
MEEN 432 –Automotive Engineering

Fall 2026

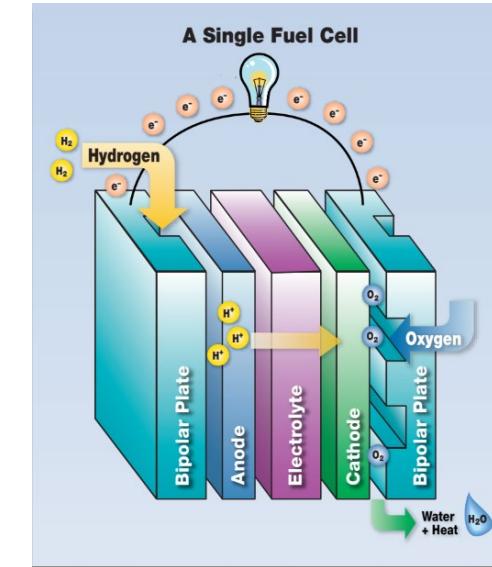
Instructor: Dr. Arnold Muyshondt

Acknowledgement: Most of the material for this class was developed by Dr. Swami Gopalswamy

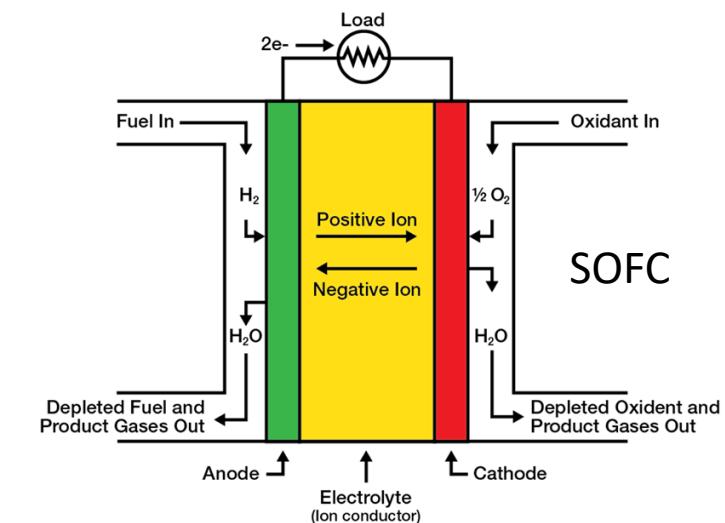
Lecture 11: Fuel Cell Vehicles

A Fuel Cell

- A Fuel Cell converts a fuel (H_2) directly into electricity!
- A Fuel Cell consists of a “membrane” that allows selective passage of ions that are extracted from fuel (H_2) and air (O_2)
 - When protons (H^+) pass through the membrane, they are classified as “Proton Exchange Membrane” (PEM) Fuel Cells
 - When Oxygen ions (O^{2-}) pass through, they are often classified as “Solid Oxide Fuel Cells” (SOFC)
- A majority of automotive powertrains are PEM FCs



PEM Fuel Cell

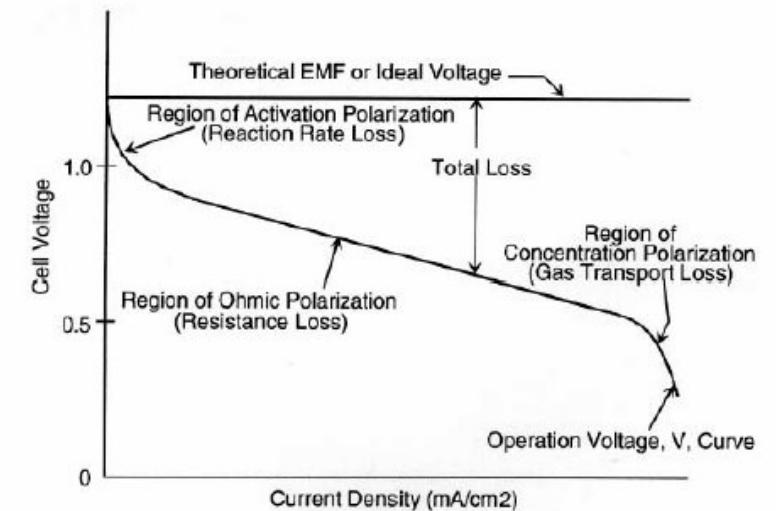
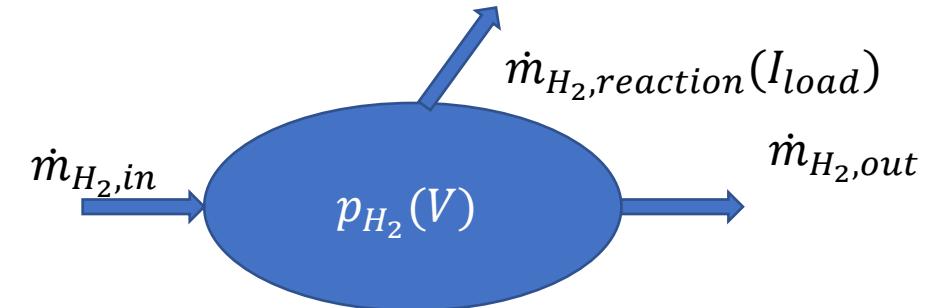


PEM Fuel Cell

- Basic Chemical Reaction:
 - $H_2 \rightarrow 2 H^+ + 2 e^-$ (at the Anode)
 - $4H^+ + O_2 + 4 e^- \rightarrow 2 H_2O$ (at the Cathode)
- The electrons flow through the external circuit providing power to any connected load
- NOTE: A Fuel Cell is NOT a battery – i.e. it does not store energy
- The voltage across the fuel cell is the result of a complex phenomena.
 - A basic electro-chemistry analysis provides the electric potential across the membrane based on the partial pressure of the reactants:
 - $E_{Nernst} = f(p_{H_2}, p_{O_2}, \dots)$
 - Thus a key mechanism for control of the voltage across the fuel cells is through appropriate control of the partial pressures on either side of the membrane

PEM Fuel Cell Control

- Partial pressure control
 - Controlling the mass flow rates in and out of the electrode chambers, while accommodating variations in the reaction flow rates (which is a function of the vehicle loading) is a control's challenge
- Humidity control
 - As the reaction proceeds, water is generated → cathode side can become saturated leading to condensation, which will reduce membrane efficiency
 - However, a dry air will also inhibit reaction efficiency!
 - A careful control of humidity is another control challenge
- Stack characterization is done through voltage vs. current density curves
- Overall, FC can be up to 60% efficient!
 - And only water vapor as emissions!!



Fuel Cells

- PEM Fuel Cells require Hydrogen as the input fuel, while SOFC are more accommodative of other types of fuels
- Often “Reformers” are used that can “convert gasoline or other standard fuels to Hydrogen”
 - The overall efficiency from fuel to power delivery is expected to be still much more efficient than a conventional ICE
- Fuel cells are not just theoretical concepts:
 - [TOYOTA Fuel cell - How does it work?](#)
 - [2025 Toyota Mirai Specifications | Toyota.com](#)
 - <https://www.bloomenergy.com/how-fuel-cells-work>
 - <https://youtu.be/YyazZk2ICPA>

Outlook

- Fuel Cells are still quite a ways off
 - H₂ Infrastructure is critical for FC to succeed
 - H₂ is available in plenty and production processes for getting H₂ are common
 - Use of electrolysis along with a renewable source of energy together make H₂ a compelling fuel
 - Transportation and storage of H₂ is an engineering challenge
 - Leakage and flammability are significant considerations
- Alternate fuels also offer promise as an alternate to H₂
 - Ammonia is one of the candidates for use instead of H₂. Ammonia is available in plenty as a by-product of many industrial processes
- The fundamental driver for Fuel Cells is the **High Efficiency of energy conversion, with No Emissions!**