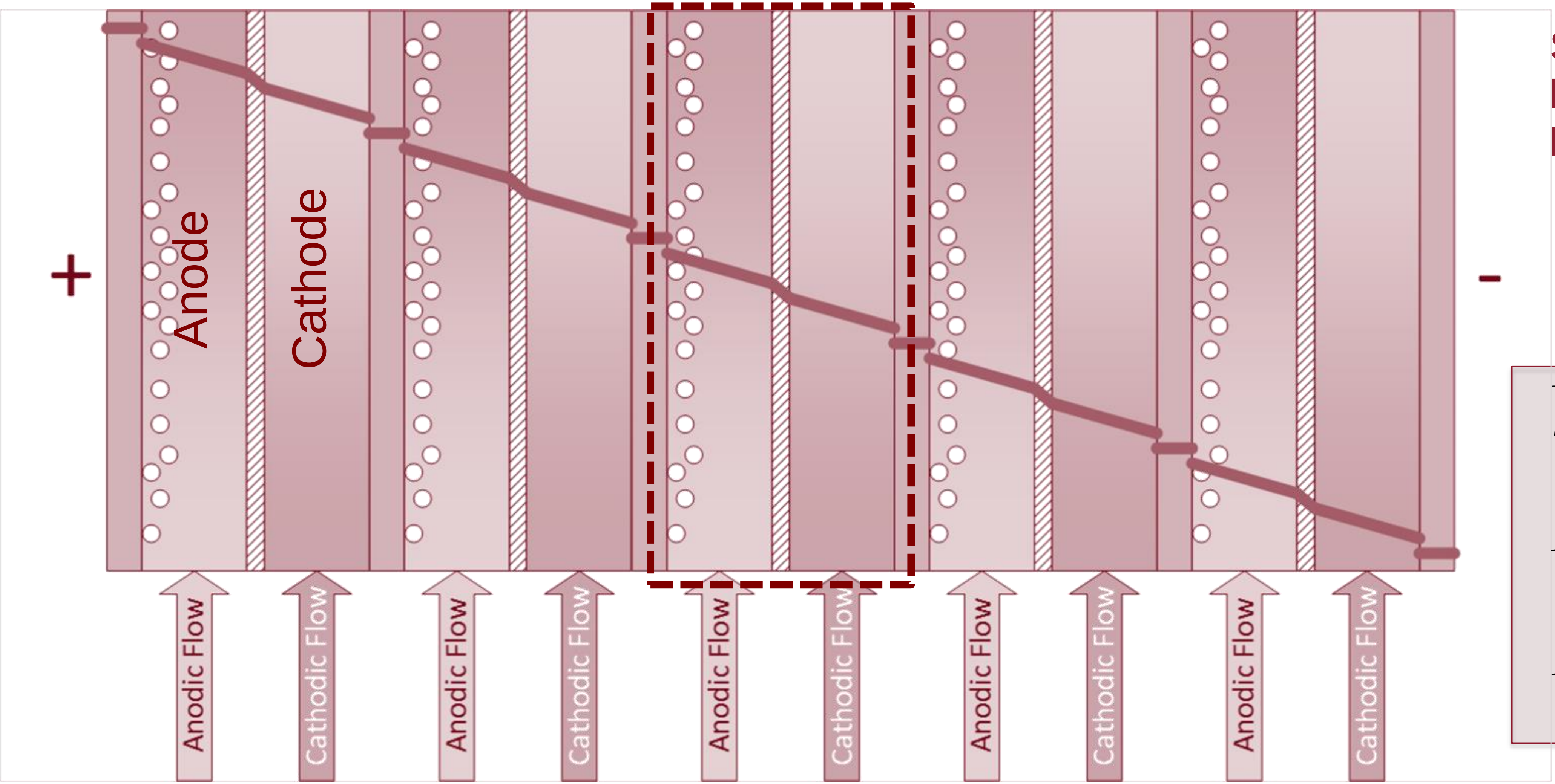




Cyclic Stability of EMAR Operations



Series Geometry



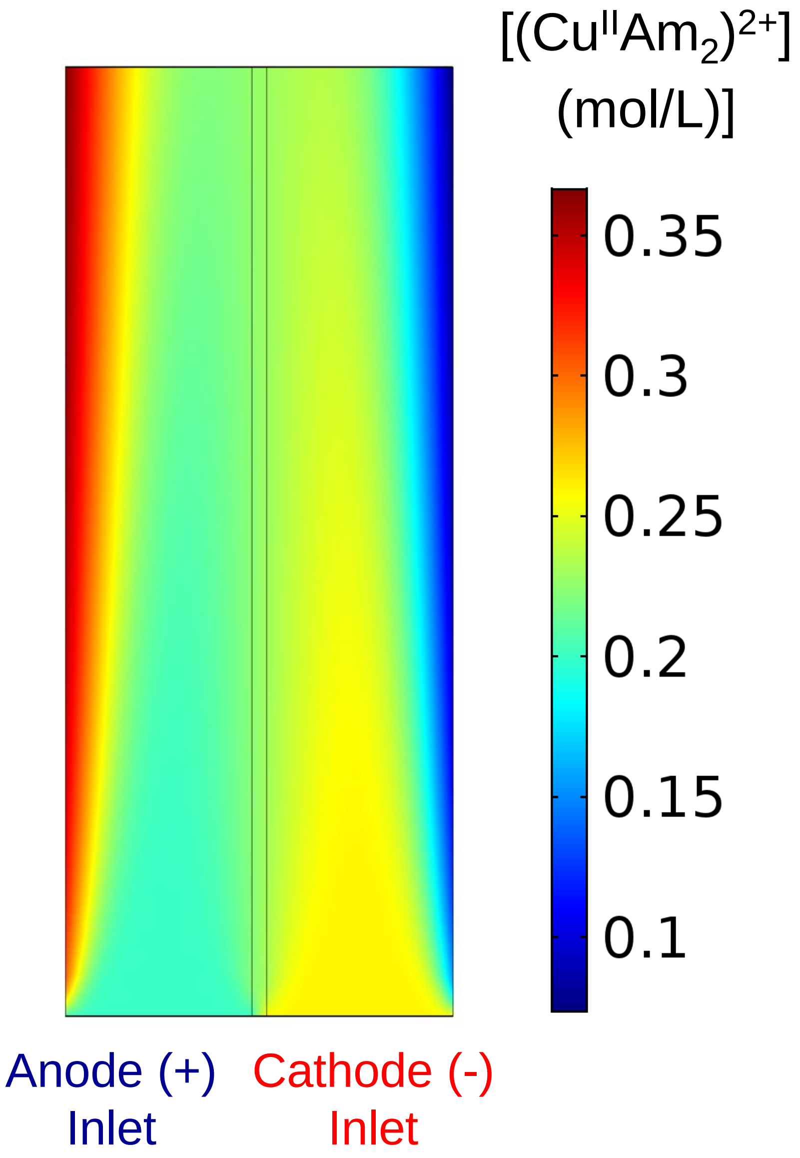
Series geometry
high voltage
low current

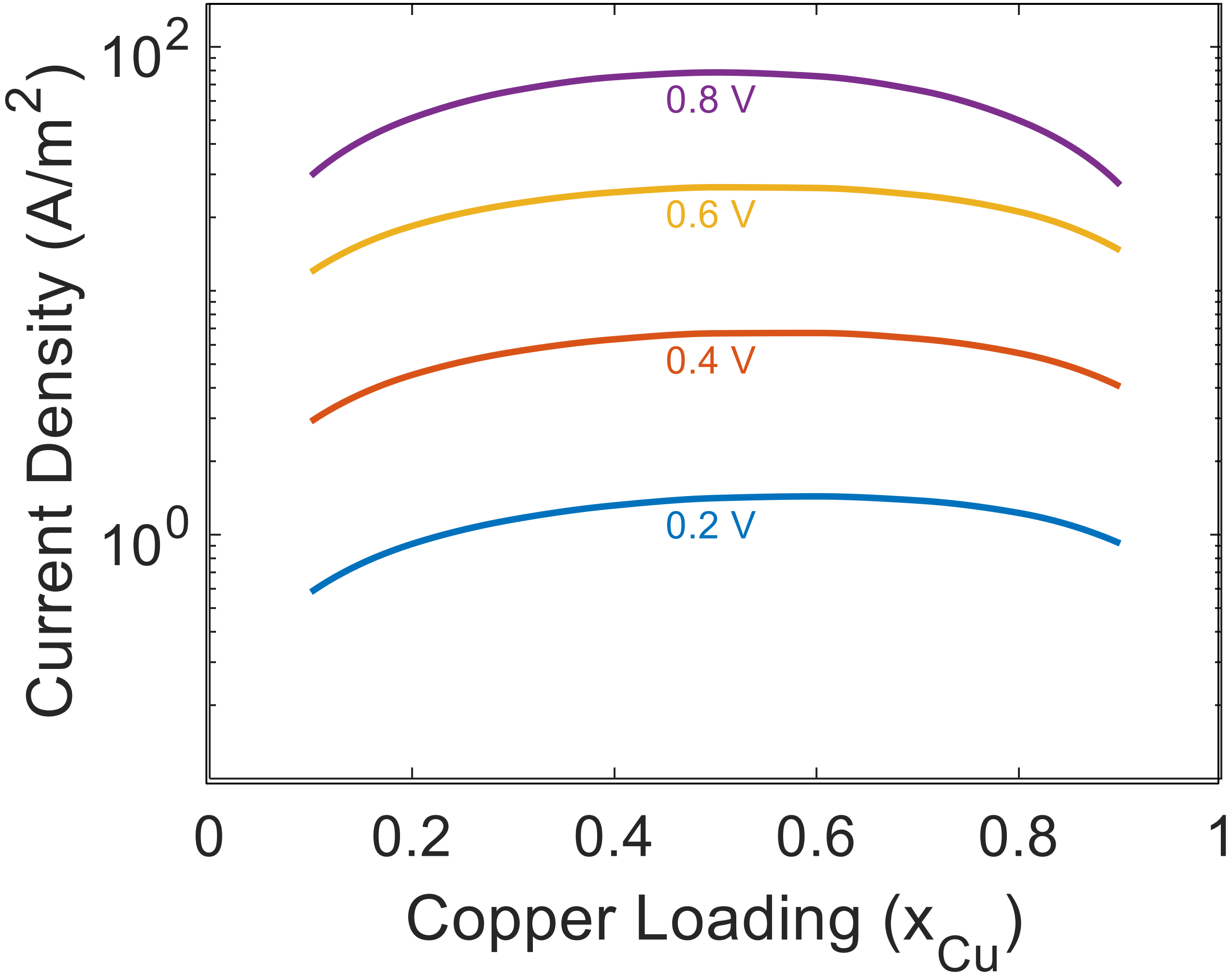
$$V_{stack} = nV_{cell}$$

$$I_{stack} = I_{cell}$$

$$P = nV_{cell} I_{cell}$$

Copper Loading Effect on Current Density





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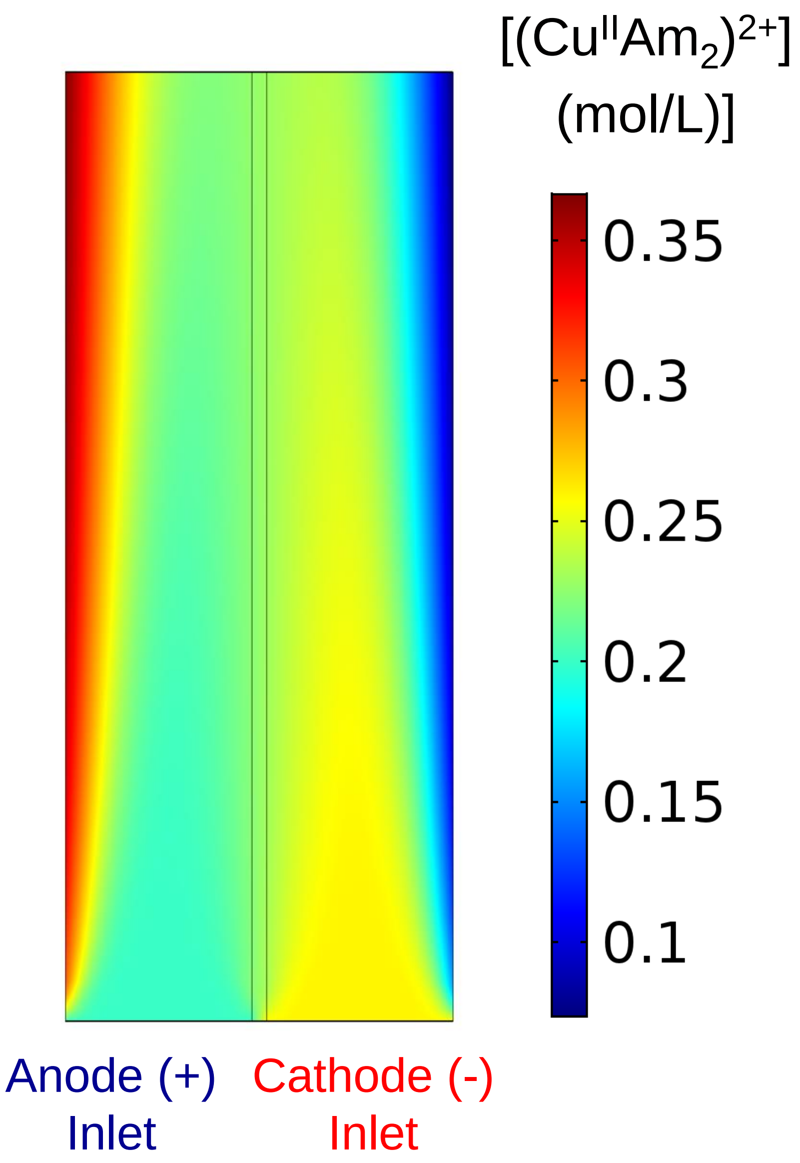
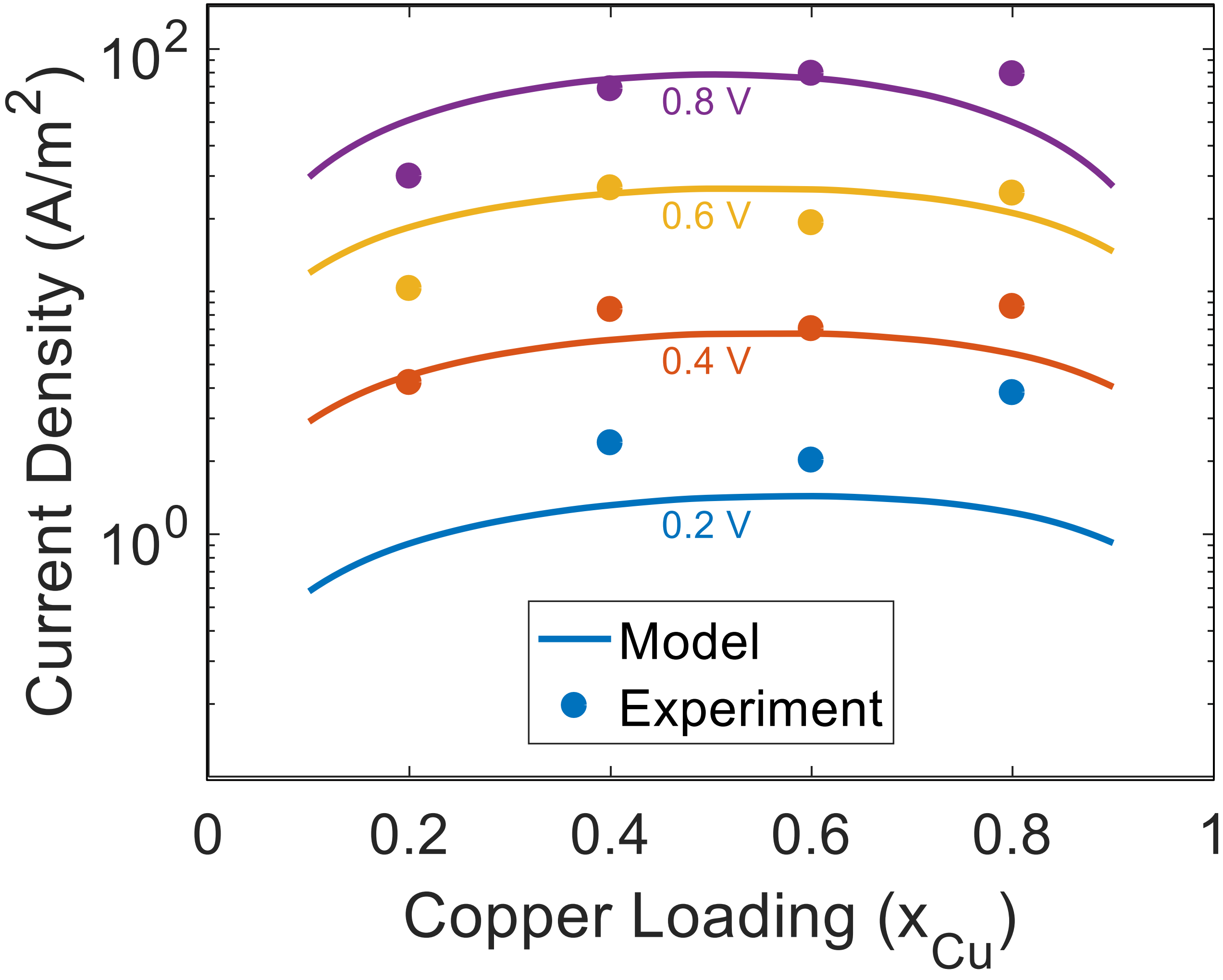
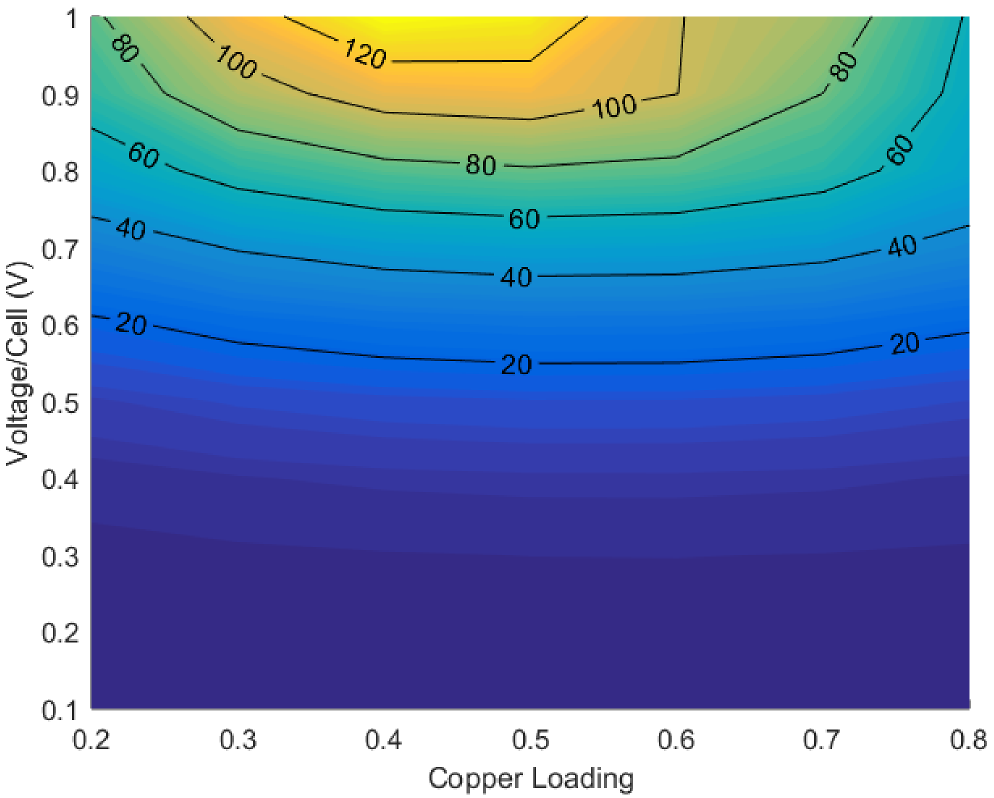


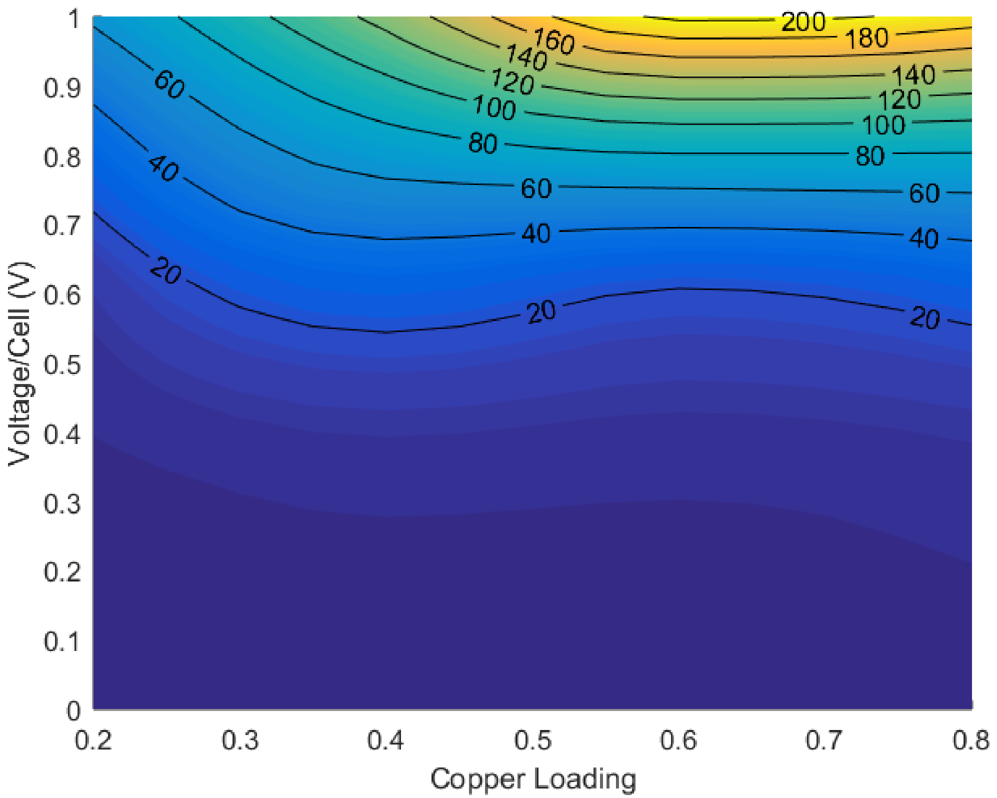


Series Experiments – Current Density

Theoretical Current Density (A/m²)

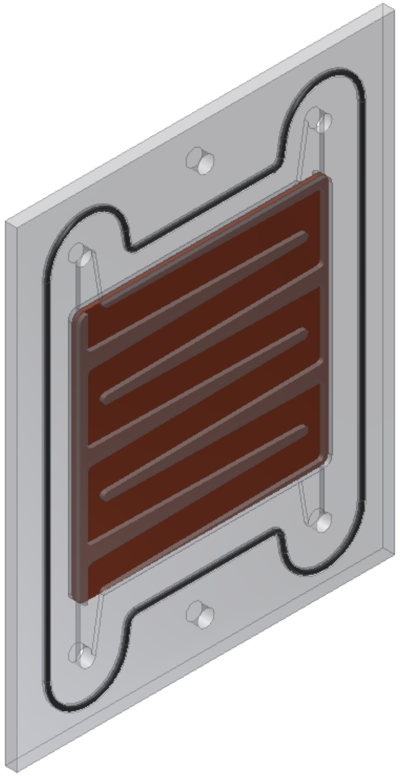


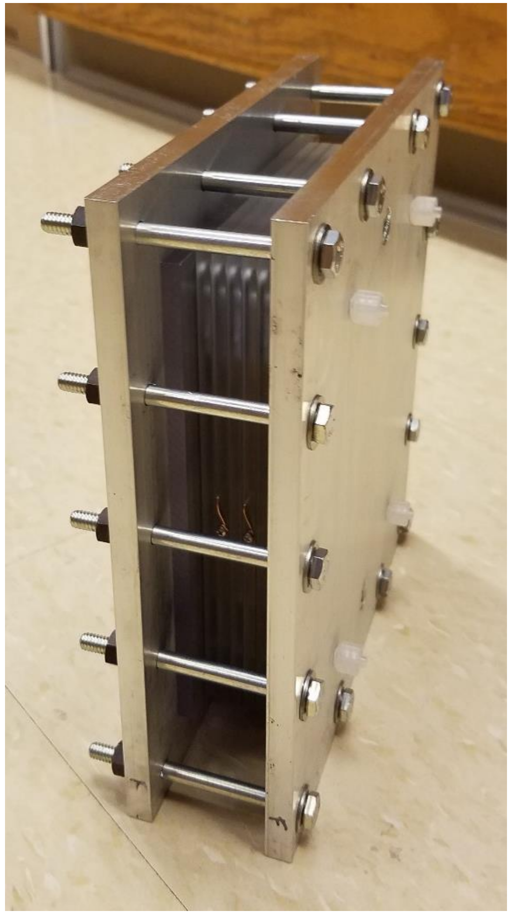
Experimental Current Density (A/m²)



- Change in the anodic reaction as CO_2 loading drops or increased advection (diminishing boundary layer resistance) caused by CO_2 production in the anode.
- Parasitic side reactions (especially in the cathode) (e.g.,. formation of CuO).

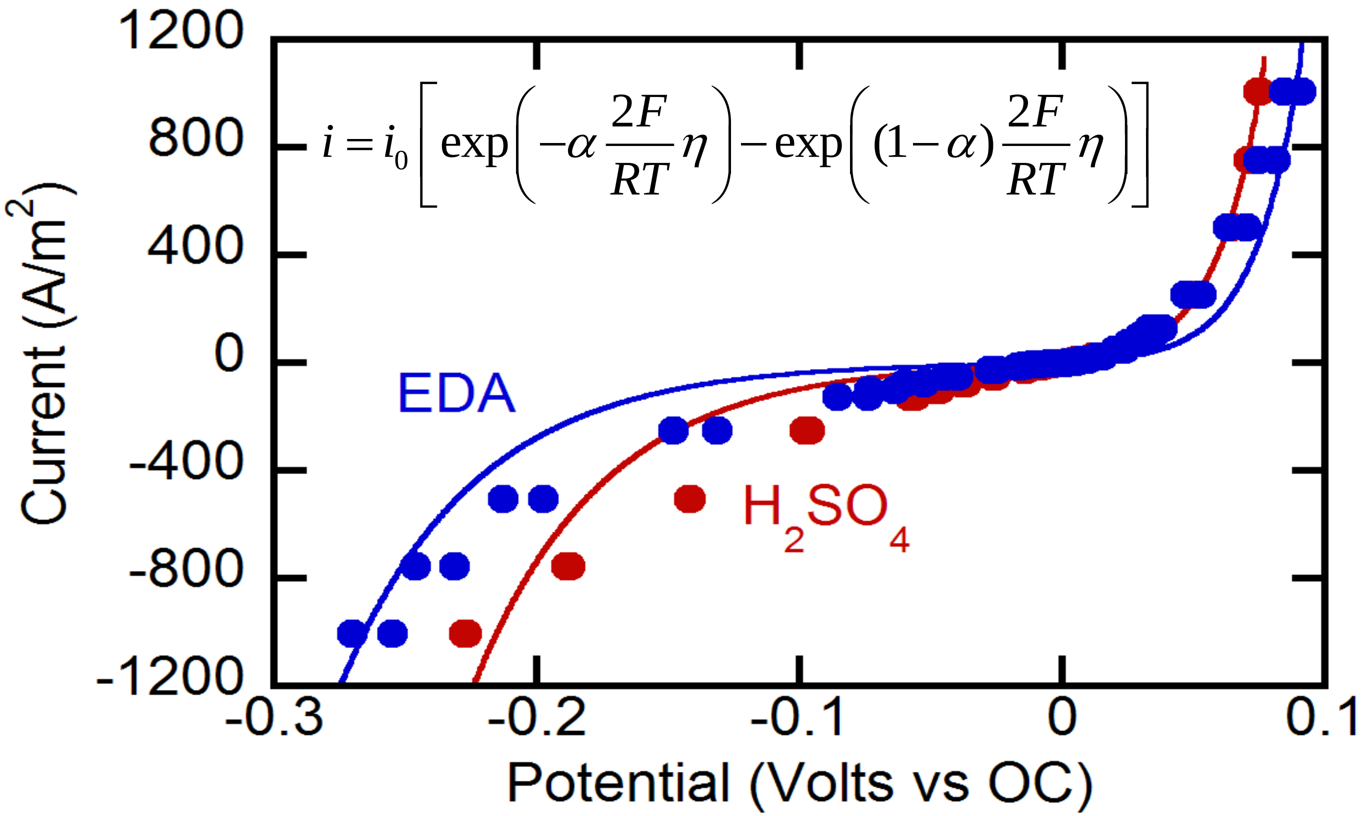
EMAR Advantages





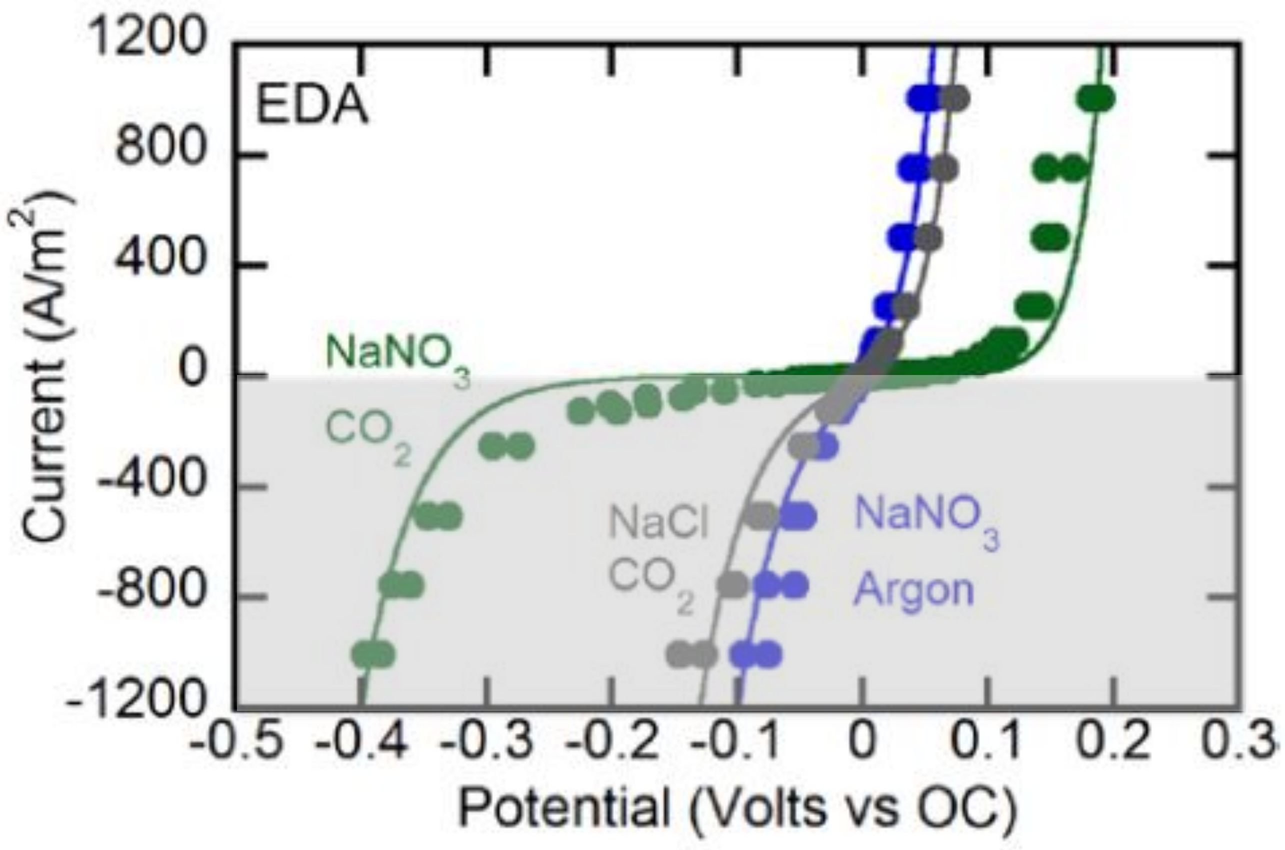
Energy Consumption	15 – 40 kJ/mole
Low temperature Operation	Yes
Ease of Deployment	Plug-and-Play
High Pressure Desorption	Yes

Overpotentials for Electrochemical Reactions



In absence of CO_2, formation of EDA complex does not significantly hinder Cu deposition and dissolution. EDA Stabilizes Cu^{2+} in solution

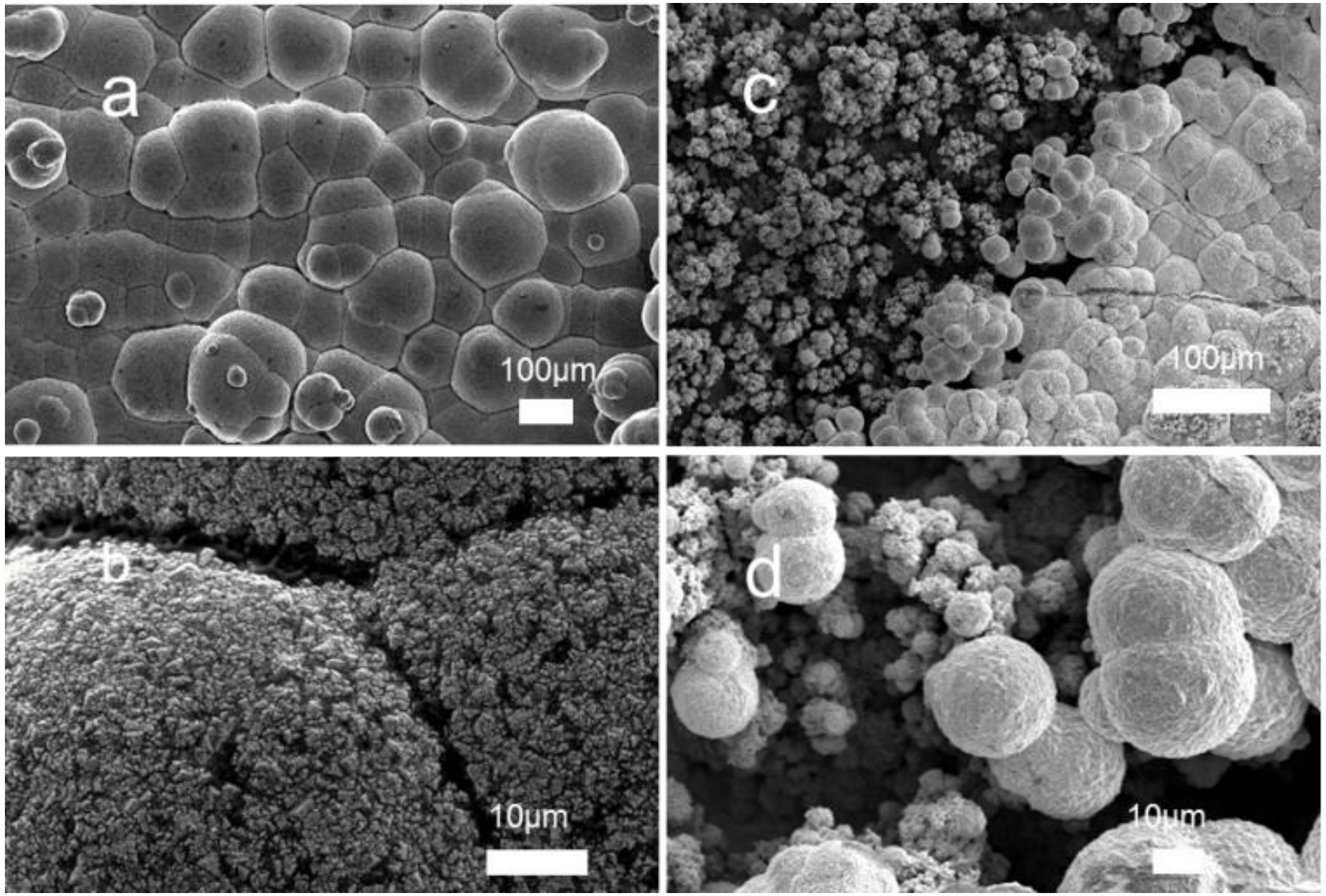
Overpotentials for Electrochemical Reactions



EMAR Cathode ideally operates in absence of CO_2

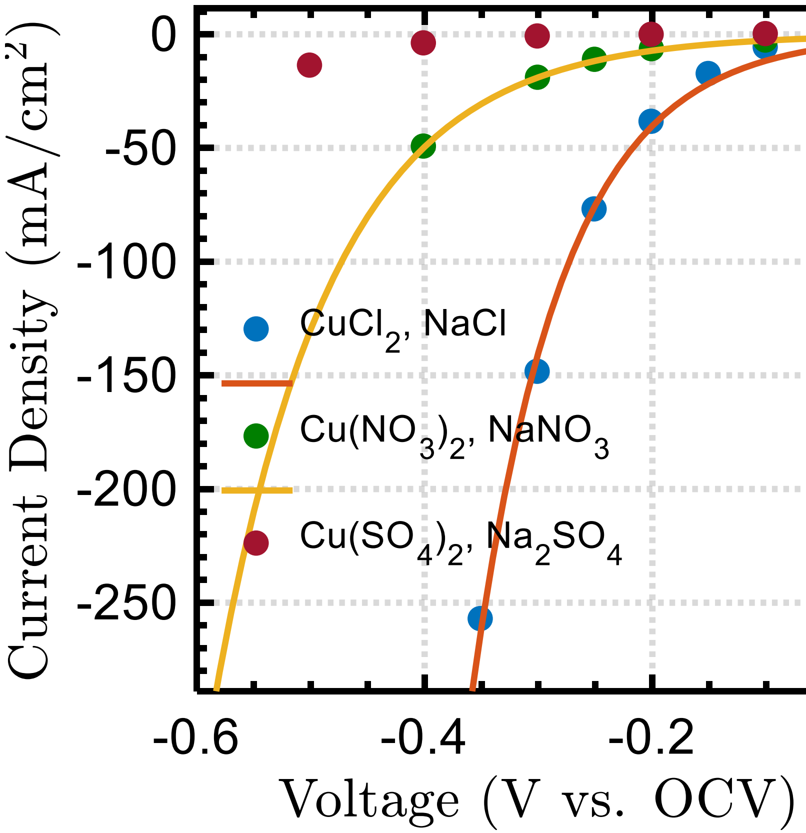
In presence of CO_2, kinetics are significantly hindered. However, chlorides were observed to improve performance significantly.

Effects of Supporting Electrolyte on Copper Reduction



NaCl

NaNO3



Project Risks and Mitigation Strategies

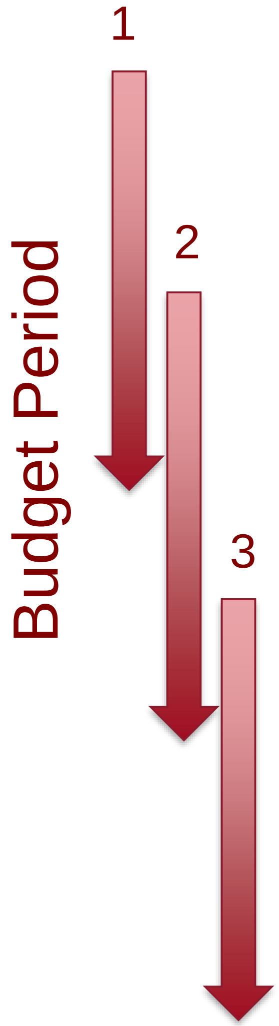
Technical Risks	Probability	Impact	Risk Mitigation
CO_2 sorbents and metal ion systems unsuccessful	Medium	Low	Wide range of candidate sorbents available. Initial results are promising
Electrochemical cell models low in fidelity and do not permit optimization	Moderate	Low	Complexity of underlying mechanisms in electrochemical cell presents risk for modeling. Parametric experiments will generate sufficient data for empirical optimization.
Process found to be too sensitive for long-term operations and disturbances	Moderate	Moderate	Preliminary testing is encouraging. Degradation of electrodes or sorbents possible, but can be mitigated through design of electrode configurations

Resource and Management Risks

Resource Risks	Probability	Impact	Risk Mitigation
Cost of bench-scale system after optimization more expensive than planned	Low	Low	Most of the components of the system have been procured and operated in previous work, but the optimized system might involve more expensive equipment, especially for automation.

Management Risks	Probability	Impact	Risk Mitigation
Process performance reaches a plateau that does not satisfy DOE research goals	Moderate	High	The progress reports will allow the project team to evaluate the performance of the process and determine whether it is possible to explore new dimensions for performance improvements.

Experimental Design and Work Plan



Task	SubTask
Evaluate and Test CO_2 Sorbents and Metal Ions for Electrochemical Regeneration	• Identify and Shortlist Candidate Molecules • Thermodynamic and Kinetic Experiments on Candidate Molecules • Cycling Stability Experiments on Candidate Molecules
Process Modeling and Cost Estimation	• Develop process model and evaluate pressure effects • Develop cost estimates
Electrochemical Cell Model Development	• Establish kinetics and mass transfer model • Model validation
Flow Channel Design and Optimization	• Model-aided design of candidate flow channels • Construction and testing of candidate flow channel configurations
Optimization of Electrode Configuration and Cell Architecture	• Evaluation of different electrode materials • Evaluation of cell architectures
Evaluation of Optimized Chemistries and Cell Designs	• Design and build instrumented lab-scale apparatus • Testing of candidate systems under wide operating conditions • Stability testing

Acknowledgements

Mike Stern

Aly Eltayeb

Ryan Shaw

Miao Wang