Advanced Alkaline Membrane H_2/Air Fuel Cell System with Novel Technique for Air CO_2 Removal

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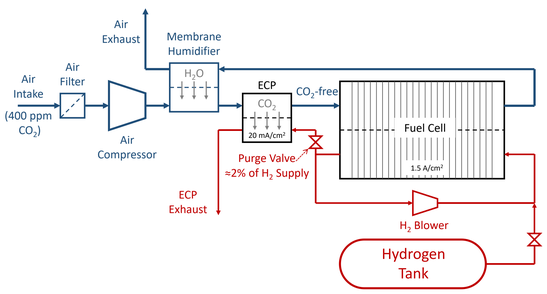
Project Vision

A proof-of-concept for automotive hydroxide exchange membrane fuel cell (HEMFC) systems, enabled by a novel electrochemical CO_2 pump (ECP) for CO_2 mitigation.

End of project deliverable, 1 kW system meeting:

Descriptor	Quantitative Target
Ambient Air	400 ppm CO_2
Low PGM stack	≤0.125 mg_{PGM} cm^{-2}
High performance	0.65 V @ 1.5 A cm^{-2}
Durable stack	400 h @ 80 °C (≤10% loss)
Compact	ECP : FC volume ≤0.3 : 1
Efficient	≤2% system H_2 to ECP
Low Cost	≤$2 kW^{-1} for ECP

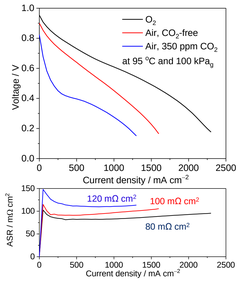
CO_2-mitigated HEMFC system

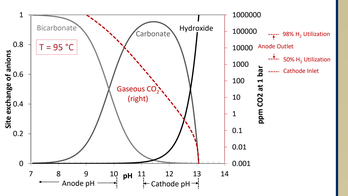


Key electrochemical CO_2 pump (ECP) attributes

- **Continuous** – no sorption or regeneration
- **Electrochemically pumped** –concentrates sub-ppm to %
- **Compact** – optimized for CO_2 mass transport,
- **Efficient** – Powered by ≤2% of system H_2 in anode purge
- **Low Cost** – Low-cost ECP MEA and module architectures

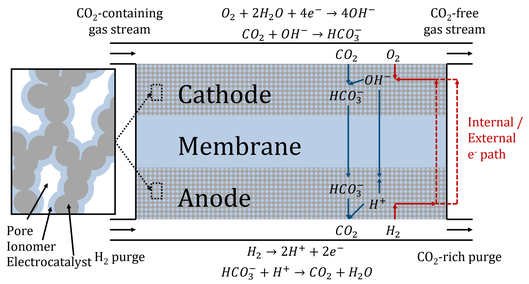
CO_2 effect in HEMFCs



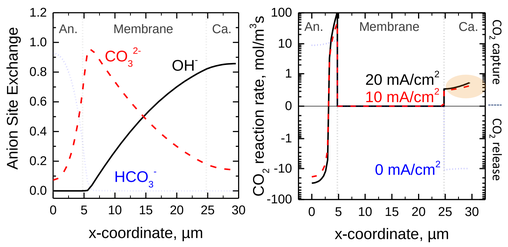


HEM: PAP-TP-85, 5 µm
Anode: Pt/C (0.4 mg_{Pt}/cm^2)
Cathode: Pt/C (0.4 mg_{Pt}/cm^2)
Ionomer: PAP-BP-60
Flow: 600 sccm H_2 (100% RH)
600 sccm O_2 or 2000 sccm air (100% RH)
BP: 100 / 100 kPa_g

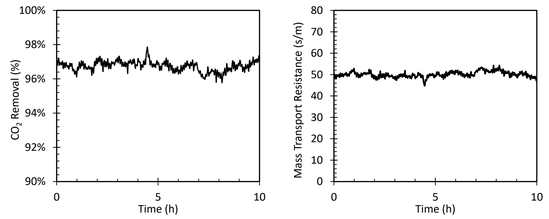
Electrochemical CO_2 Pump



1-D MEA model
Simulating local conditions at 99.9% removal
70 °C | **Anode: 100,000 ppm CO_2 | 0.4 ppm CO_2**



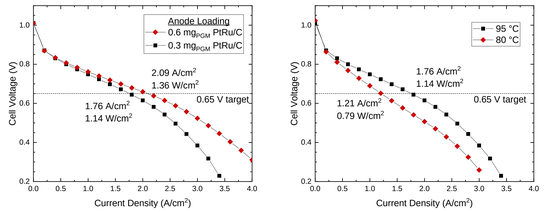
ECP Performance



MEA Construction
HEM: PAP-TP-85, ~20 µm
Ionomer: PAP-BP-100 or **PAP-TP-100***
Anode: **5-40** wt% Pt/C, 0.01-**0.1** mg_{Pt}/cm^2
Anode GDL SGL 29BC
Cathode: Ag, 0.6 mg/cm^2 or **40 wt% Pt/C 0.1 mg_{Pt}/cm^2**
Interlayer: Vulcan XC72 + 30-**40**% ionomer, ca. 1 mg/cm^2
Cathode GDL SGL 25BA or **SGL 29BC**

Testing conditions
Temperature: 60 - **70 °C***
Anode Flow: **7**-50 sccm H_2 (**80**-90% RH)
Cathode Flow: 100-1000 sccm air (80-90% RH)
500 sccm air, 80% RH
BP: 0 / 0 kPa_g
Condition: 1 h hold, average last 30 min
***Bold values apply to top figures**

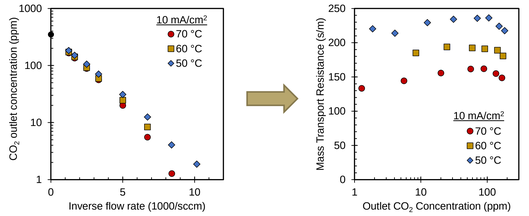
CO_2-free HEMFC performance



MEA Construction
HEM: PAP-TP-85, 15 µm
Ionomer: PAP-TP-100
Anode: 75 wt% 2:1 PtRu/C, 0.3-0.6 mg_{PGM}/cm^2
Anode GDL SGL 29BC
Cathode: 40 wt% Pt/C 0.4 mg_{Pt}/cm^2
Cathode GDL SGL 25BA or SGL 29BC
Pretreatment: Soak in 3 M KOH, blot dry (no rinse)

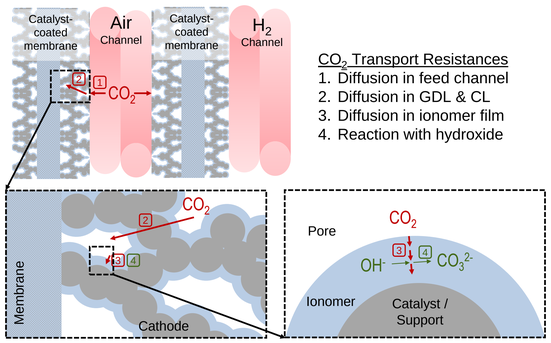
Testing conditions
Temperature: 80-95 °C
Anode Flow: 1000 sccm H_2, 75% RH
Cathode Flow: 2000 sccm CO_2-free air, 106% RH
BP: 250 / 250 kPa_g
Condition: 5 s hold, 0.2 A/cm2 step, average of forward and reverse scans

ECP Transport Characterization



$$R_M = \frac{1}{k_M} = \frac{A}{v_{air}}\left[\ln\left(\frac{x_{CO2}^{in}}{x_{CO2}^{out}}\right)\right]^{-1}$$

R_M CO_2 mass transport resistance (s/m)
k_M CO_2 mass transport coefficient (m/s)
A cell area (m^2)
v_{air} volume flowrate of air (m^3/s)
x_{CO2} mole fraction of CO_2 in air



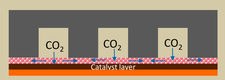
CO_2 Transport Resistances
1. Diffusion in feed channel
2. Diffusion in GDL & CL
3. Diffusion in ionomer film
4. Reaction with hydroxide

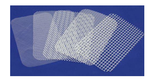
Roadmap for ECP Modules

Comparison of basic architectural requirements

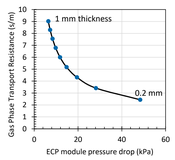
Fuel cell
- >1 A/cm²
- >1 W/cm² heat
- <0.03 Ohm-cm² e⁻
- Flow field land and GDL increase gas phase R_{MT}

ECP requirements
- ≤0.05 A/cm²
- ≤0.06 W/cm² heat
- ~2 Ohm-cm² e⁻
- Can use convection-inducing mesh spacer to create flow channels
- Can eliminate GDL
- Ultra-low gas R_{MT}

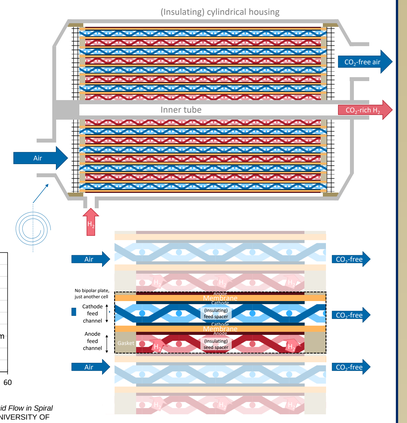




Mass transport / pressure drop tradeoff

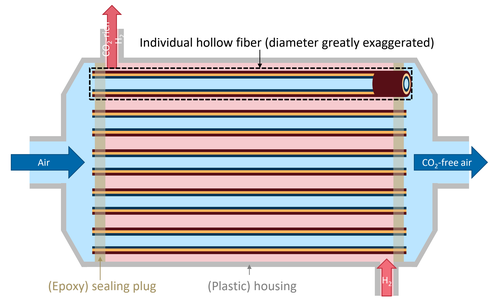


Correlations from: G. Srivathsan, *Modeling of Fluid Flow in Spiral Wound Reverse Osmosis Membranes*, thesis, UNIVERSITY OF MINNESOTA (2013).



Directions for Future Research

Hollow fiber ECP



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