Integrated Carbon-Neutral Methanol Production from Direct Air Capture and Carbon-Free Hydrogen (FE0032401)

2024 FECM/NETL Carbon Management Research Project Review Meeting

August 8th, 2024

Phase 1

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UNIVERSITY OF DELAWARE

NATIONAL ENERGY TECHNOLOGY LABORATORY

DE-FE0032401

Project Overview

Total Funding
$500,000

Teams	Total	
	DOE Funds	**Cost Share**
UD	$131,500	$54,250
ORNL	$142,500	-
Versogen	$50,000	$12,500
WUSTL	$76,000	$33,250
Total	$400,000	$100,000
Total Cost Share (%)		20%

Period of Performance
12/20/2023-09/19/2025

Our Team

University of Delaware

Versogen™
The Hydrogen Generation.

Washington University in St. Louis

Oak Ridge National Laboratory

AIR COMPANY


Prof. Yan


Dr. Lakshmanan


Prof. Jiao


Dr. Sheehan


Marco Colin
3rd year PhD


Dr. Setzler


Dr. Meng
Post Doc


Dr. Toops


Justin Harrington
2nd year PhD


Lincoln Pritt
BS Chem E

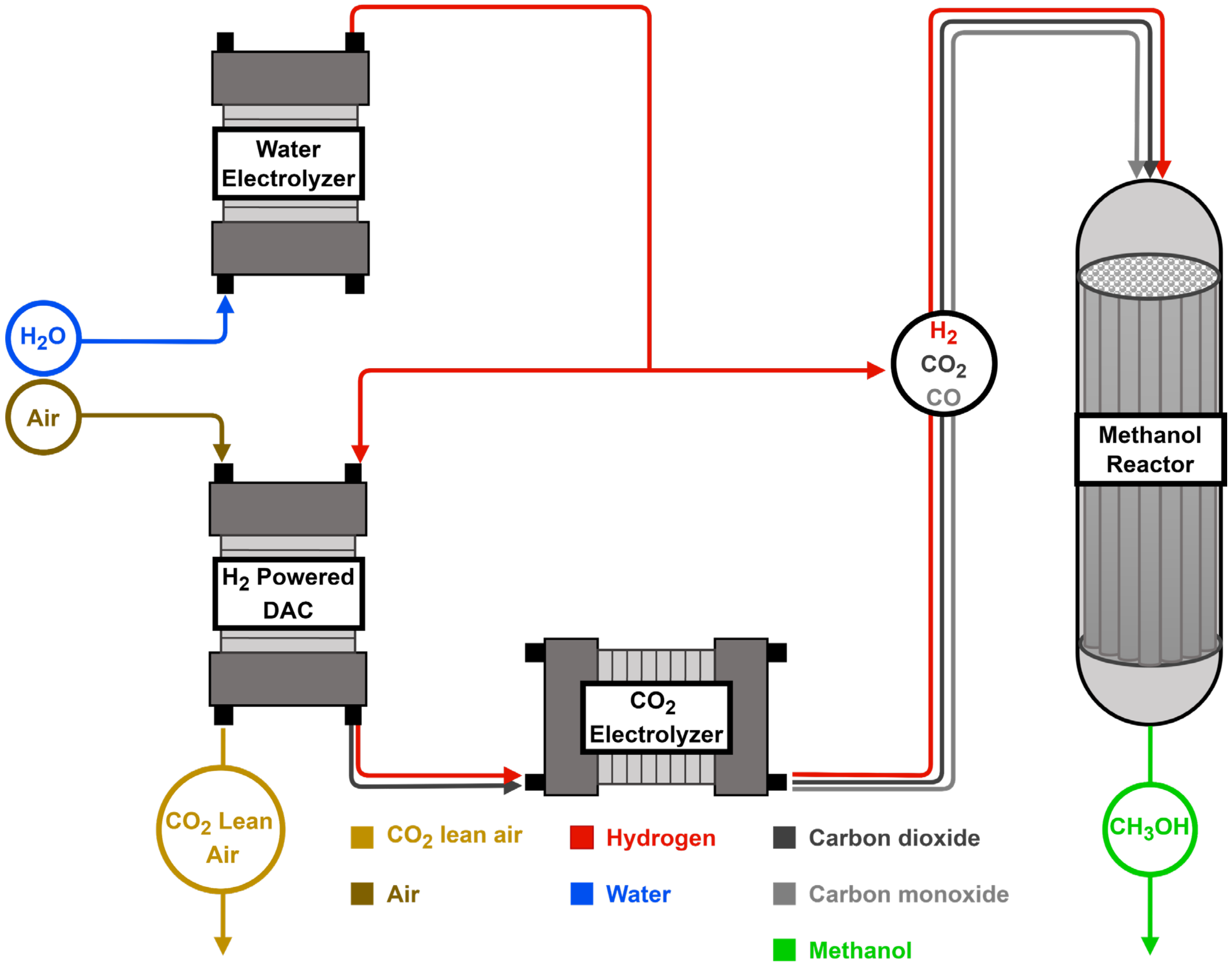

Wentao Dai
1st year PhD


Dr. Banboukian


Rebekah Marks
3rd year undergrad


M.S. Armstrong

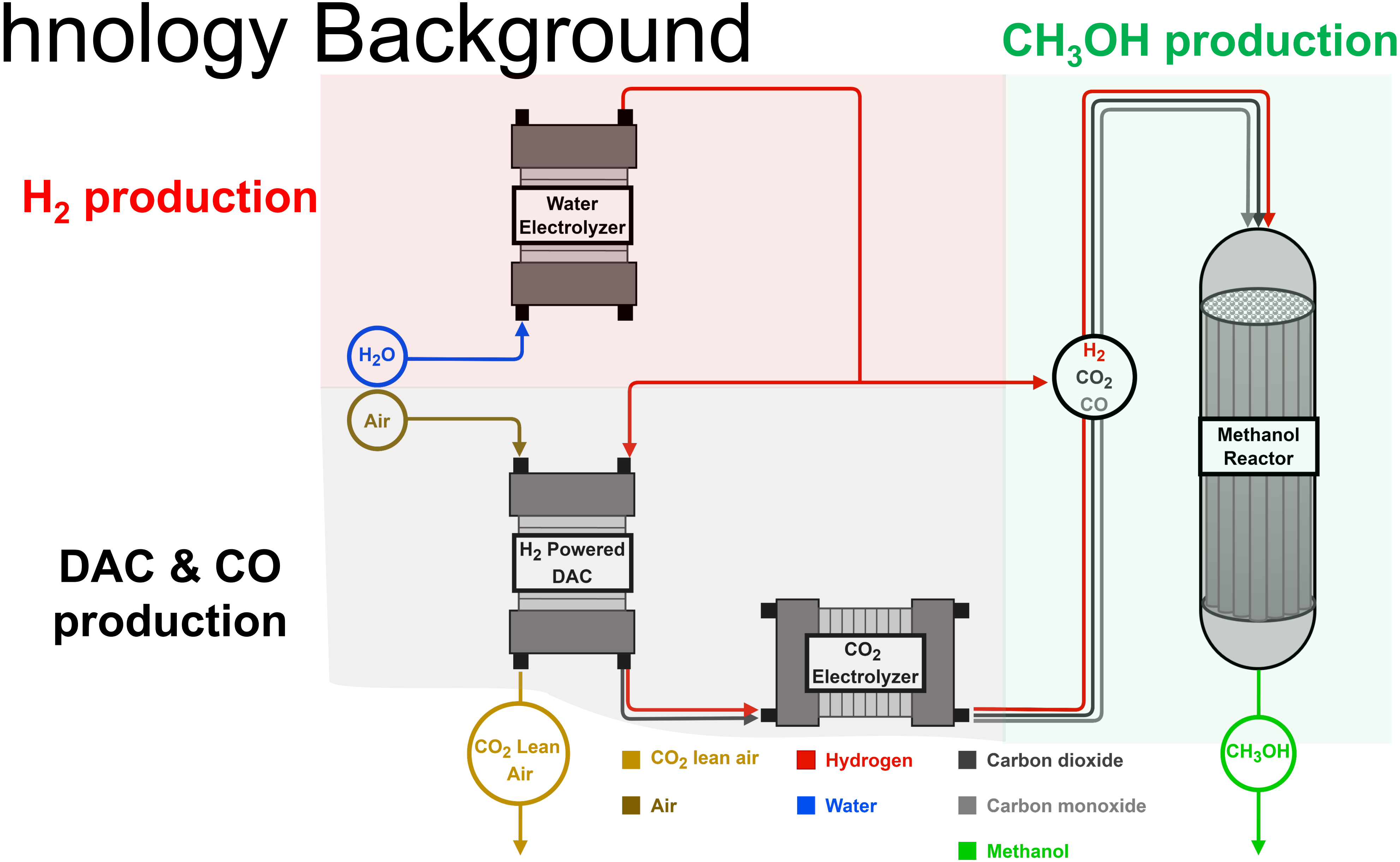
Project Overview (Phase 1)



Phase 1 TEA objectives

Deliver a detailed and integrated process design that can meet $800 per tonne of carbon neutral methanol

Technology Background

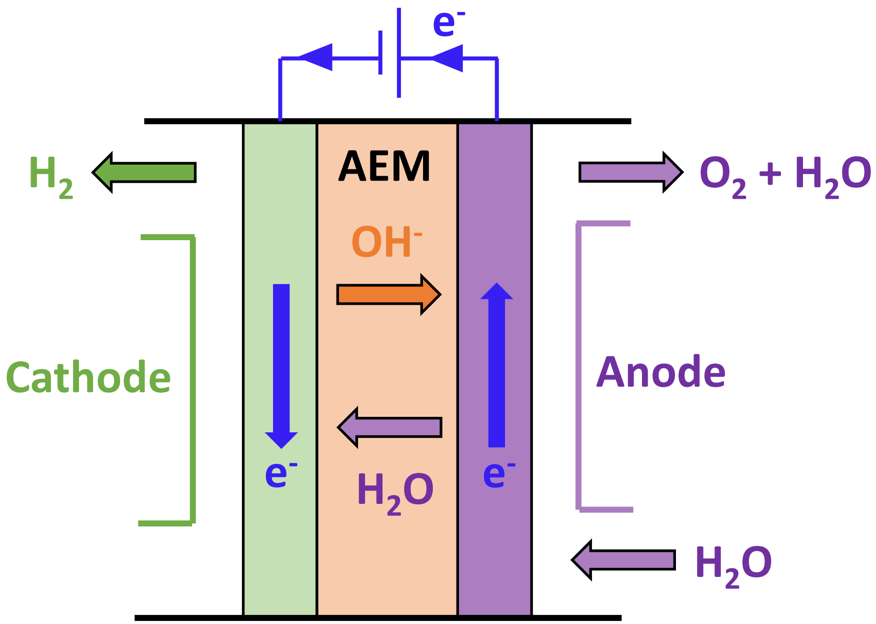


$$3H_2 + CO_2 \rightarrow CH_3OH + H_2O$$

$$H_2O + CO \rightarrow CO_2 + H_2$$

Technology Background

Water electrolyzer



H_2 evolution reaction

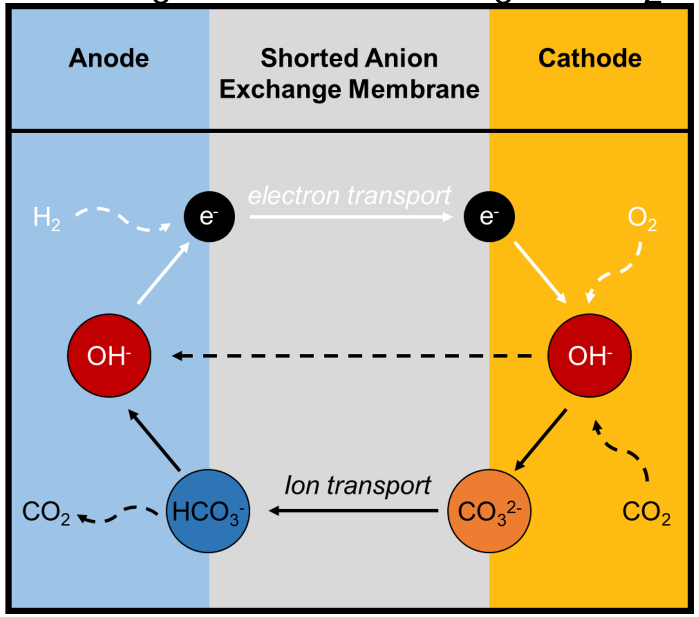
$$4H_2O + 4e^- \rightarrow 2H_2 + 4OH^-$$

O_2 evolution reaction

$$4OH^- \rightarrow O_2 + 2H_2O + 4e^-$$

Electrochemically-driven CO_2 Separator

$$CO_2 + OH^- \leftrightarrow HCO_3^-$$
$$HCO_3^- + OH^- \leftrightarrow CO_3^{2-} + H_2O$$



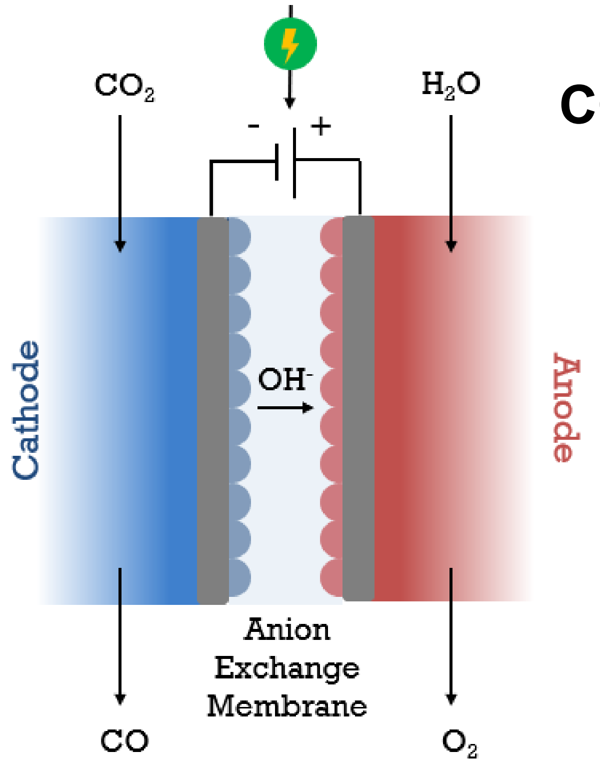
H_2 oxidation reaction

$$H_2 + 2OH^- \rightarrow H_2O + 2e^-$$

O_2 reduction reaction

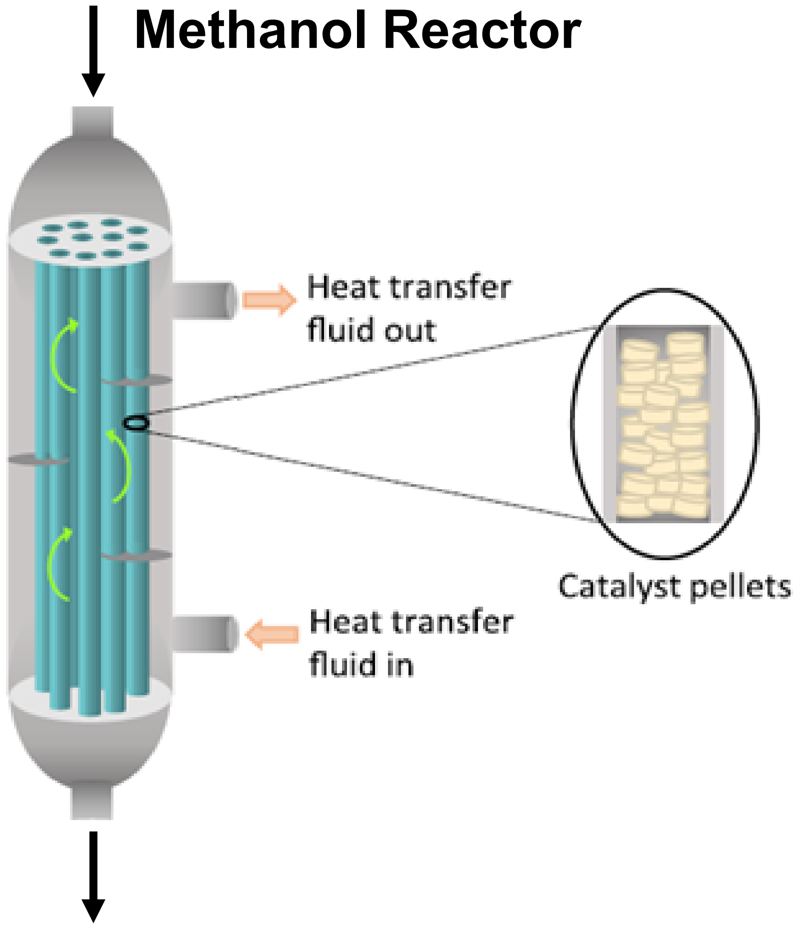
$$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$$

Technology Background



CO_2 electrolyzer

Methanol Reactor



CO_2 electrolysis

$$2CO_2 + 4e^- + 2H_2O \rightarrow 2CO + 4OH^-$$

H_2 evolution reaction

$$H_2O + 2e^- \rightarrow H_2 + 2OH^-$$

O_2 evolution reaction

$$4OH^- \rightarrow O_2 + 2H_2O + 4e^-$$

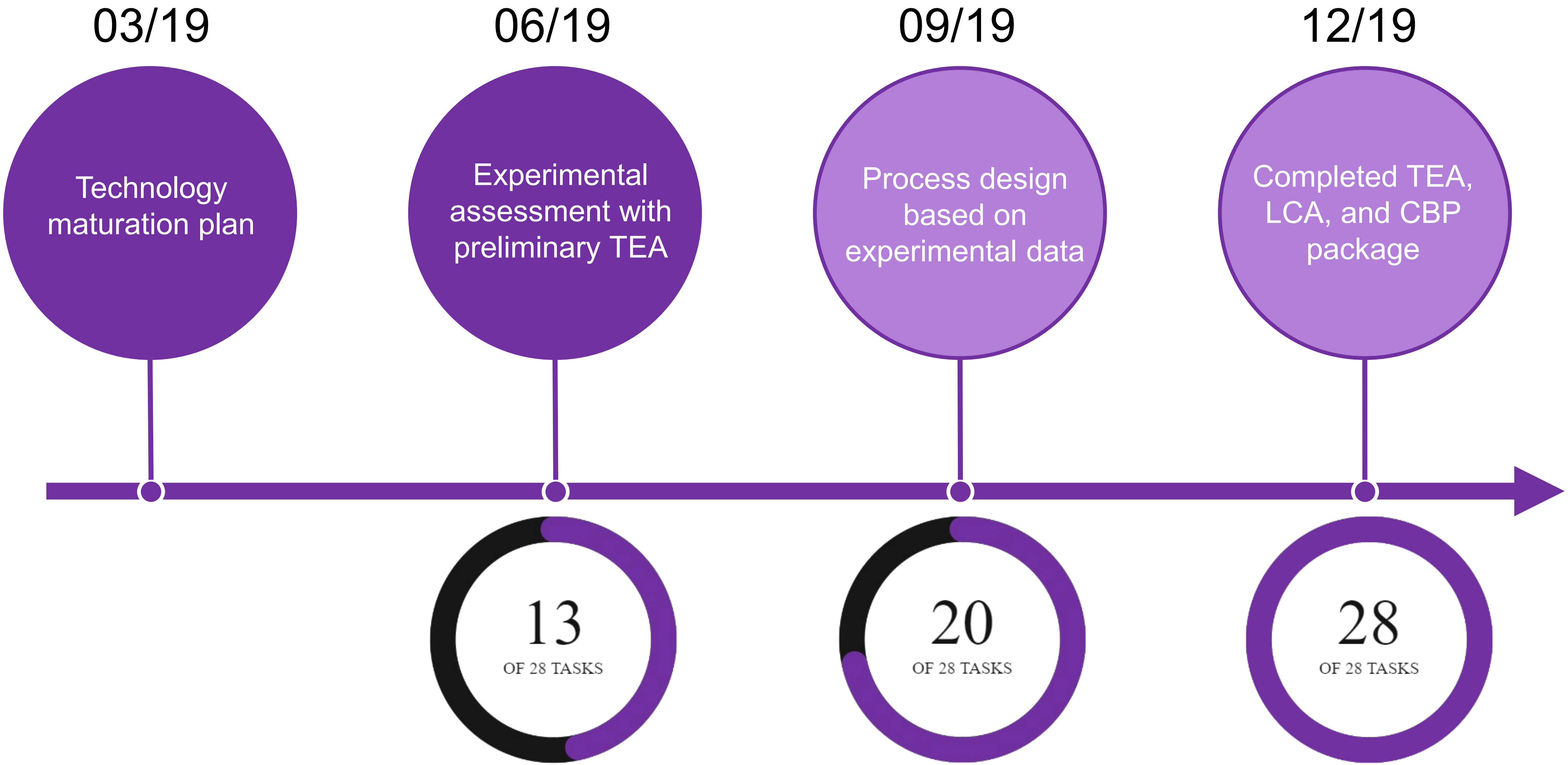
CO_2 hydrogenation

$$CO_2 + 3H_2 \rightarrow CH_3OH + H_2O$$

Water-gas shift reaction

$$CO + H_2O \rightarrow CO_2 + H_2$$

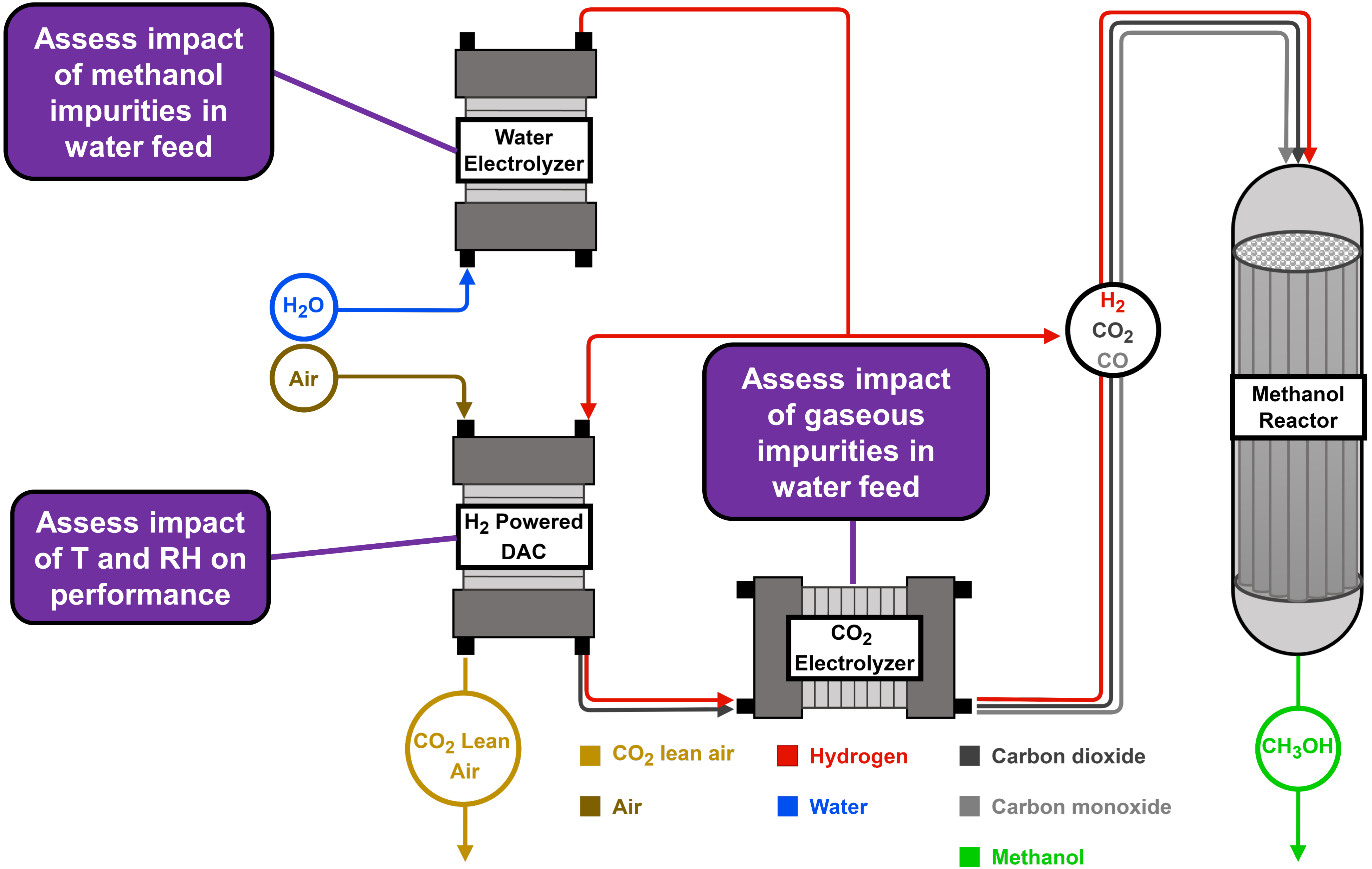
Project Scope and Progress



Risk Management

Perceived Risk	Risk Rating			Mitigation/Response Strategy
	Probability	Impact	Overall	
Cost/Schedule Risks:				
Phase 2 cost and schedule risks can arise from design requirements identified in Phase 1 for separate technologies.	Medium	Medium	Medium	In Phase 1, obtain preliminary quotes for long lead time items (e.g., custom compressors, fans, reactors, separators) to expedite Phase 2 work if approved.
Management, Planning, and Oversight Risks:				
Inconsistent description and knowledge gaps between technologies may hold off the progress of economic and process modeling.	Medium	Medium	Medium	Regular meetings between institutions will: -Share progress on components -Identify design alignment needs
ES&H Risks:				
Flammable gases, such as H_2 and CO, involved in the experiments pose potential hazards during the project.	High	Low	Medium	Engage Environmental Safety & Health Departments early to identify potential safety issues and implement controls.

Experimental Approach



Outline

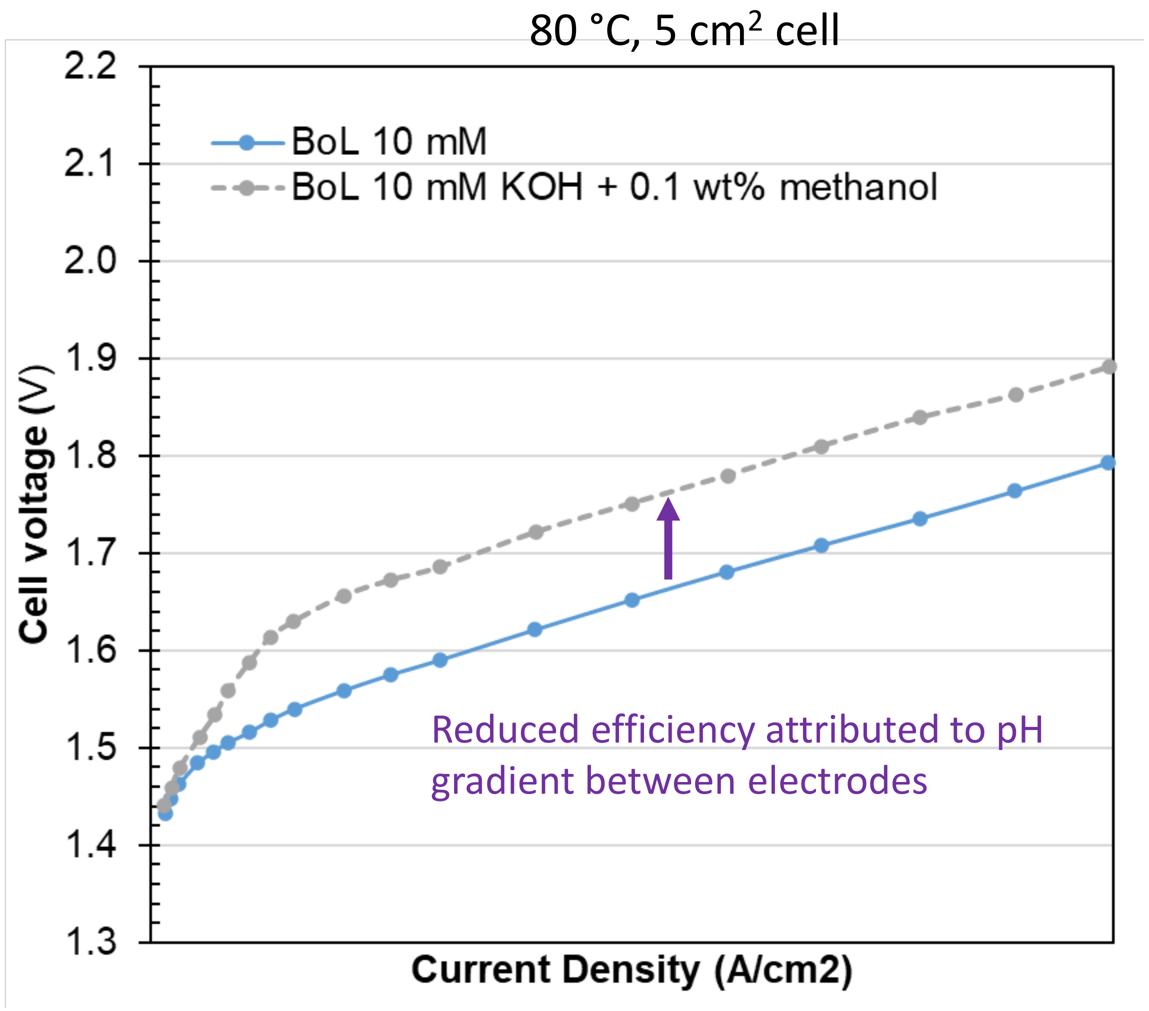
Experimental work

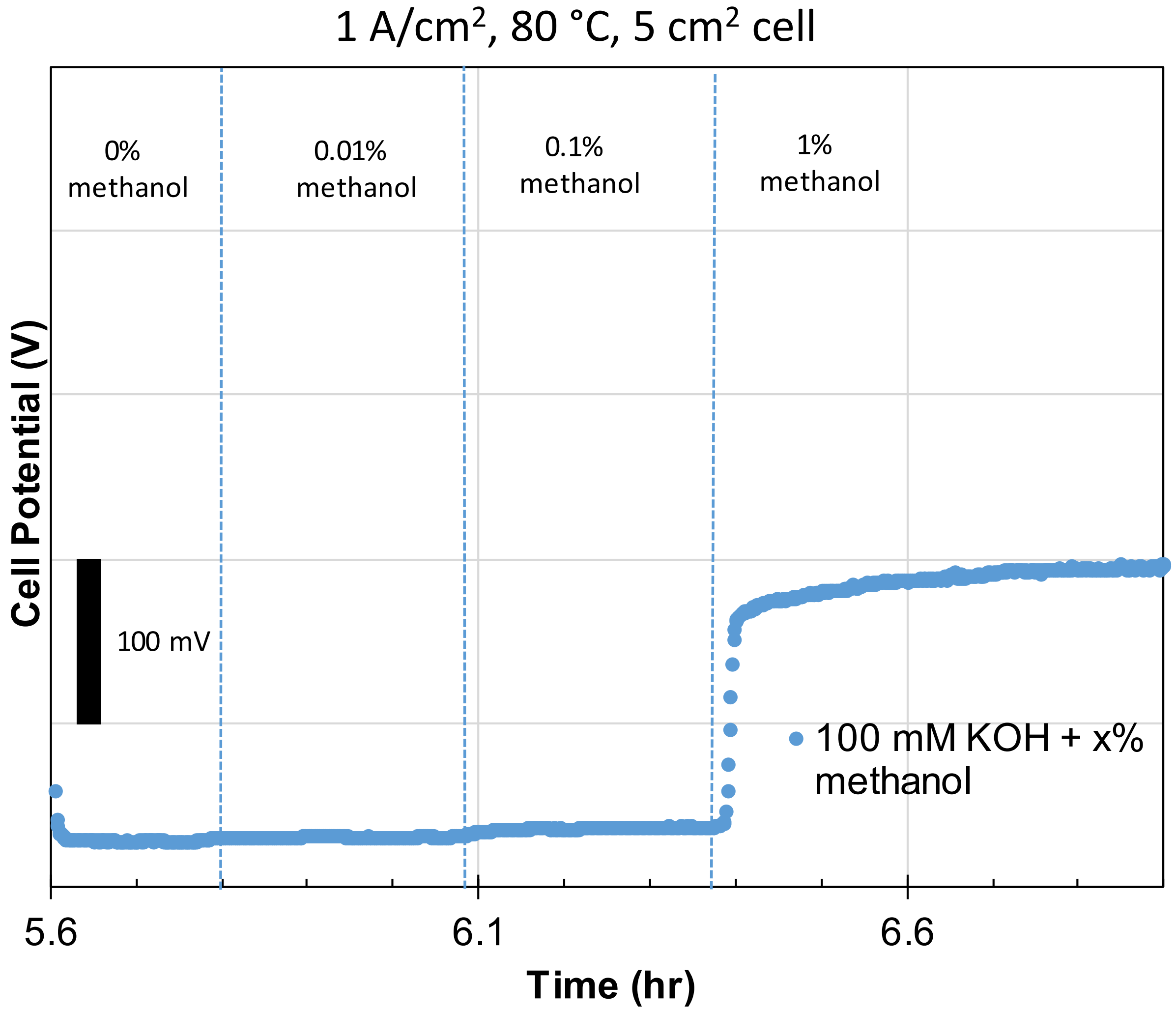
1. Water electrolyzer
2. EDCS
3. CO_2 electrolyzer

Technoeconomic analysis

1. Water electrolyzer
2. EDCS
3. CO_2 electrolyzer

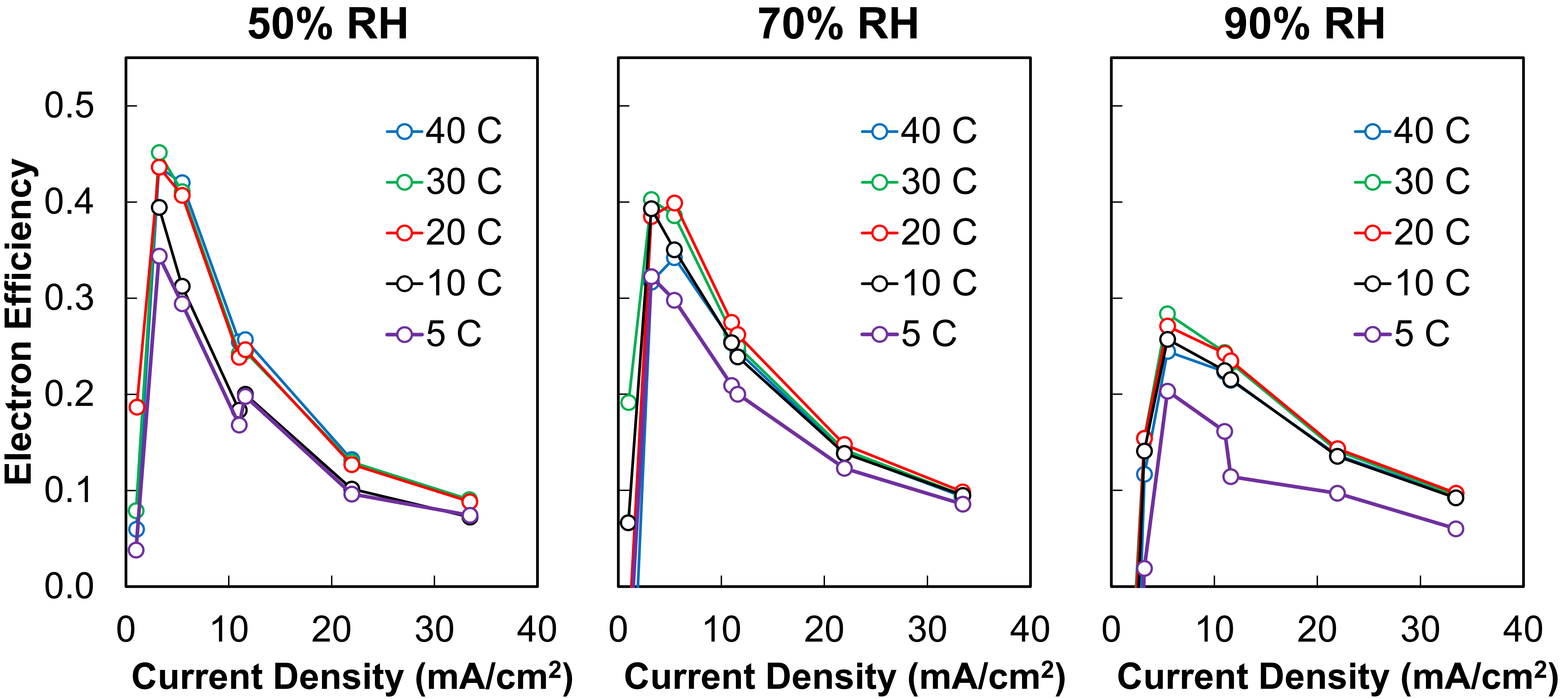
Methanol Contamination in Water Electrolyzer





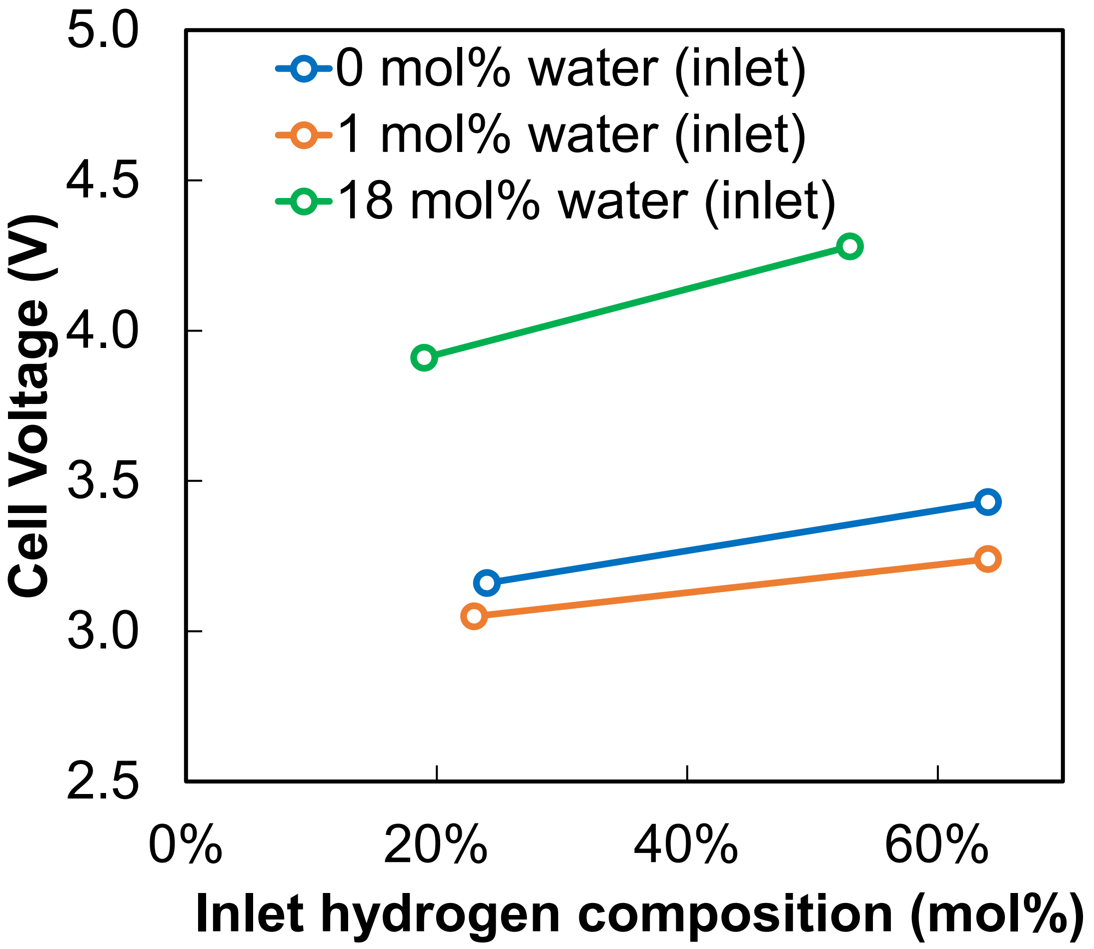
Recycling of methanol byproduct water is possible with sufficient KOH and system-level solution for carbonate buildup

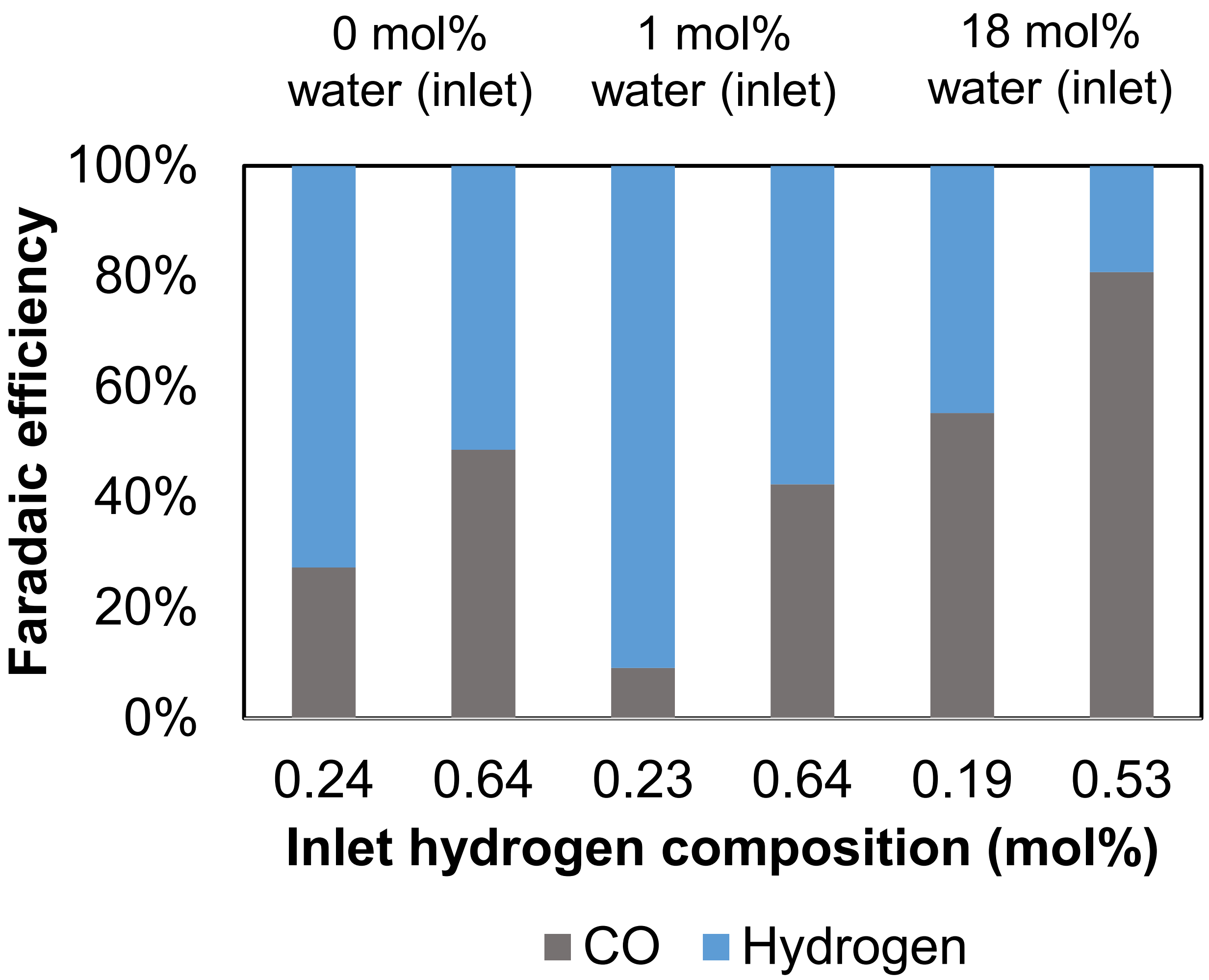
RH has a Strong Impact on EDCS Performance



Lower humidity improves performance, while higher temperatures offers a smaller boost

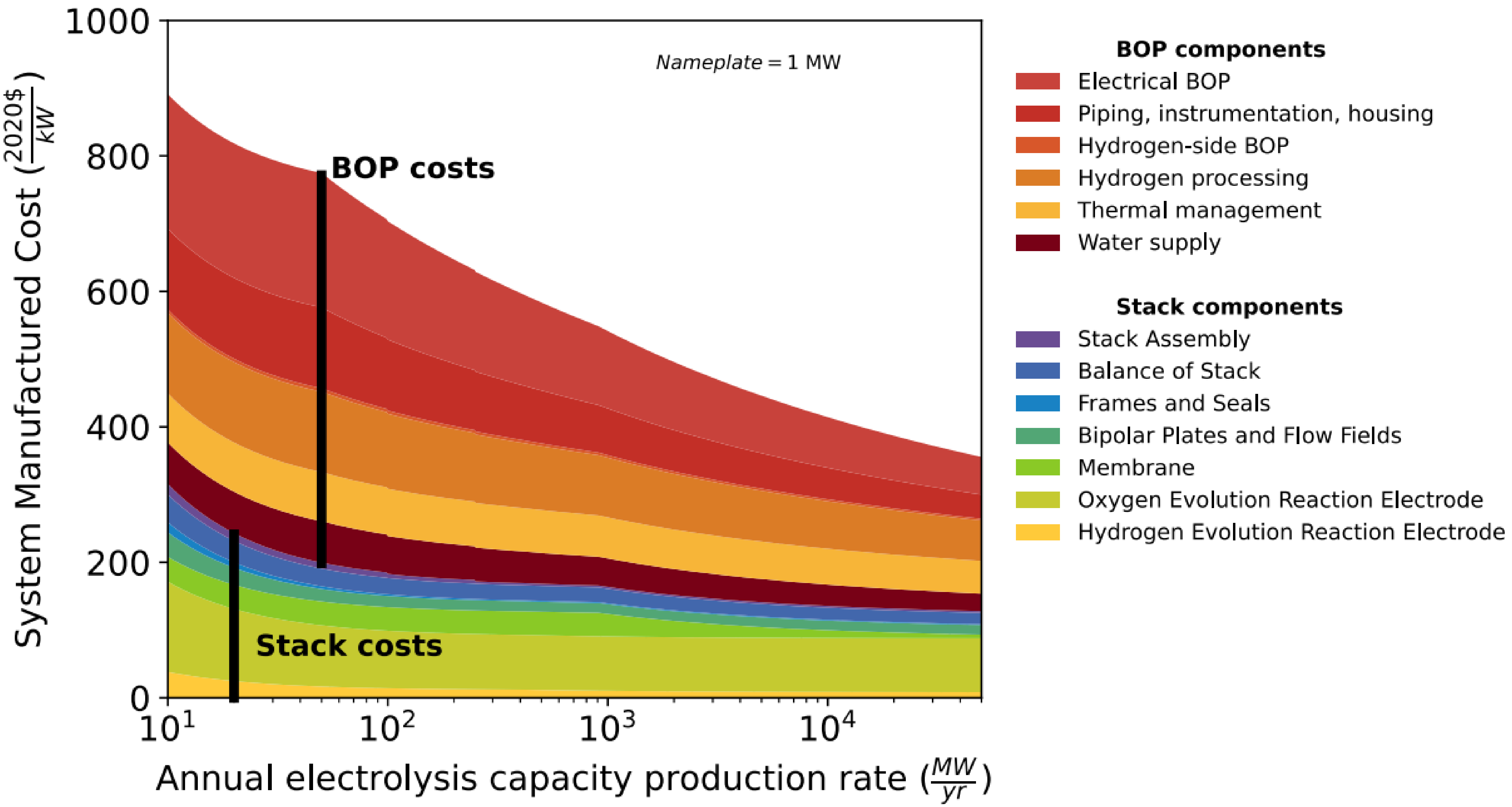
Effects of Inlet Composition on CO_2 Electrolyzer





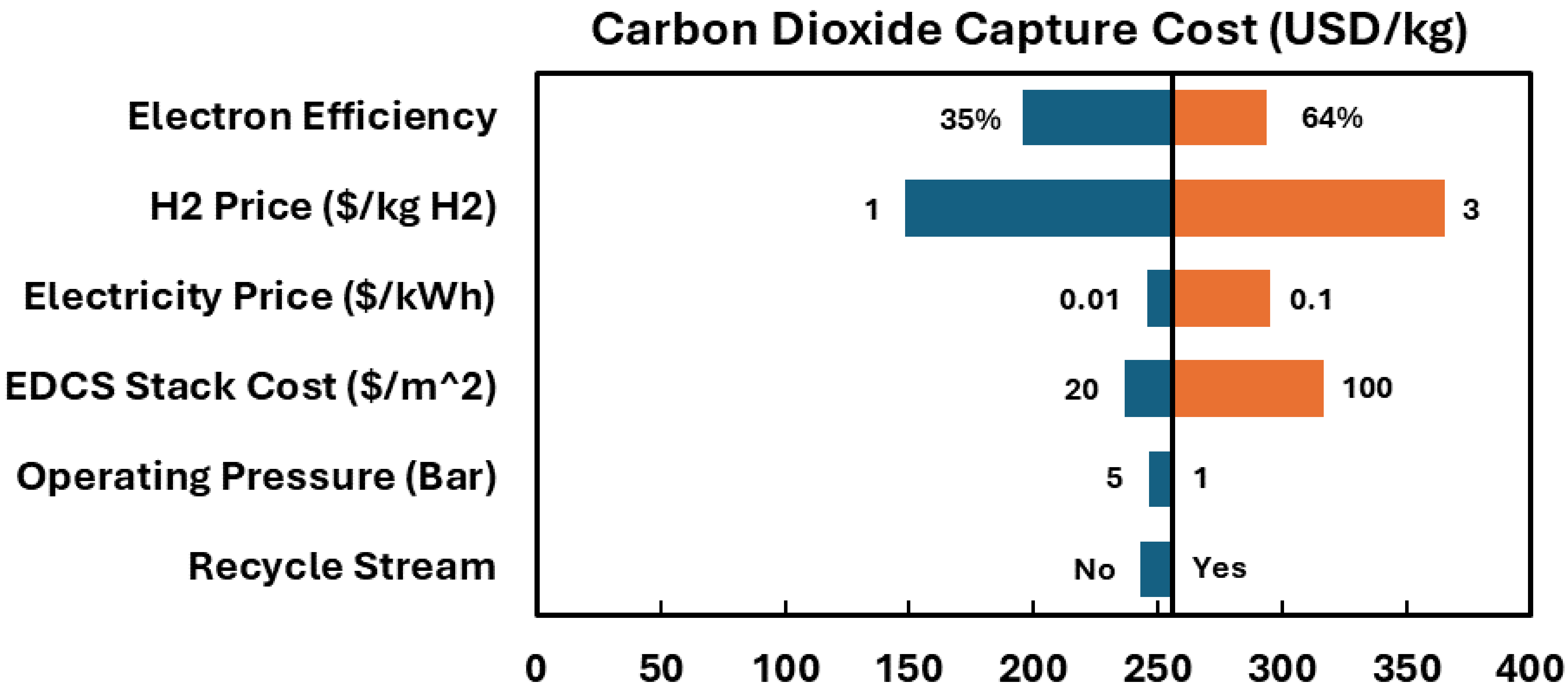
Optimal performance is achieved by minimizing inlet hydrogen content and adding a small amount of humidity

Preliminary TEA Water Electrolyzer

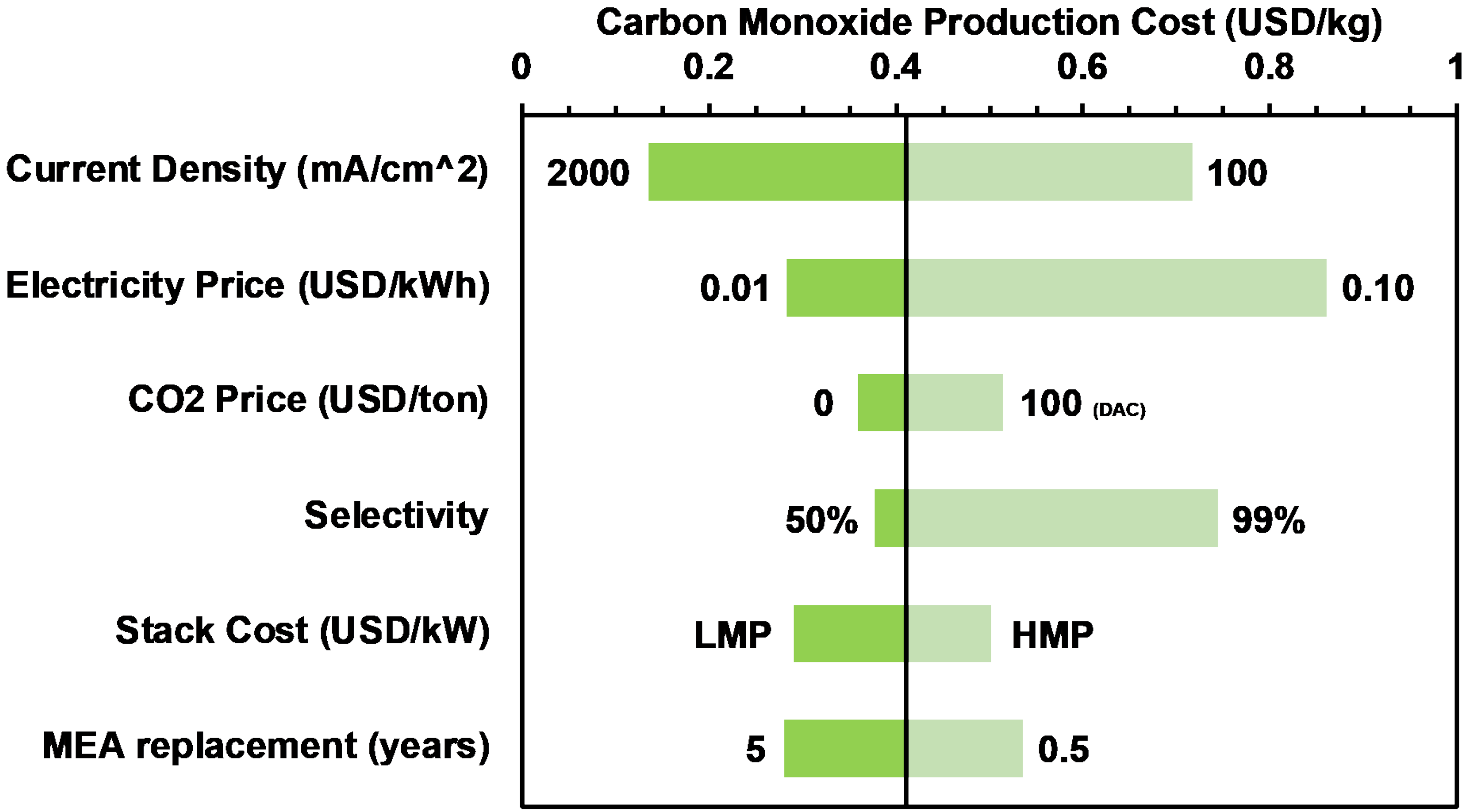


Alex Badgett et al., "Updated Manufactured Cost Analysis for Proton Exchange Membrane Water Electrolyzers," National Renewable Energy Laboratory (NREL), Golden, CO, NREL/TP-6A20-87625, Feb. 2024. [Online].

Preliminary TEA EDCS



Preliminary TEA CO_2 Electrolyzer



Lessons Learned

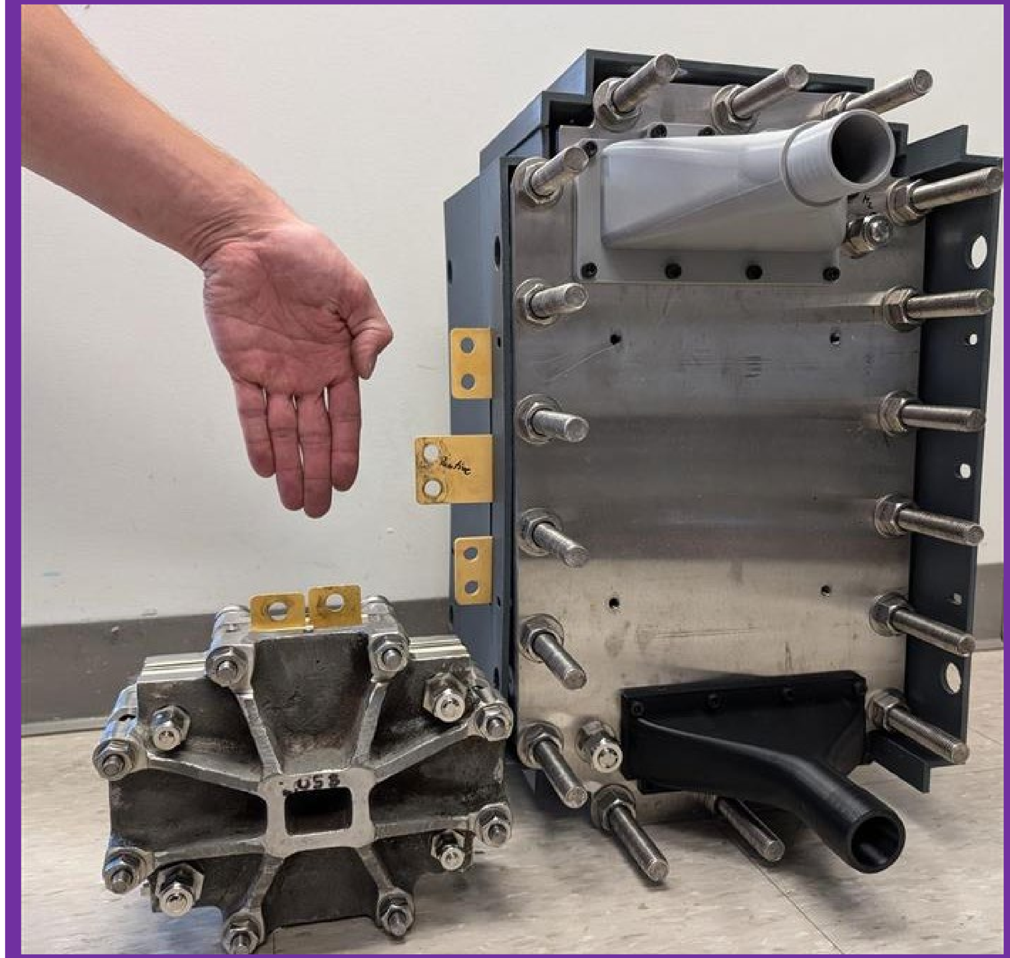
Water electrolyzer
While methanol impurities lower performance, this performance loss can be mitigated via KOH management.

EDCS
Low RH is favorable for high performance and therefore lower H_2 OPEX.

CO_2 recycle stream needs careful attention

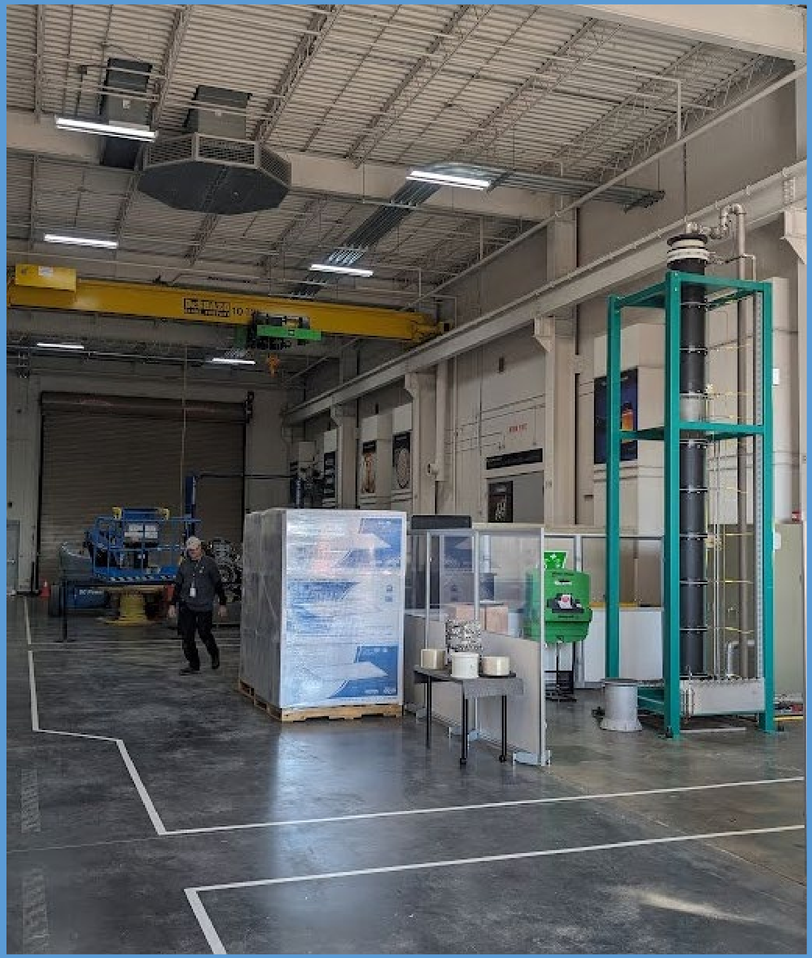
CO_2 electrolyzer
Meticulous control needed for current density and reactant ratios to optimize performance and minimize wear.

Future Work



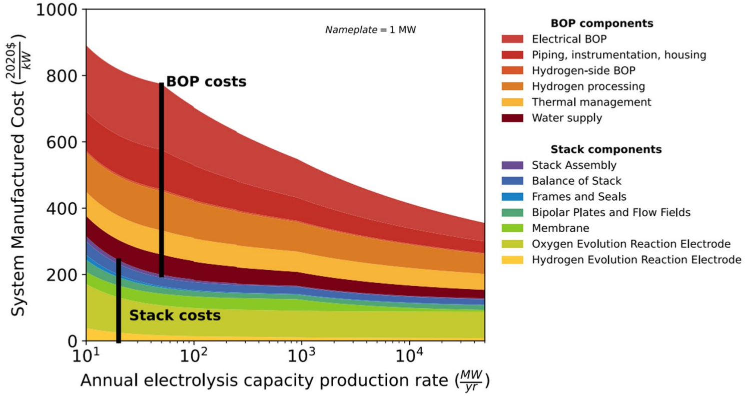
H_2 generation
1 kW AEM electrolyzer

CO_2 DAC
1 kg/day HEMCC



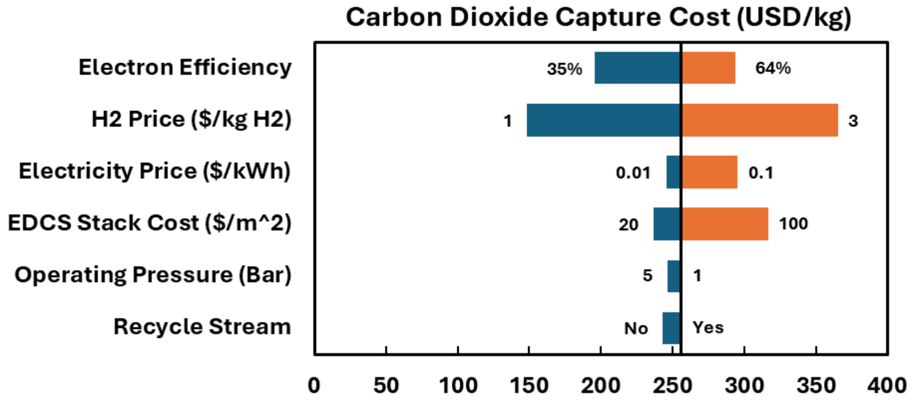
Wide range of space for laboratory-scale demonstration in Phase 2 at ORNL

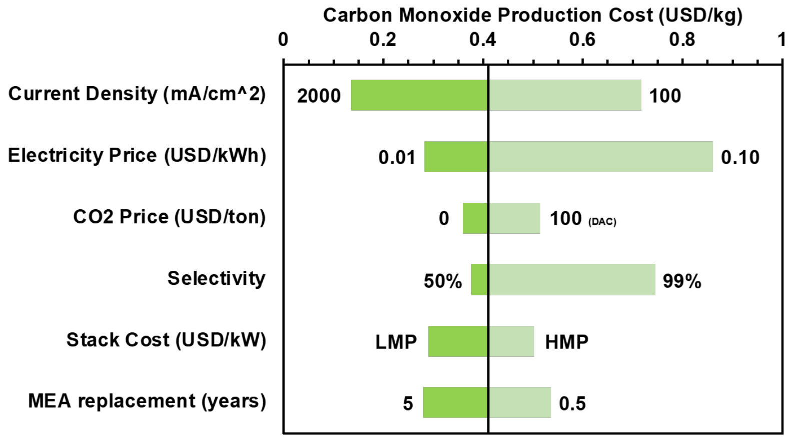
Summary



- Effects of MeOH impurities are avoidable through KOH
- OER catalyst is relatively expensive

- Low RH and high T improve performance
- Hydrogen OPEX plays major role in EDCS





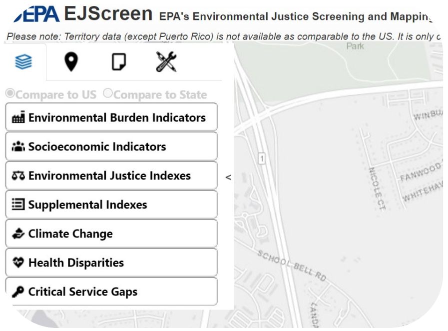
- Careful balance of inlet composition is critical
- Current density is a key variable for CO cost

Summary of Community Benefits and Impacts

Undergrad internship opportunity for DEIA

- Undergrad working under Justin Harrington (UD) working on DAC research
- Developing a more physically robust shorted membrane by tuning carbon additives
- 5-week mentorship program

Social characterization assessment



- Determined that neighboring communities face economic disadvantages as shown by
  - Higher poverty
  - Unemployment rates
  - Household income
- Impact analysis showed negligible harm to surrounding communities for Phase 2

Electochemical engineering survey

- 7/20 responses collected
- Preliminary insights demonstrate

100% rated importance

- o Cell potential
- o Nernst equation
- o Hydrogen electrode
- o Electrode potential
- o Electrochemical rxn eq
- o Standard potentials
- o Rate laws
- o Hydrogen fuel cell
- o Water electrolyzer

Thank you