Electrochemical Conversion of Carbon Dioxide to Alcohols (FE0029868)

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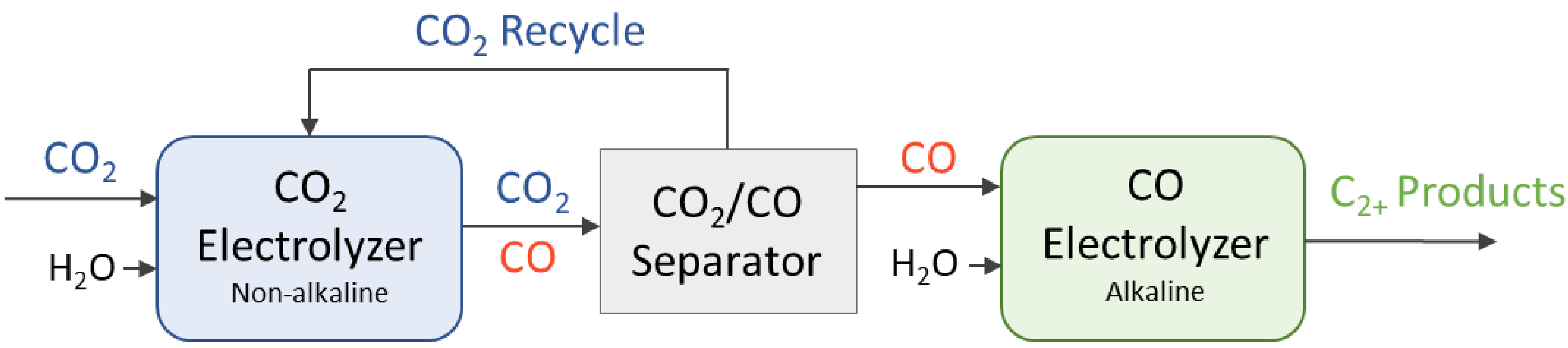
Project Objectives and Approach

1) Development of critical components for an electrochemical system that is able to convert CO_2 into C_2/C_3 alcohols
2) Demonstration of key functions of an integrated electrochemical system for CO_2 conversion using flue gas from coal-fired power plants
3) Full analysis of economics and life-cycle of the CO_2 electrolysis technology for CO_2 emissions mitigation from coal-fired power plants

Our Approach:



Project Funding: $1M ($800k DOE share; $200k UD Share)

Budget Period 1: 06/01/2017-2/28/2019

Budget Period 2: 3/01/2019-08/31/2020

Kick off
Jun. 2017

Go/no-Go #1
Feb. 2019

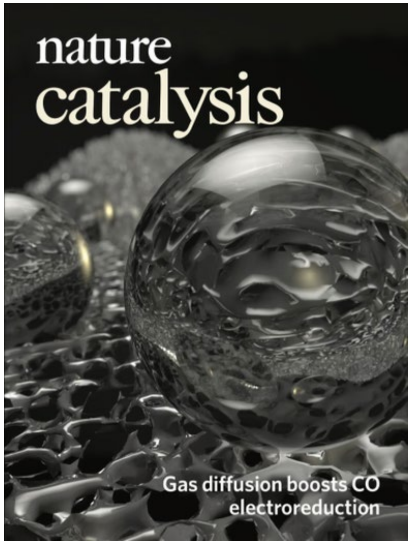
Final Report
Aug. 2020

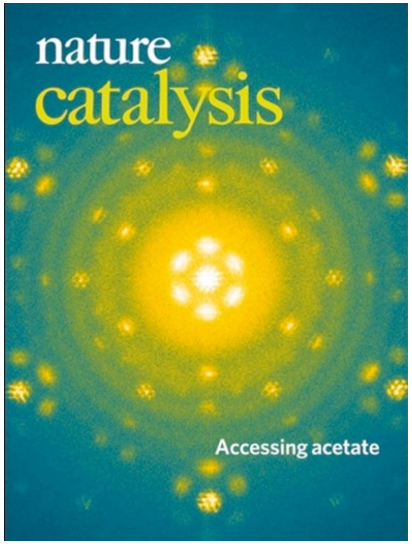
BP 1: Subsystem components development and evaluation

BP 2: System integration and evaluation, TEA, LCA

Major Achievements

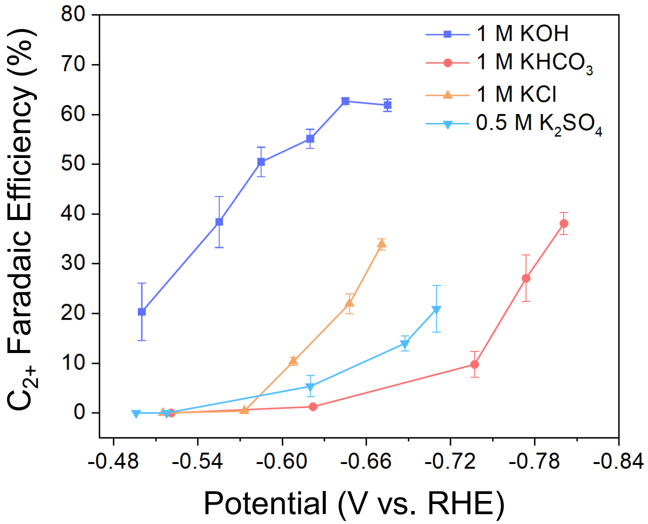
- Met all the milestones and performance targets
- Published key results in leading scientific journals
  - *Nature Catalysis* 1, 748-755 (2018)
  - *Nature Catalysis* 2, 423-430 (2019)
  - *Nature Chemistry* 11, 846-851 (2019)
  - *Nature Catalysis* 2, 1062-1070 (2019)
- Filed a U.S. patent application
- Testified before the U.S. Senate Committee on USE IT Act (Chaired by Senate Barrasso)





Challenges in direct CO_2 reduction in alkaline electrolytes

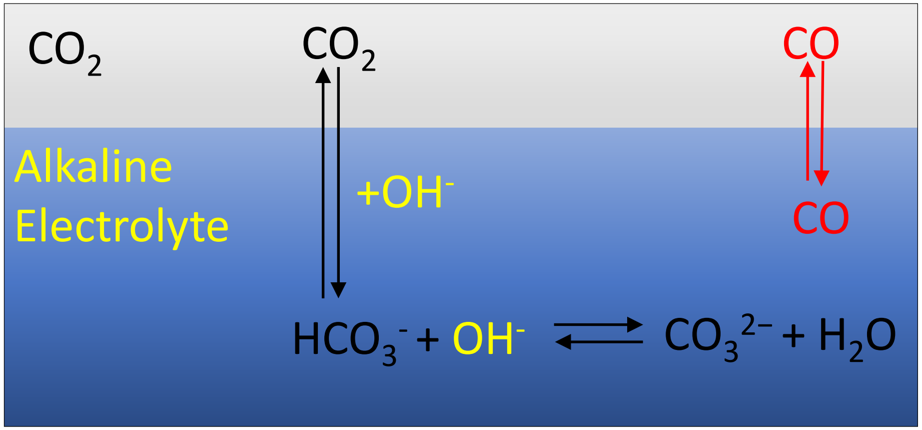
pH effect



Enhanced multicarbon products in highly alkaline electrolytes

1. Suppressed hydrogen evolution reaction
2. Enhanced C-C coupling

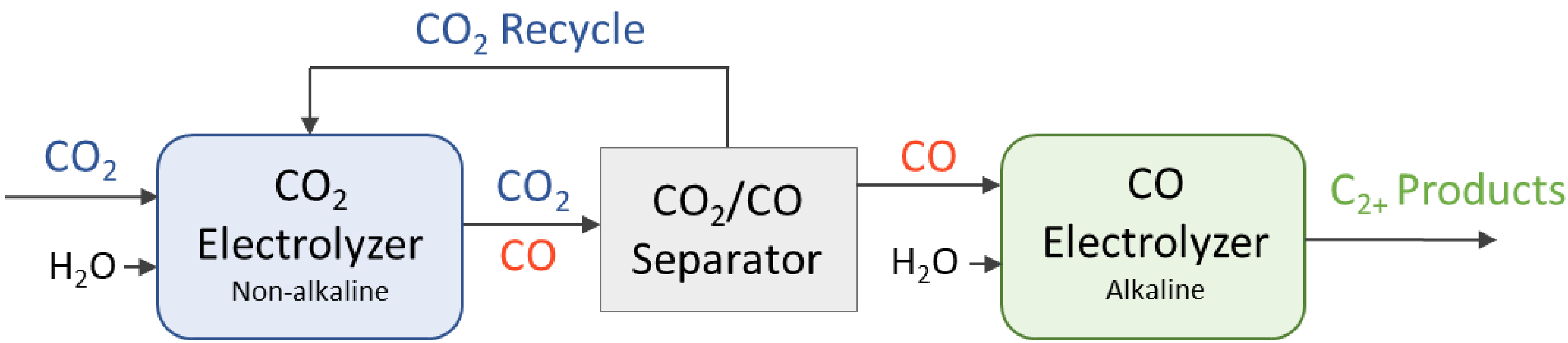
Carbonate formation in alkaline electrolytes



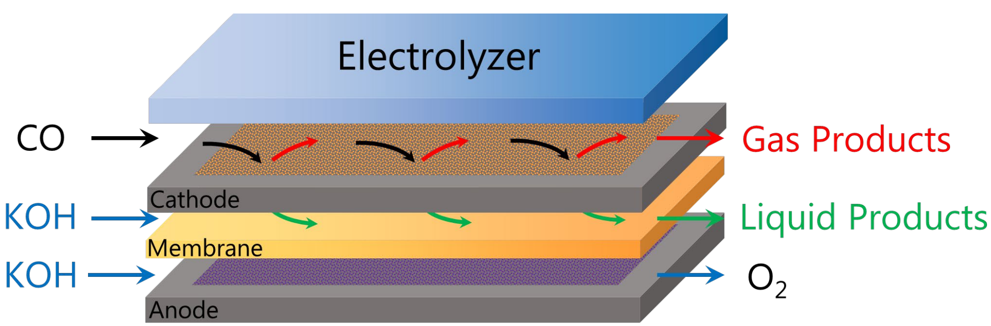
Direct CO_2 electrolysis in alkaline condition is unsustainable

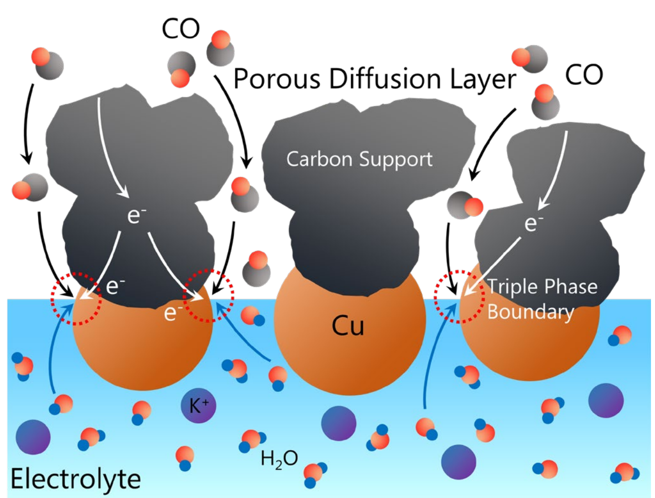
1. Carbonate precipitate degrades electrolyzer performance
2. CO_2 consumed
3. Electrolyte consumed

Two-step electrolysis through CO intermediate



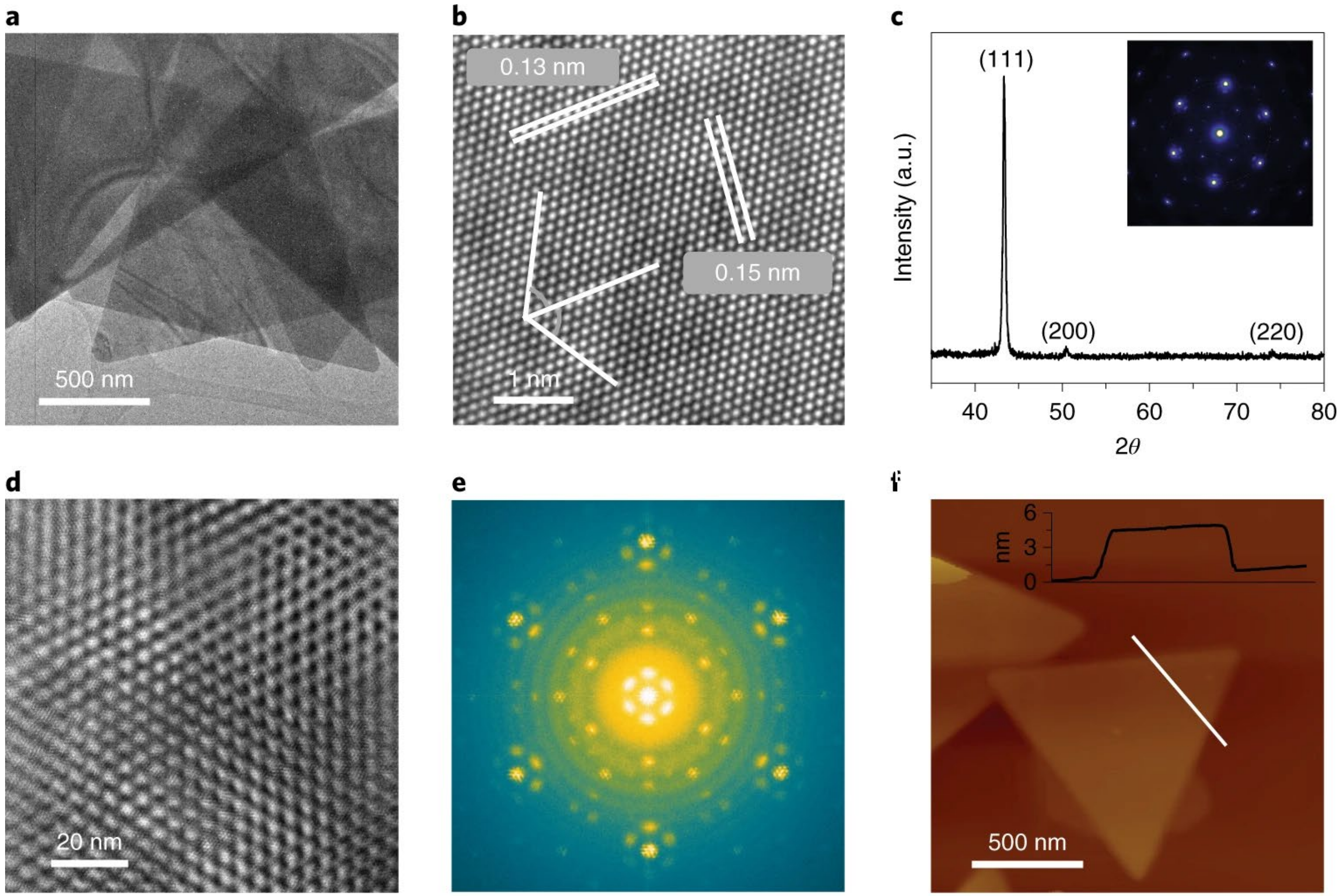
→ Decoupling of the electrolysis steps allows sustainable C_{2+} production





M. Jouny, W. Luc, & F. Jiao, *Nature Catalysis* 1, 748-755 (**2018**).

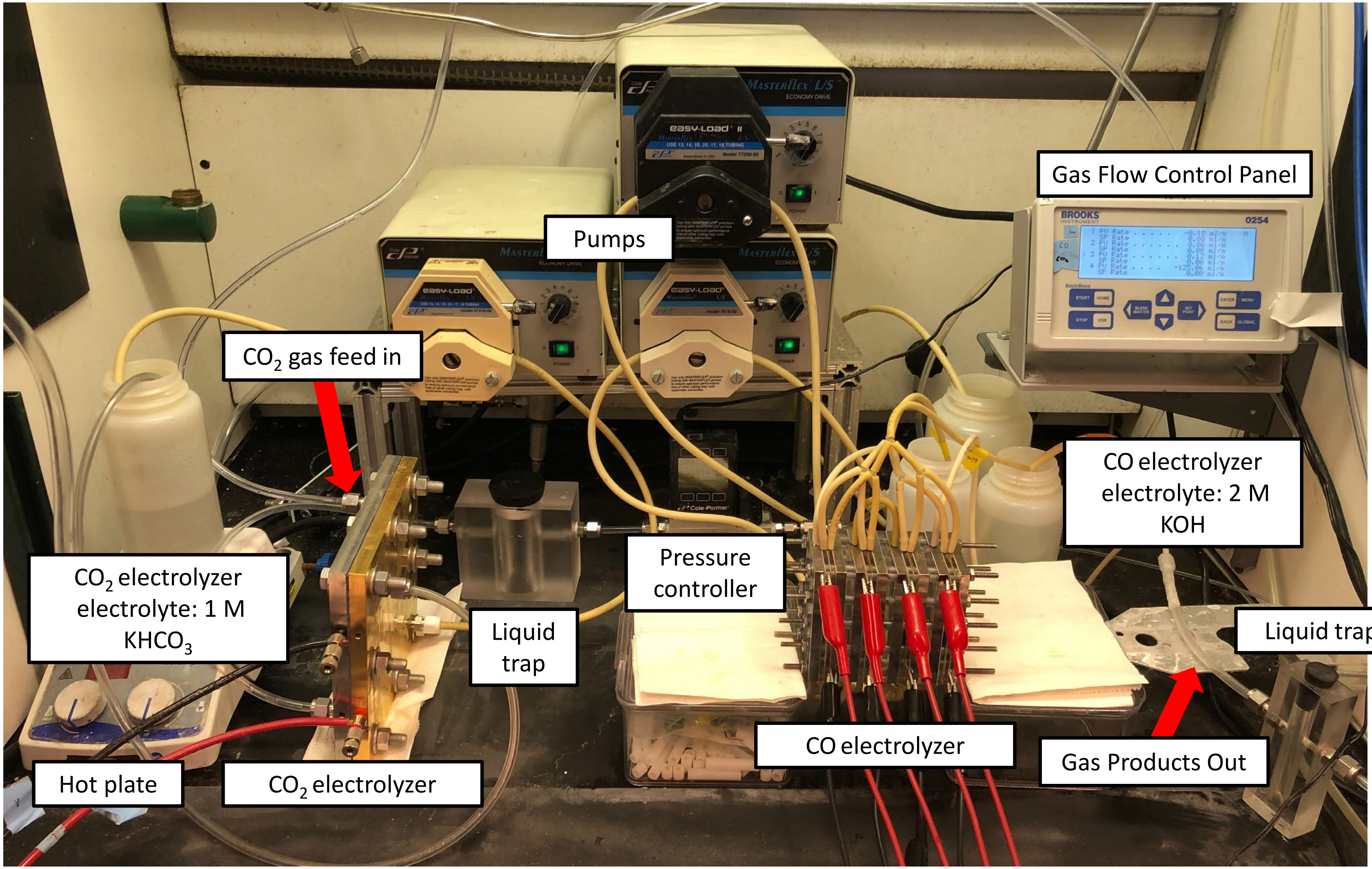
Two-dimensional Cu nanocatalyst



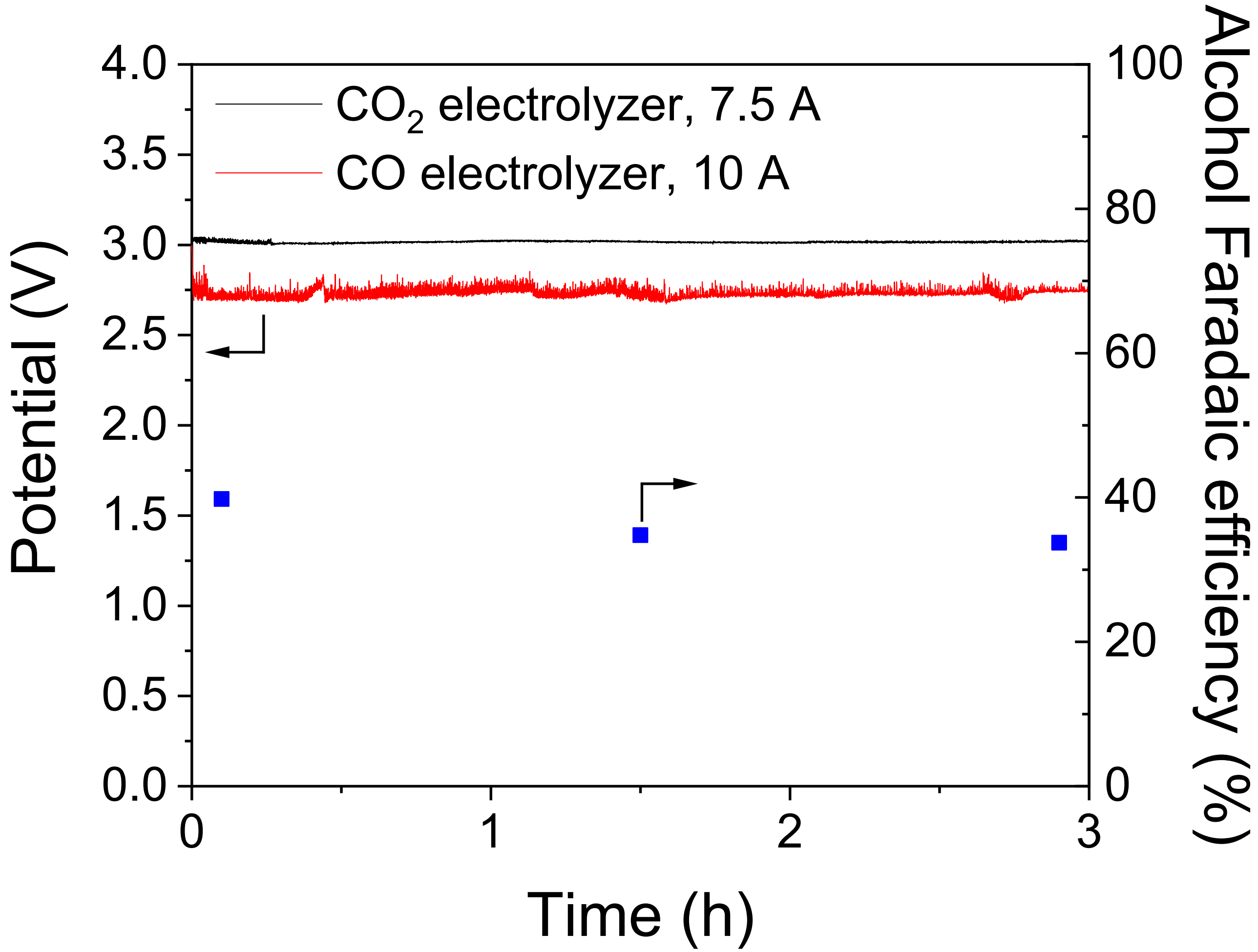
- Cu nanosheets with Cu(111) exposed were successfully synthesized
- Triangle shape (a few micron in dimension) and 4-5 nm in thickness

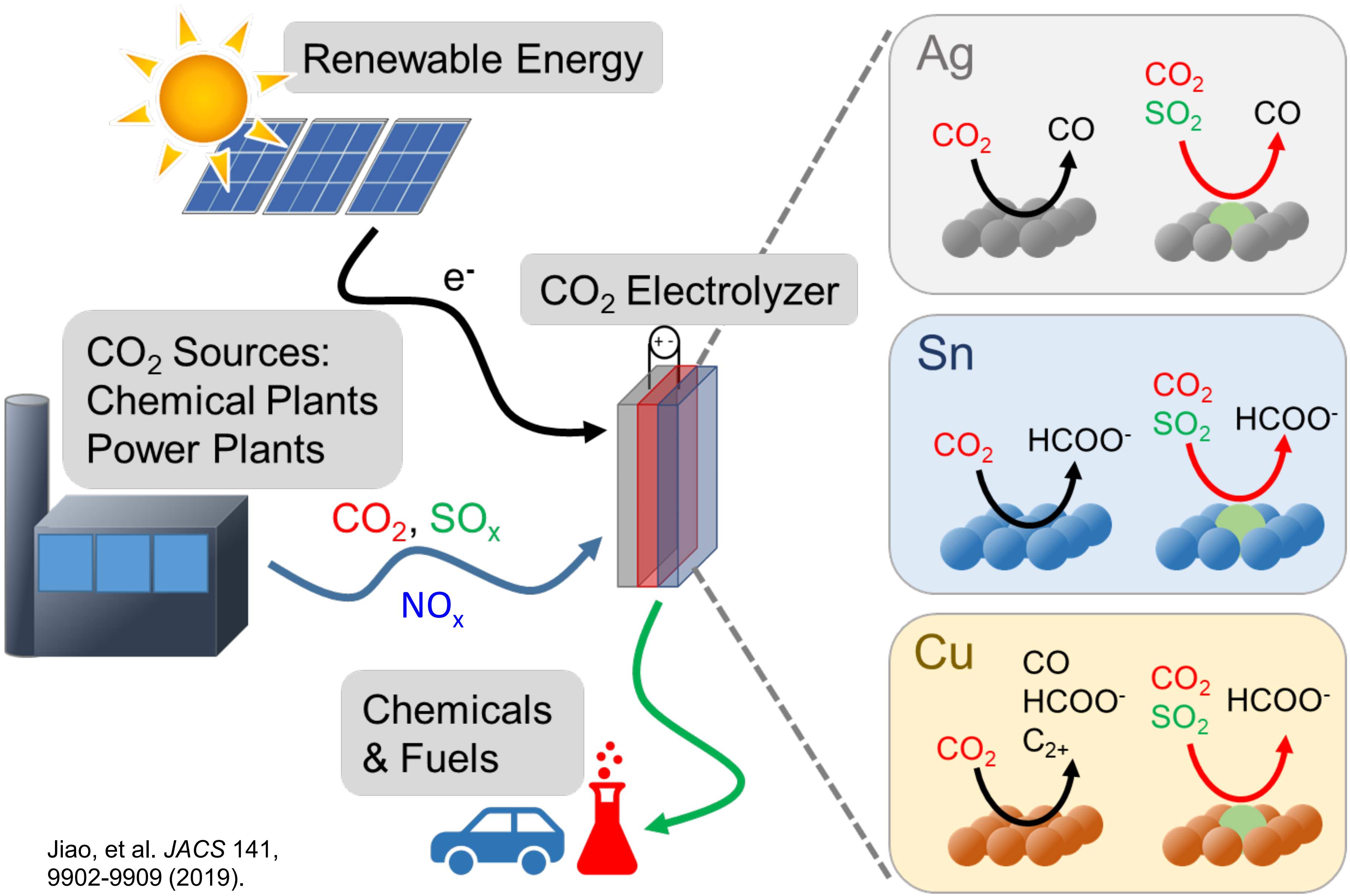
Jiao, et al. *Nature Catalysis* 2, 423-430 (**2019**).

Two-Step Electrochemical Conversion of CO_2 to Alcohols



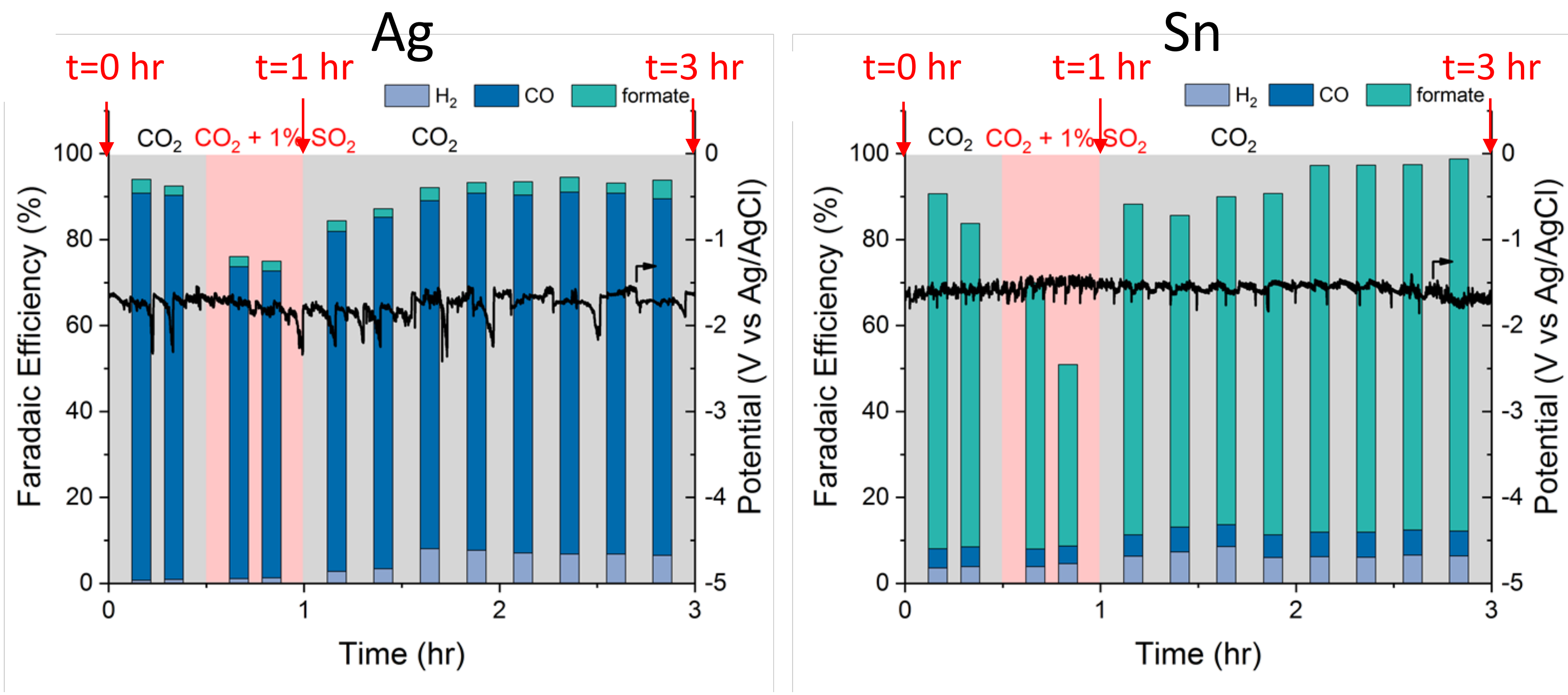
Two-Step Conversion of CO_2 to Alcohols: Performance





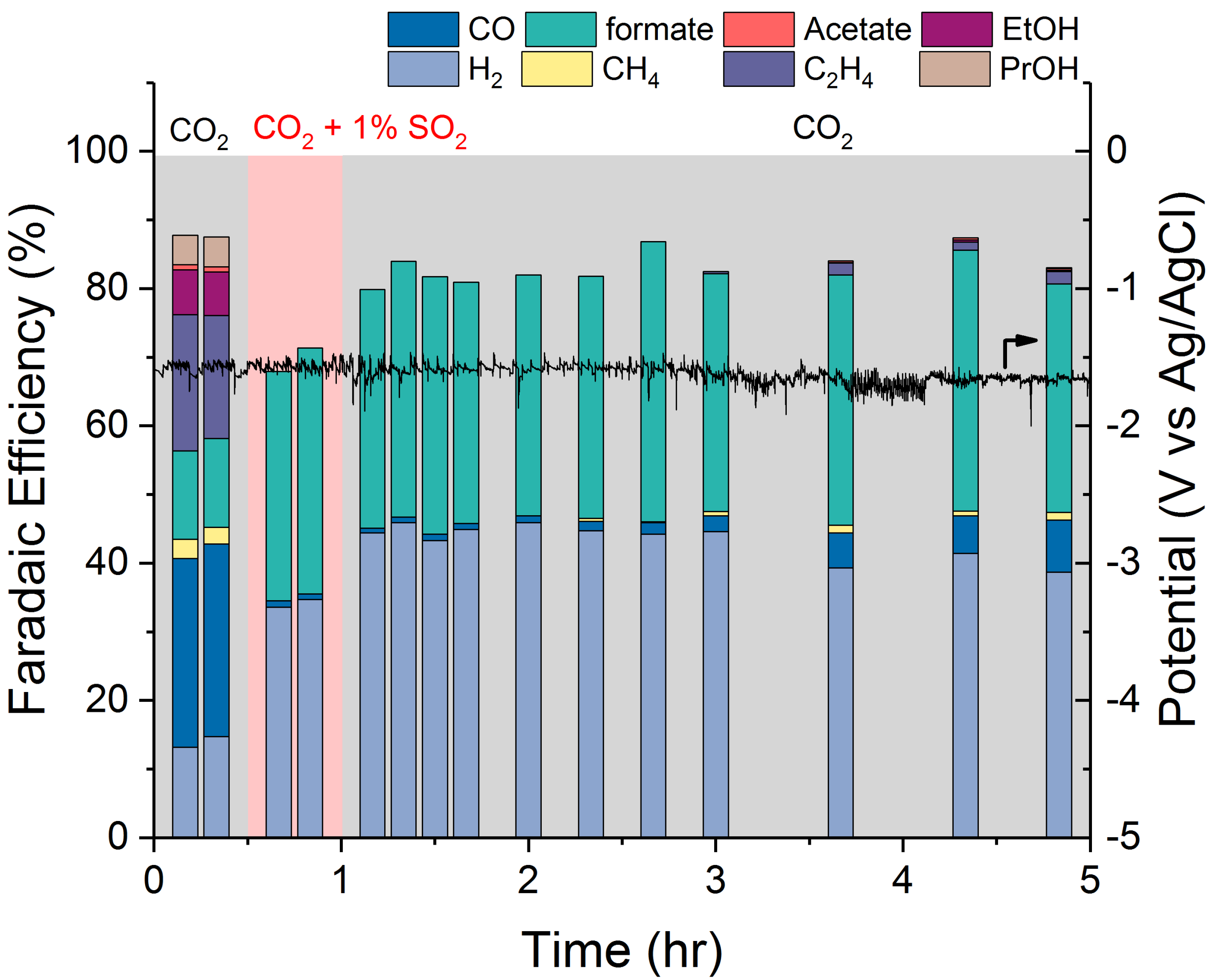
Jiao, et al. *JACS* 141, 9902-9909 (2019).

Influence of SO_2 on Ag and Sn catalyst



- Reduction in total CO_2 reduction FE due to preferential reduction of SO_2
- Performance recovered after SO_2 injection has been stopped

Influence of SO_2 on Cu catalyst

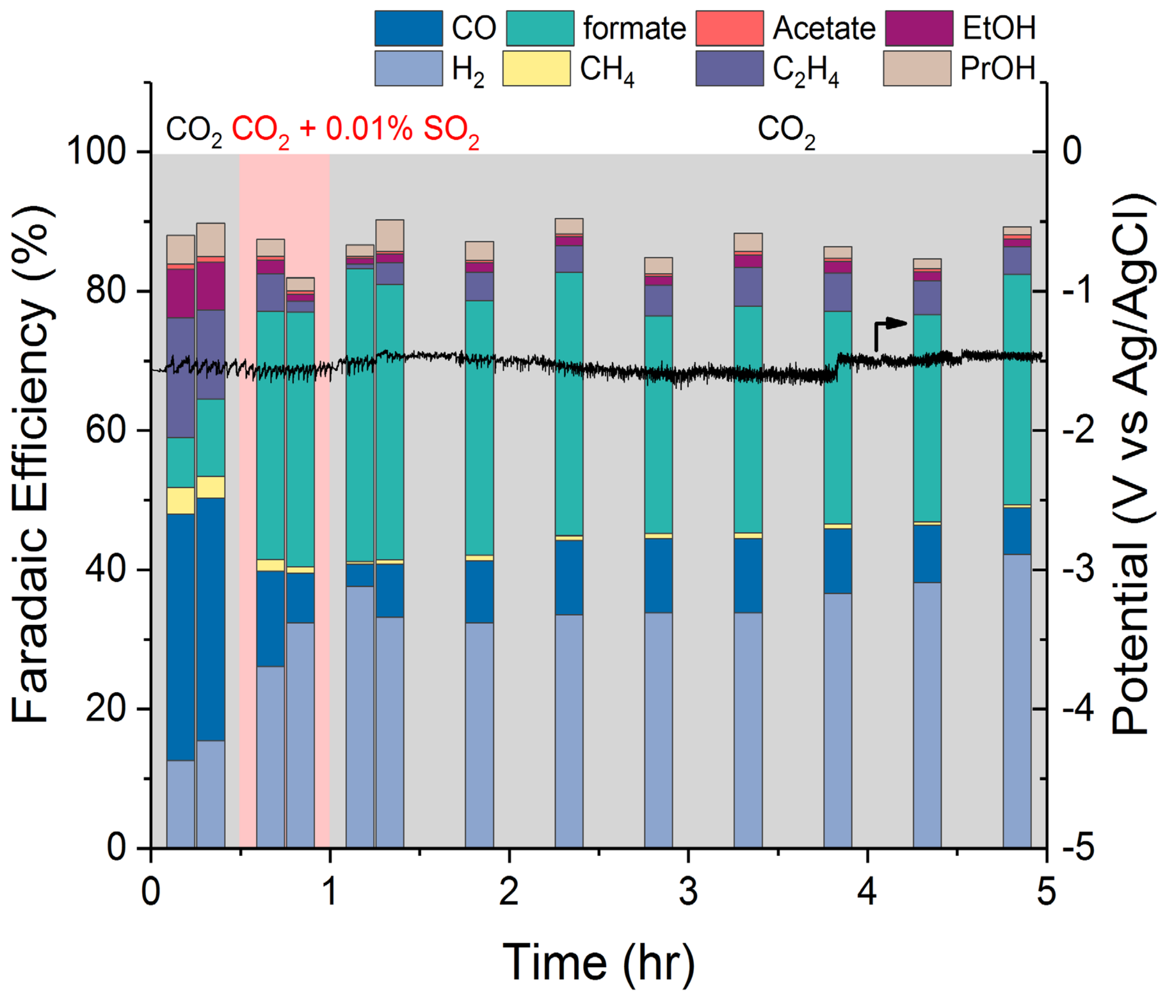


1% SO_2 in CO_2

A clear selectivity change towards formate

Slow recovery of C2+ selectivities

SO_2 concentration study on Cu



C2+ selectivity cannot be fully restored after 0.01% SO_2 exposure.

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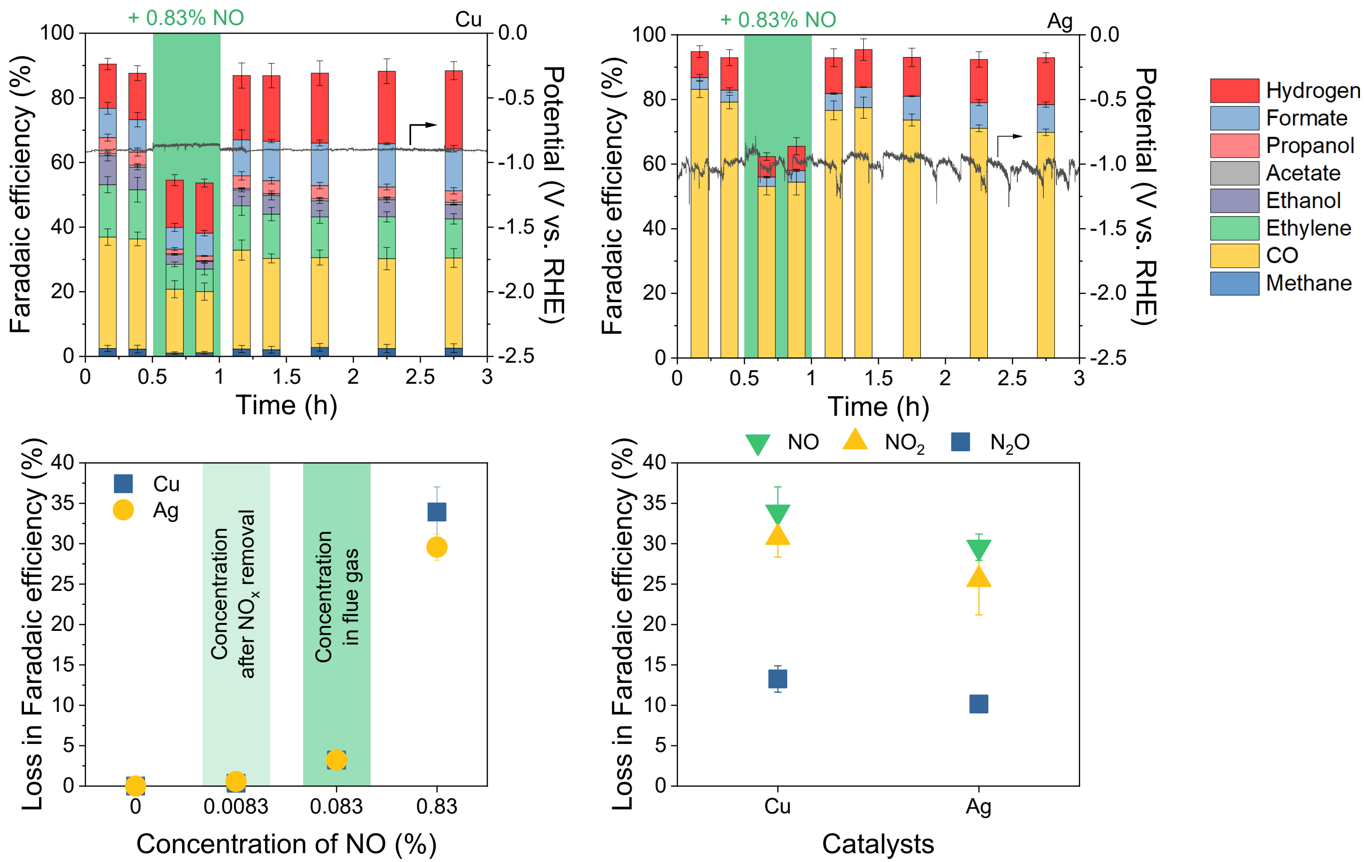
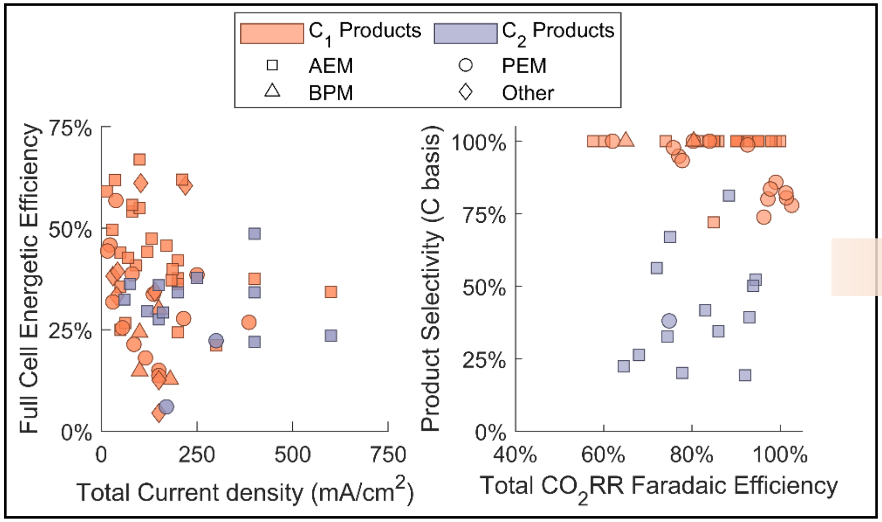
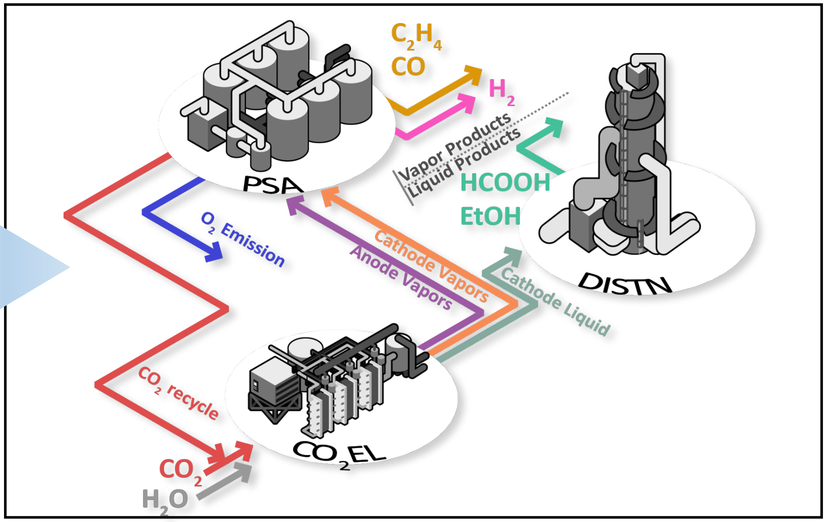
Impact of NO_x impurities on CO_2 electroreduction



- Losses in CO_2 electroreduction FE due to preferential reduction of NO
- Quick performance recovery after NO is removed from CO_2 stream
- NO_x at typical concentrations in flue gases is compatible with CO_2 electroreduction

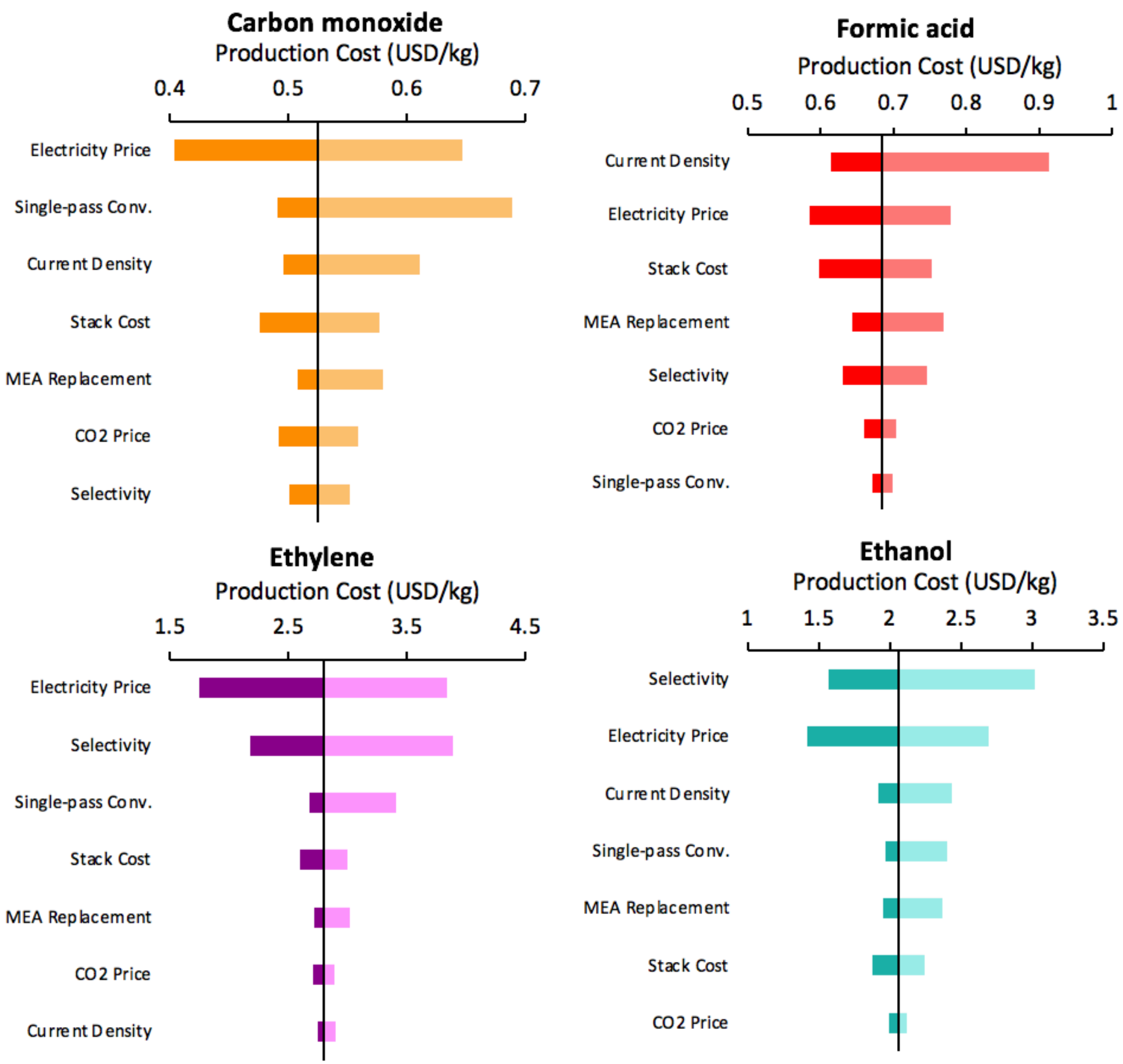
Techno-economic Analysis of CO_2 Electrolysis





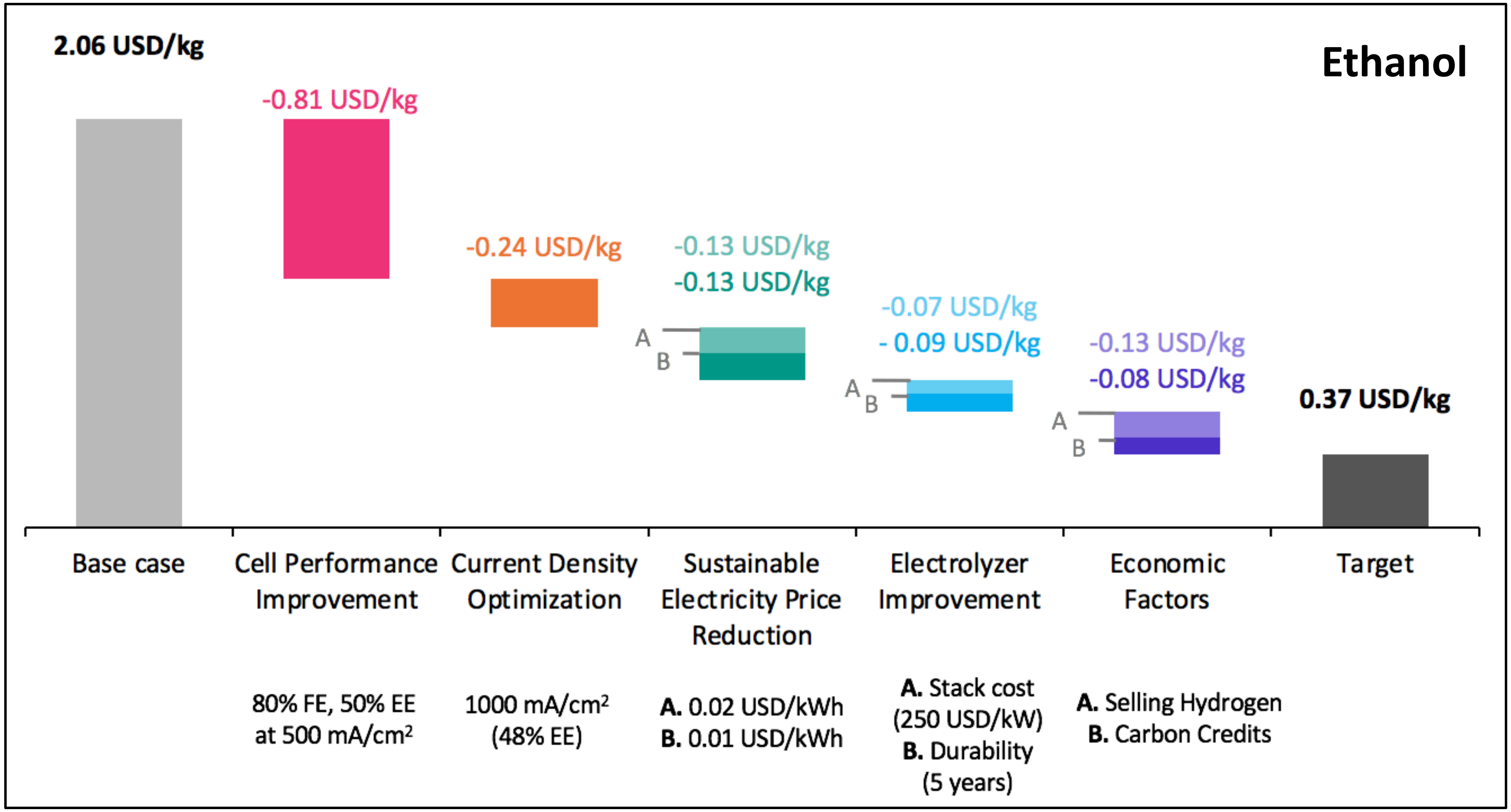
- Survey the current state-of-the-art technology in the field for the past 5 years.
- Incorporate the current leading-edge performances into TEA.
- Evaluate the economic feasibility of electrochemical CO_2 conversion to products.
- Provide a roadmap for future research direction.

Roadmap to Market-competitive Production



- Overall, **electricity cost** is one of the key parameters in cost reduction for all products.
- With a current technology, C_1 product production is economically viable, while C_2 product production still demands tech enhancement.

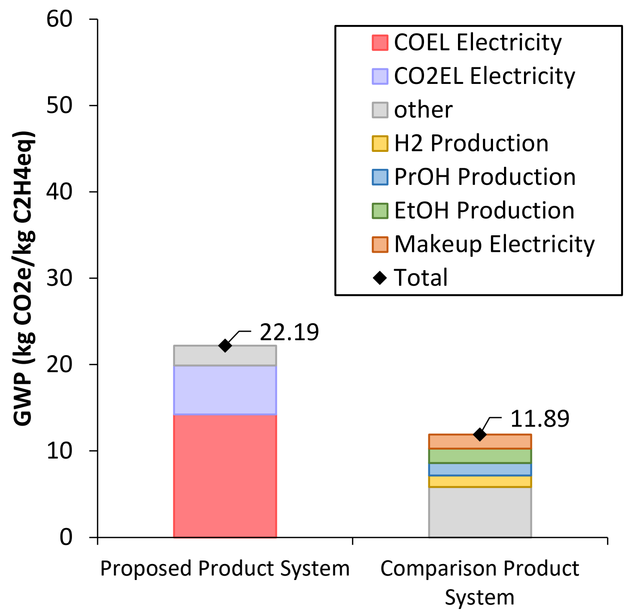
Roadmap to Market-competitive Production

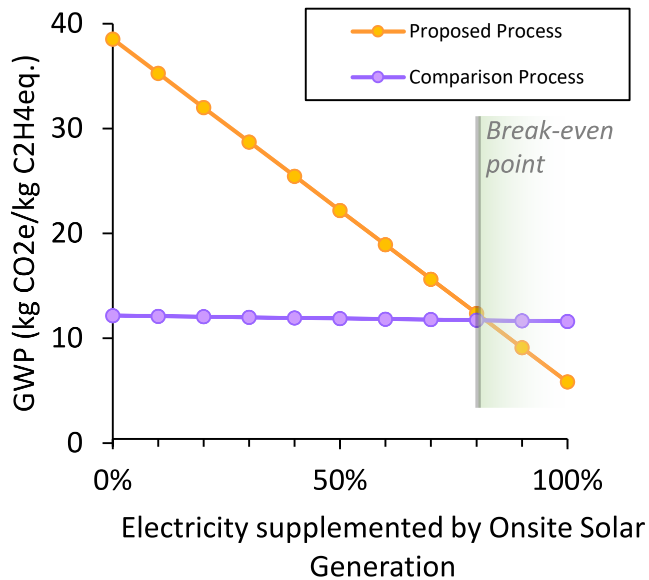


- The roadmap suggests improving cell performance (50% EE) is crucial to cut down to < 1 USD/kg.
- With technical development along with appropriate policymaking, ethanol production via CO_2RR will be market-competitive. (0.4-0.8 USD/kg)

Life Cycle Analysis

Electrolysis of CO_2 to alcohols requires a clean source of electricity.

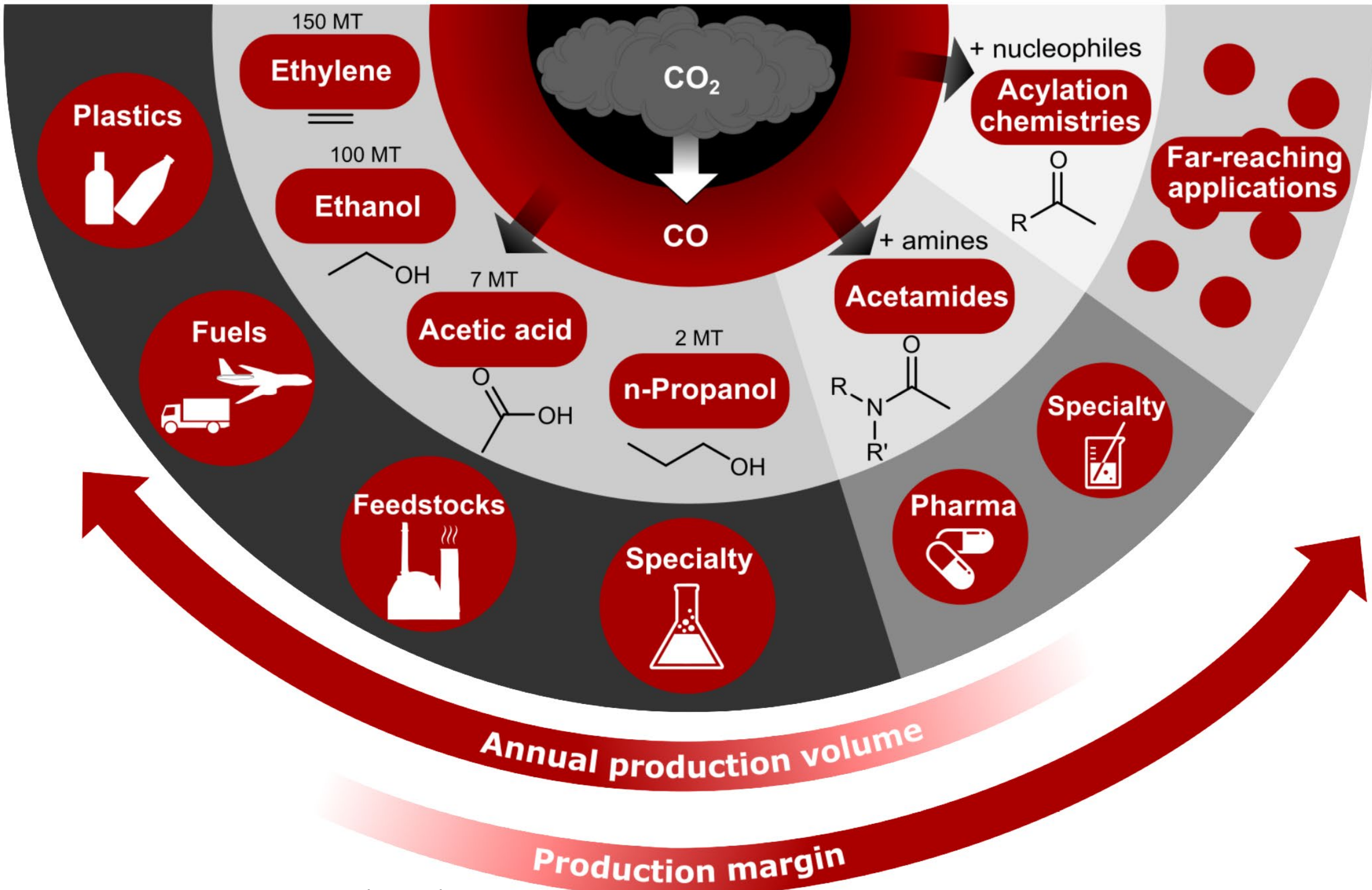




Process emissions breakdown. Electrolyzer parameters are taken from experimental data. LCA modeled in openLCA with TRACI 2.1 (NETL) method using **2025 capacity expansion US MIX profile for electricity**. The proposed product system is assumed to have 50% of electricity demand supplemented by onsite solar PV electricity.

Breakeven analysis. Process emissions dependence on the proportion of electricity supplemented by onsite solar PV . All other parameters are held constant.

Outlook



Jouny, Hutchings, Jiao, Nat. Catal. (2019)

Acknowledgements

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Thank you