Design of a Hydrogen Electrolysis System and Fuel Cell for Vehicle Applications

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Background

Gasoline powered engines have long been the industry standard for vehicles

- Burning gasoline releases greenhouse gasses such as CO_2, CO, and NO_2

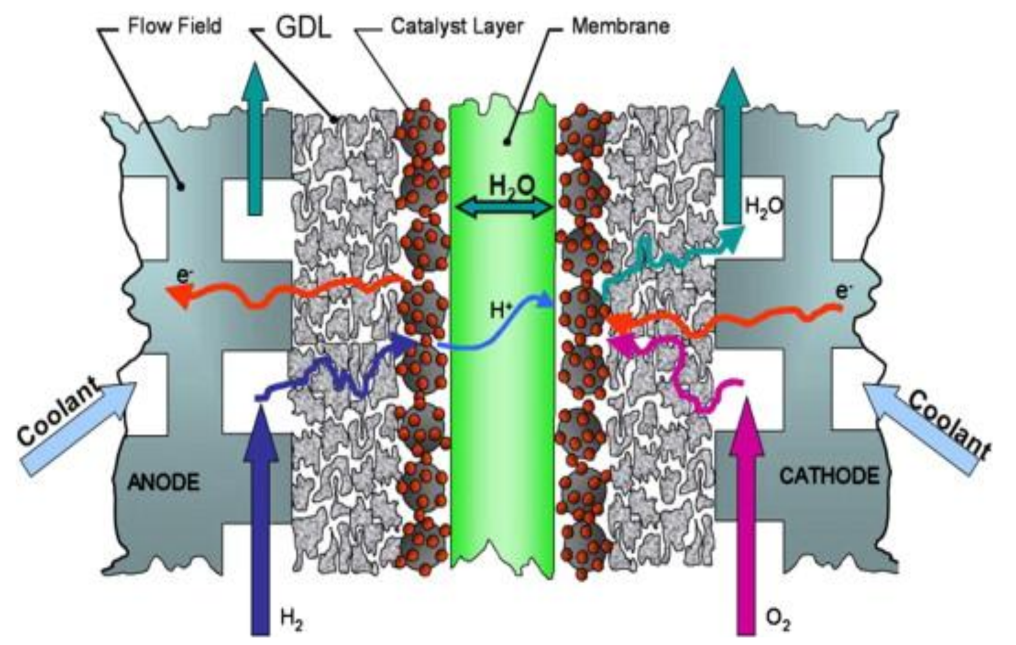
The electric engine has been newly popularized due to its higher efficiency and lack of tailpipe emissions

- Electricity to power these vehicles comes from burning fossil fuels
  - Net output of greenhouse gasses

Hydrogen fuel cells solve both issues:

- No emissions when used in an engine
- H_2 fuel can be produced cleanly

H_2 Fuel Cell Mechanism



Owejan, J., Gagliardo, J., Sergi, J., Kandlikar, S., & Trabold, T. (n.d.). Water management studies in PEM fuel cells, part I: Fuel cell design and in situ water distributions. Retrieved February 14, 2025

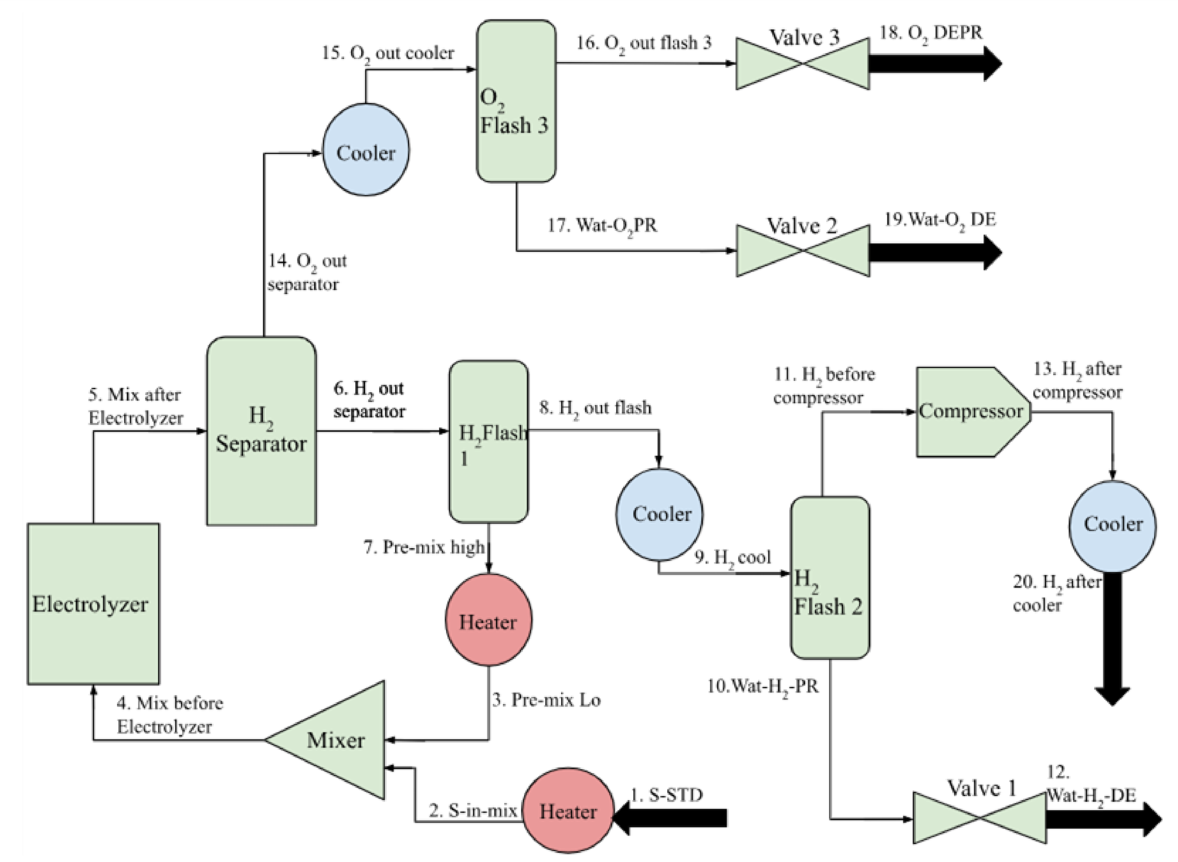
H_2 splits in half → Releases an e^- → Electricity

Anode Reaction: $H_2 \rightarrow 2H^+ + 2e^-$

Cathode Reaction: $½O_2 + 2H^+ + 2e^- \rightarrow H_2O$

- Protons travel through the membrane and meet O_2 flowing over the cathode
- e^- travel through an external circuit, generating electricity

Clean H_2 Production



Electrolysis, powered by solar energy, splits H_2O into H_2 and O_2 with zero emissions

Input: KOH (catalyst) + H_2O + 48,400 W

Output: 99.5% pure streams of H_2 and O_2

Electrolysis Governing Equations

Butler - Volmer Equation:

$$i = i_0 [EXP(\frac{a_a F \eta_s}{RT}) - EXP(-\frac{a_c F \eta_s}{RT})$$

i = current density, i_0 = exchange current density, a_a and a_c= transfer coefficients, η_s=surface overpotential

- Quantifies the rate of oxidation and reduction
- Models rate of electron transfer → how much energy is required to produce hydrogen

Faraday's Law:

$$r = \frac{i*A}{N*F}$$

A = electrode surface area, N = number of electrons

- Predicts amount H_2 consumed and O_2 needed

Our parameters produced **4.678 kg/hr H_2**, enough for a full tank

Fuel Cell Governing Equations

PEM Polarization Equation:

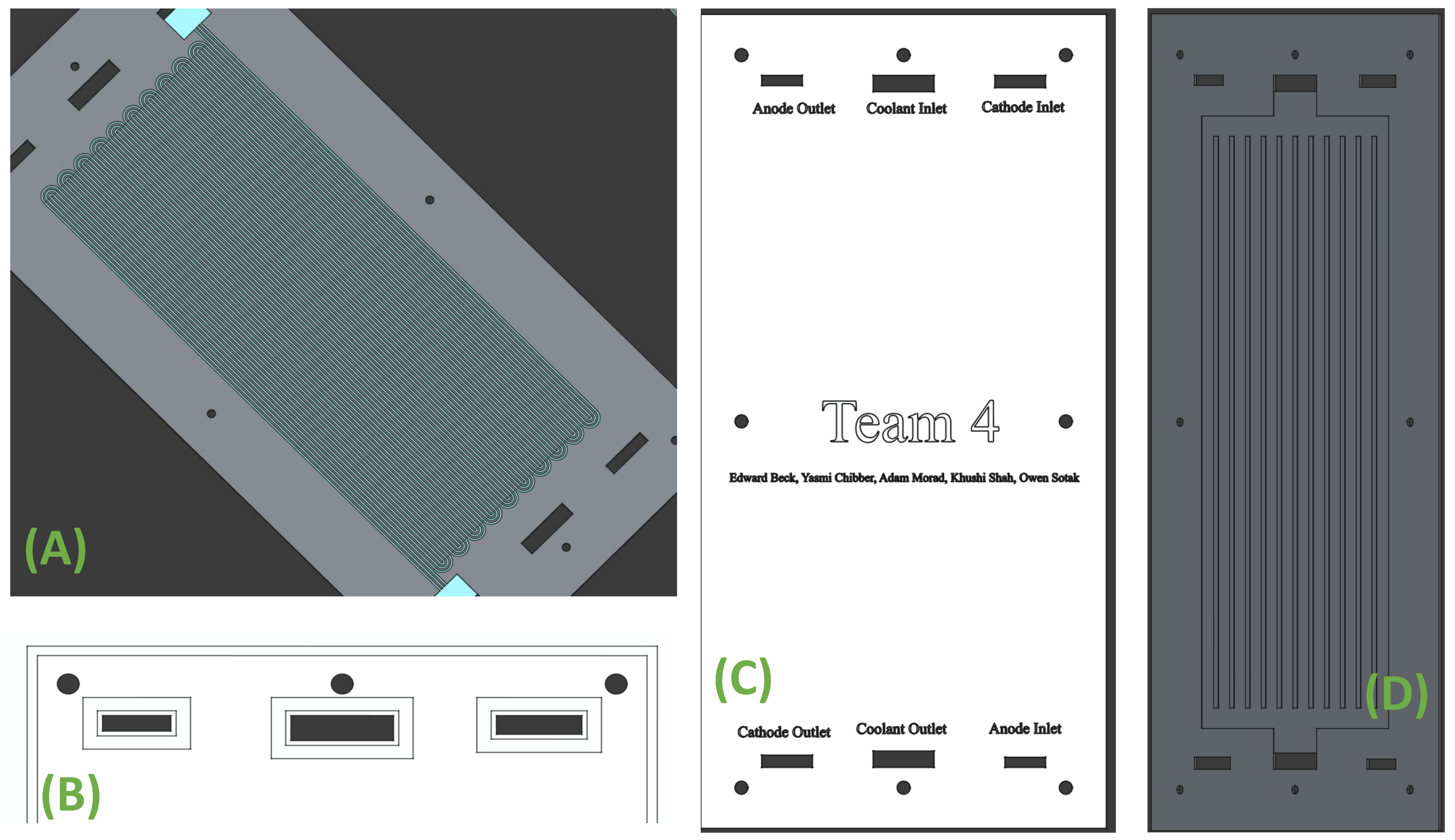
$$V_{Cell} = constant - 2.303\frac{RT}{F}\{log(\frac{i}{i_{ref}}) - log(\frac{P_{O_2}}{P_{ref}}) - log(1 - \frac{i_{load}}{j_D})\} - R_{\Omega} i_{load}$$

R_{Ω}=Ohmic Resistance, P_{O2}=partial pressure O_2, i_{load}=current density through external circuit, j_D=limiting current density

- Quantifies the performance of our fuel cell via several key parameters

Our parameters resulted in 345 cells required to reach optimal power production

Fuel Cell Design



(A): The multiple serpentine channels forces gas reactants to spread out evenly on the usable surface

(B): The manifolds allow for gasses and fluids to flow throughout the entire system

(C): The endplates act as the inlet and outlet for all products and reactants

(D): The cooling system pumps coolant both around the cell and in between the two bipolar plates

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