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The Role of Cation and Anion Exchange Membranes on Power Generation and Nutrient Removal in a Microalgae-Assisted Microbial Fuel Cell

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INTRODUCTION & AIM

Background

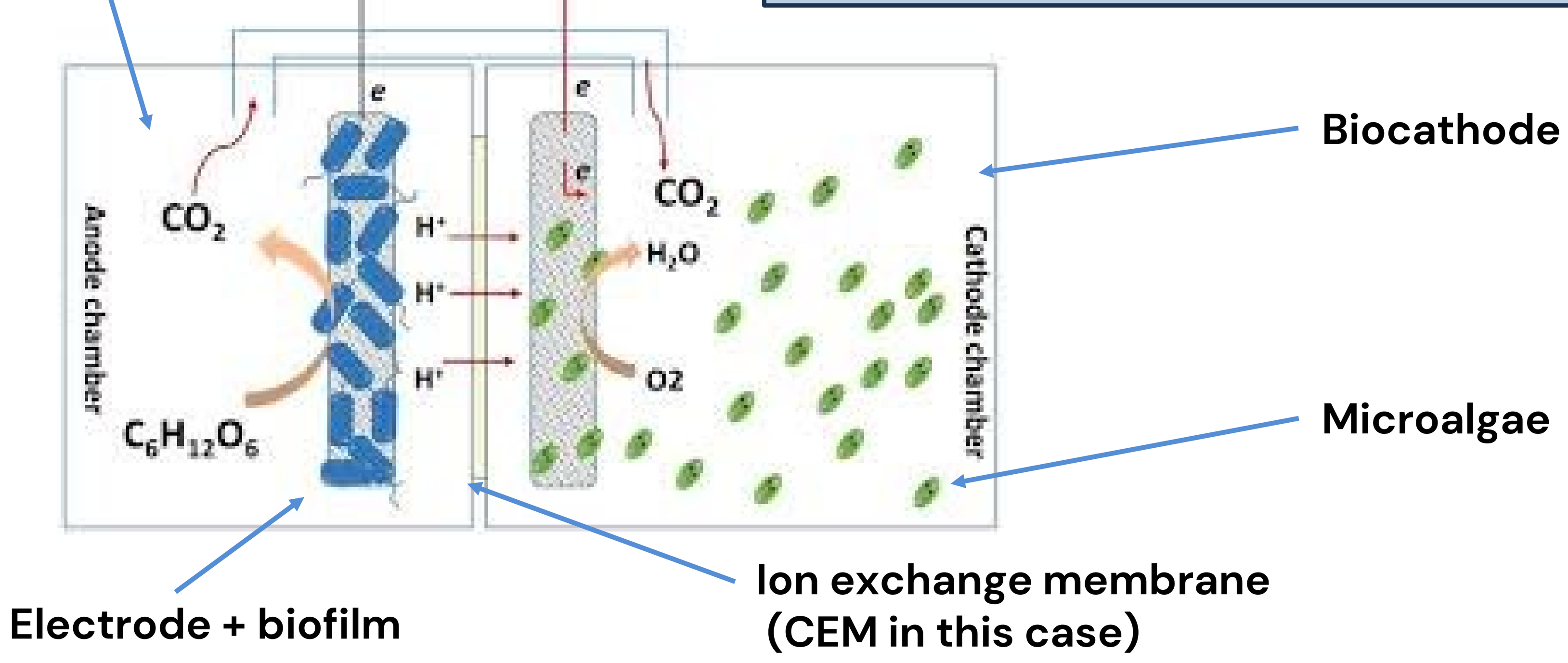
- Wastewater Treatment Plants (WWTPs) are energy intensive (3-4% of US electrical load - 110 TWh/year - 9.6 million households' annual electricity)
- Microbial Fuel Cells (MFCs) convert stored chemical electricity in wastewater directly to electricity, as well as lower chemical oxygen demand (COD)
- MFC limitations:
  - Low power density
  - Limited nutrient removal
  - Electrode/membrane costs

Microalgae-Assisted MFCs

(Anode) Substrate → $CO_2 + H^+ + e^-$ [unbalanced]

(Cathode) $O_2 + 4H^+ + 4e^- \rightarrow H_2O$

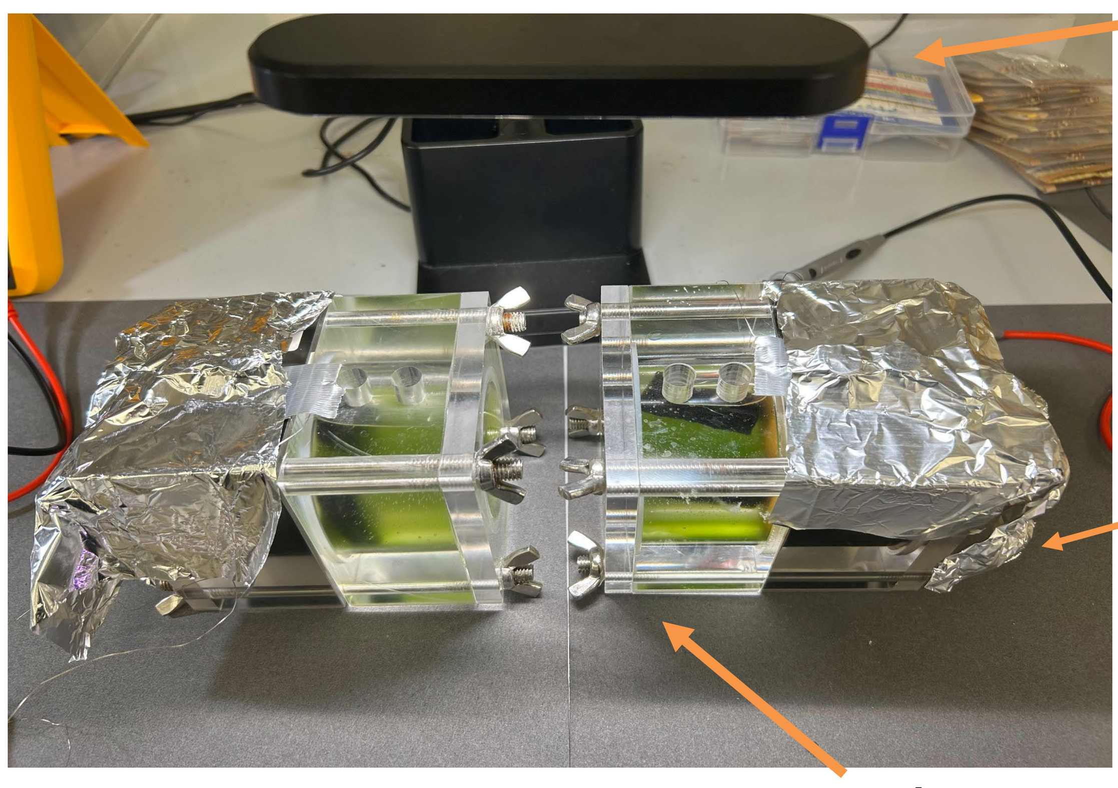
(Algae) $CO_2 + H_2O$ + light → biomass + O_2



- Ion exchange membranes facilitate the exchange of ions between the MFC anode and cathode chambers
- Both cation exchange membranes (CEMs) and anion exchange membranes (AEMs) can be used, among other types
- CEMs allow positive ion transport (e.g., H^+, NH_4^+)
- AEMs allow negative ion transport (e.g., OH^-, NO_3^-, PO_4^{3-})
- This research aims to assess whether CEMs or AEMs best address MFC limitations (power density, nutrient removal)

METHOD

Biocathode MFC configuration



- One MFC using AEM, one MFC using CEM
- Voltages recoded with multimeter (1000 Ω resistor, titanium wire)
- Measured water quality parameters (COD, nutrients, pH, dissolved oxygen, etc.) and voltage
- Results are based on the average of 8 experiments

RESULTS

System Comparison

COD Removal
- AEM: ~36.9%
- CEM: ~41.9%

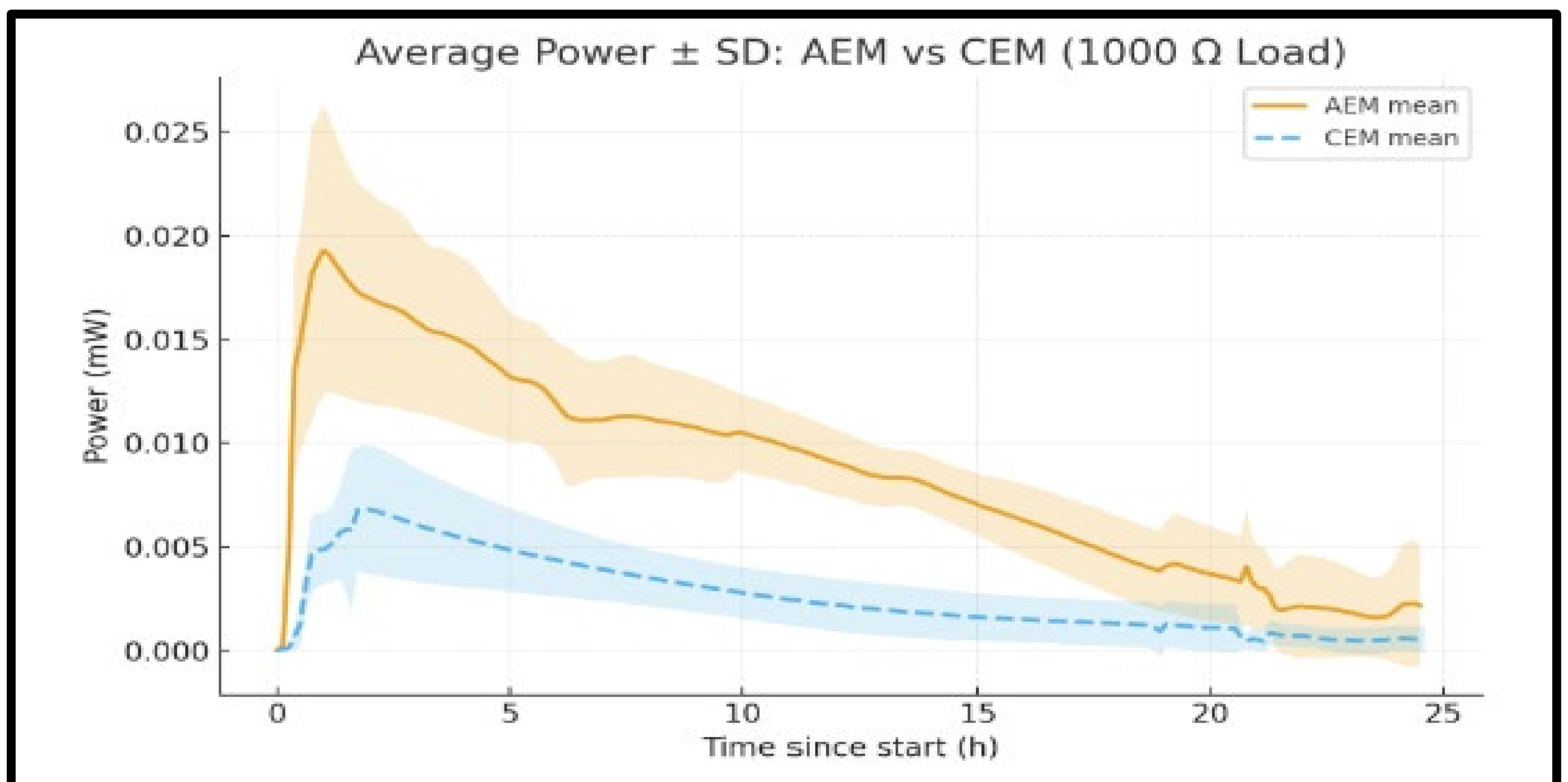
Dissolved oxygen (cathode)
- AEM: ΔDO ≈ −0.65 mg/L
- CEM: ΔDO ≈ -1.48 mg/L

pH (cathode)
- AEM: ΔpH ≈ -0.49
- CEM: ΔpH ≈ -0.49

Total N removal (anode)
- AEM: ~8.7% (high variability)
- CEM: ~76.5% (consistently high)

NH_4^+ removal (anode)
- AEM: ~10.7%
- CEM: ~72.7%

PO_4^{3-} removal (anode)
- AEM: ~31%
- CEM: around -10% (slight apparent increase)



DISCUSSION

Electrical performance

- Under a 1 kΩ load, AEM systems achieved mean power outputs roughly 2–4× higher than CEMs

Mechanistic Insights

- AEM favors anion (OH^-, HCO_3^-) transport → improved pH balance and favorable algal environment → enhanced cathodic oxygen reduction and voltage stability
- CEM promotes cation (H^+, NH_4^+) migration → anode acidification + cathode stress → reduced bio electrochemical performance

Conclusion

- AEM membranes offer a better balance between energy generation and cathode stability, while CEMs emphasize nutrient removal at the cost of electrical efficiency

FUTURE WORK

- Other exchange membranes in algae-integrated MFCs, e.g., proton exchange membranes (PEMs) or bipolar membranes (BIMs)
- Mixed algal-bacterial consortia synergizing pollutant uptake (organics, nitrogen, phosphorous) with power generation

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