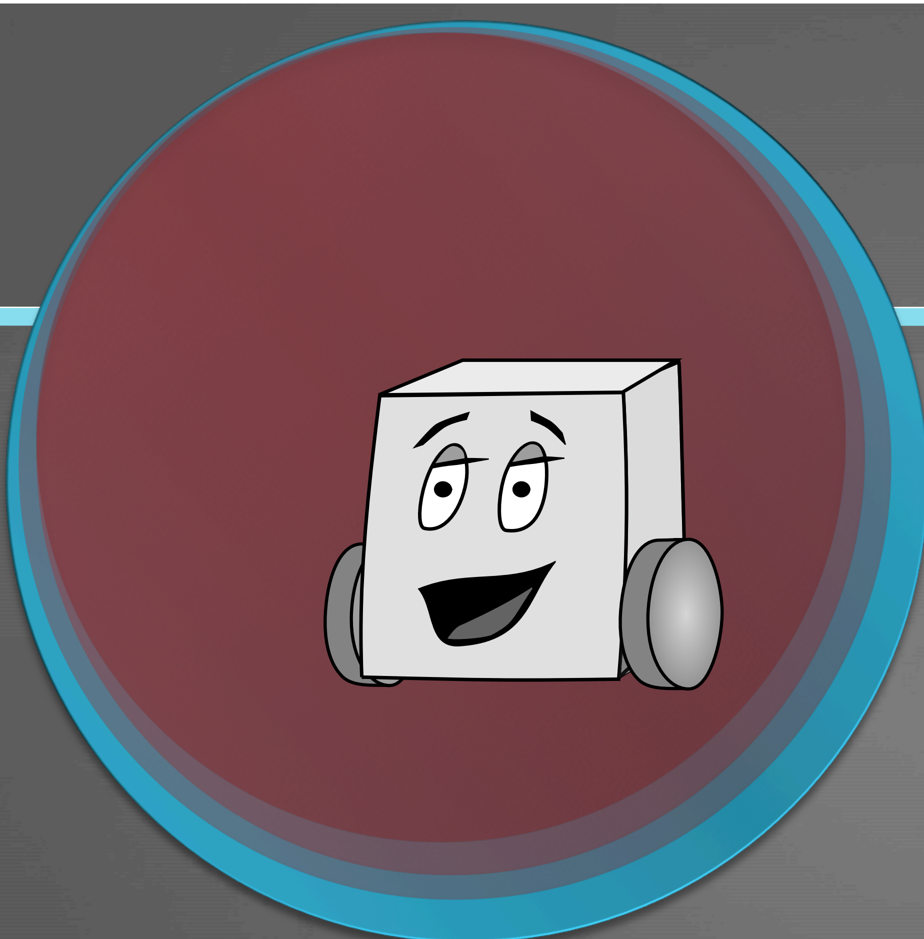


E11 Lecture 6: Fuel Cells

Professor Lape

Fall 2010

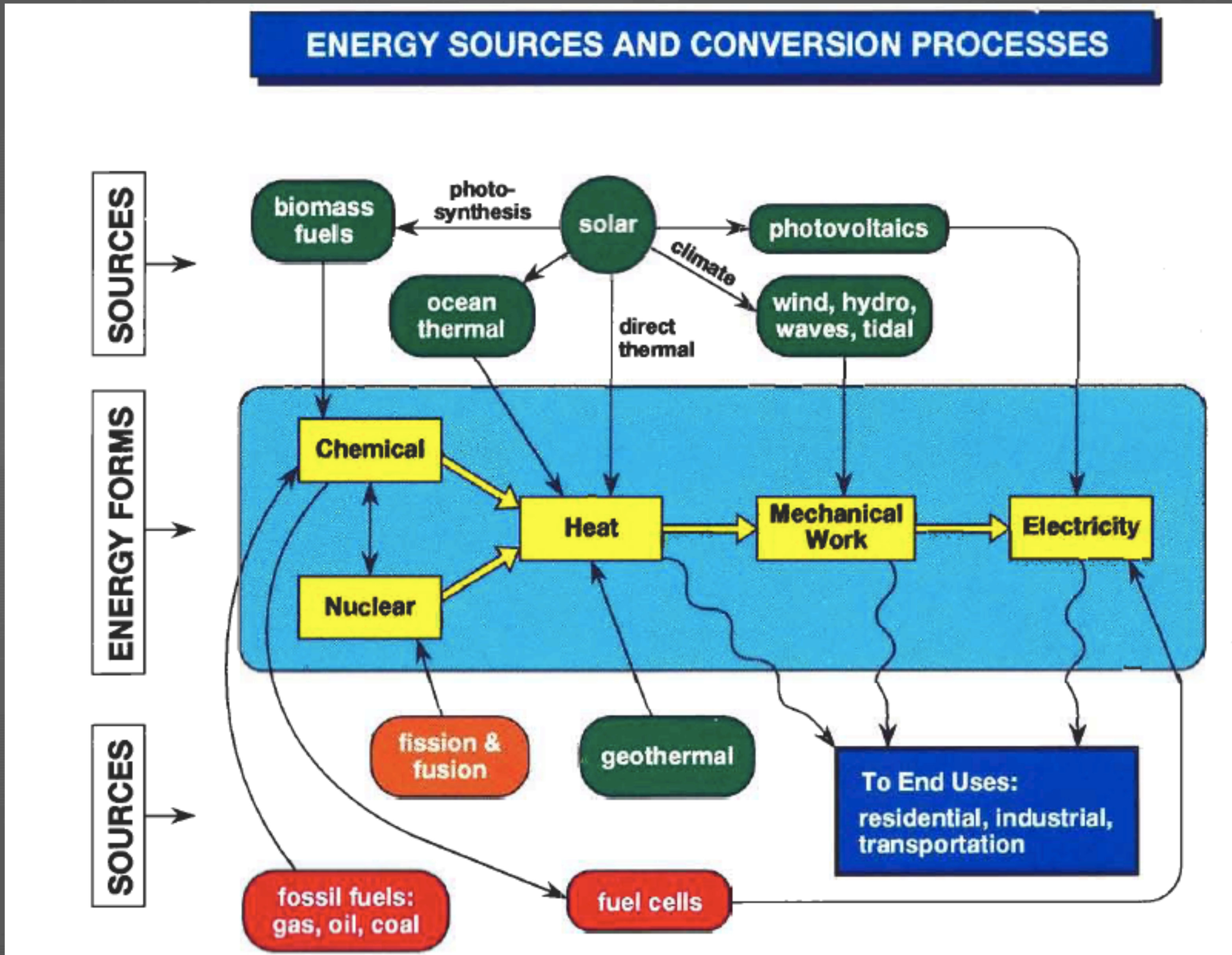


Figure from MIT OpenCourse Ware "Sustainable Energy" 2005 course notes.

Traditional Power Plant

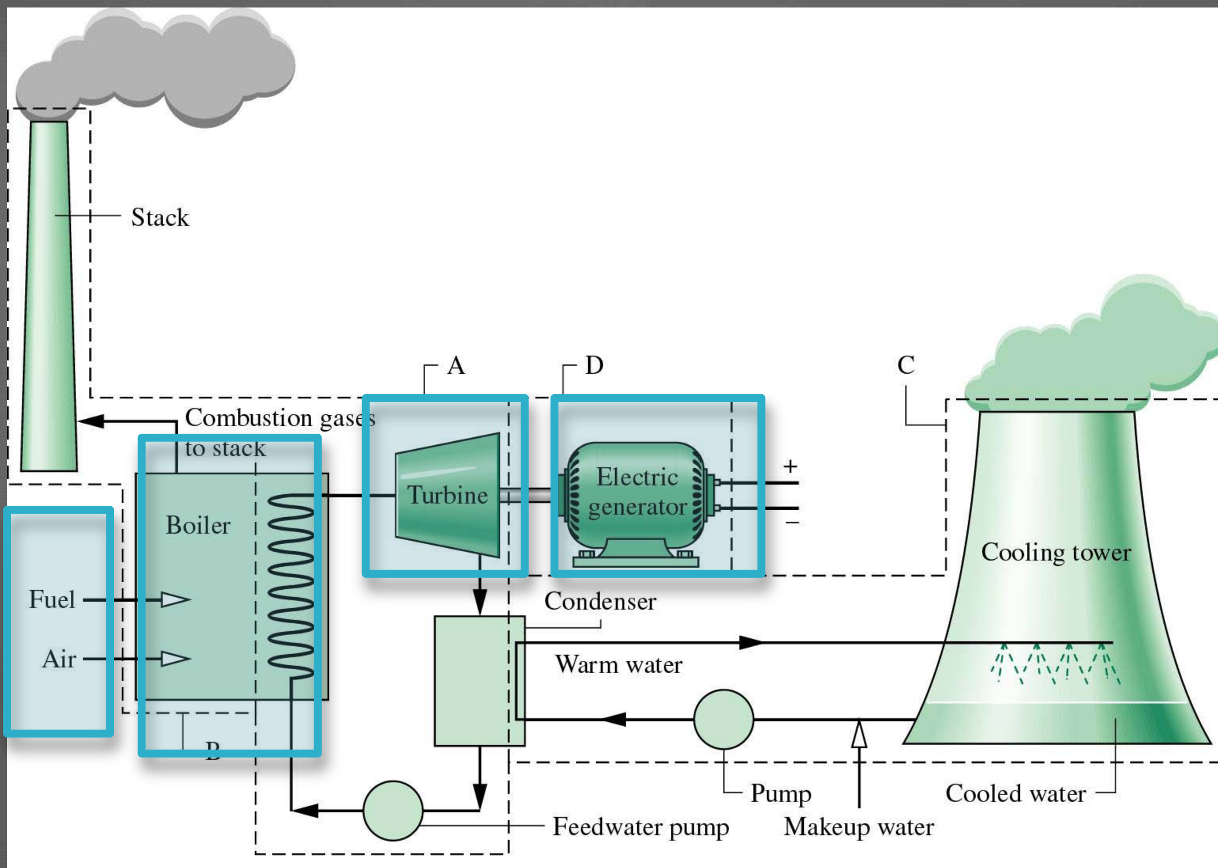


Figure from Moran and Shapiro "Fundamentals of Engineering Thermodynamics, 4th edition.

Chemical Energy → **Heat** → **Mechanical Work** → **Electricity**

Fuel Cell

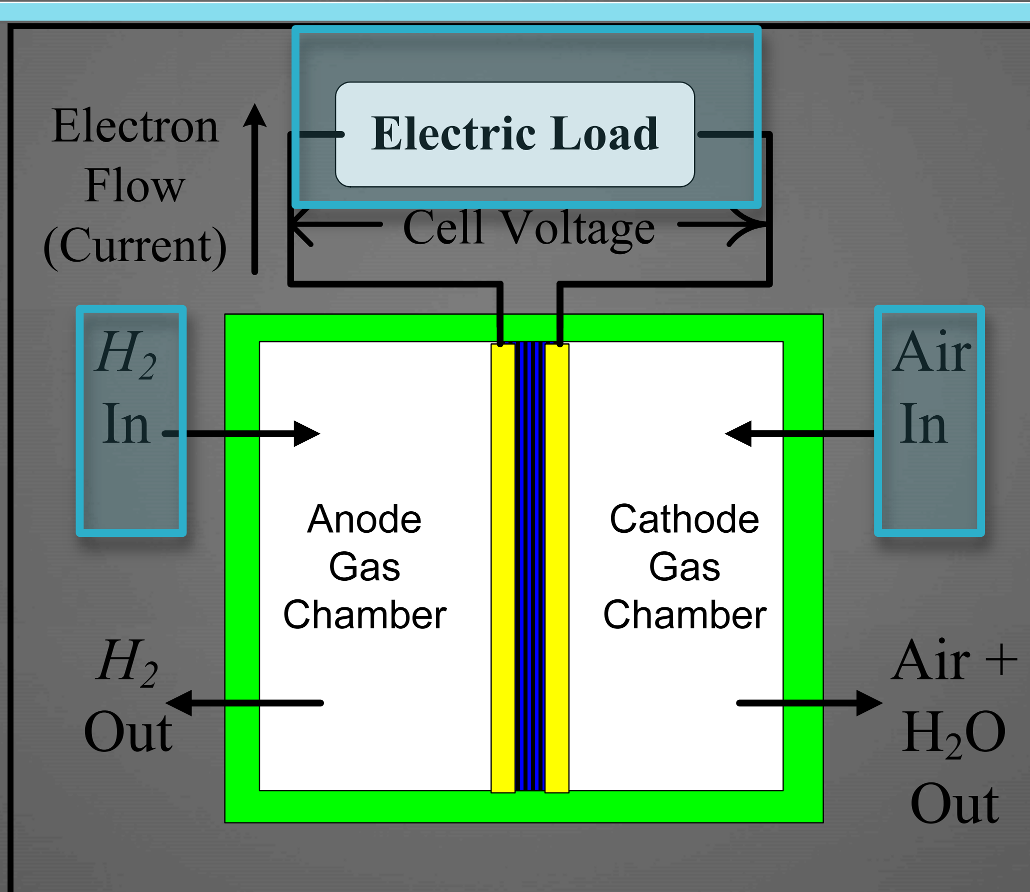


Figure from "Fuel Cell Efficiency", a CACHE Module on Energy in the Curriculum.

Chemical Energy → **Electricity**

The Carnot Efficiency

- Heat engine efficiency is defined as

$$\eta = \frac{\text{Work Output}}{\text{Heat Input}}$$

- The **Carnot Efficiency, η_{max}** describes the limit on the conversion of heat to work in heat engines (power cycles).

$$\eta_{max} = 1 - \frac{T_L}{T_H}$$

where T_H is the temperature (in K) of the heat source and T_L is the temperature (in K) of the heat sink.

- **Even a perfect (termed "reversible") heat engine cannot exceed η_{max}.**

Fuel Cell Efficiency

- Fuel cells are NOT heat engines
  - Not limited by Carnot efficiency!
- Maximum fuel cell efficiency depends on the ratio of the change in available, useful energy (Gibbs Free energy) and total energy released during the chemical reaction (change in enthalpy):

$$\eta_{max,\,FC} = \frac{\Delta G^\circ_{rxn}}{\Delta H^\circ_{rxn}}$$

- At 30°C, the maximum fuel cell efficiency is 83%.

Types of Fuel Cells

- **Fuel Cells can use a variety of fuels and electrolytes** (substance which allows charged particles to pass from anode to cathode).

- **Sample Fuels:**
  - **Hydrogen/Oyxgen**
  - **Methanol /Oxygen**
  - **Carbon Monoxide/Oxygen**

- **Sample Electrolytes:**
  - **Proton Exchange Membrane/ Polymer Electrolyte Membrane (PEM)**
  - **Solid Oxide**
  - **Molten Carbonate**

**This is just a partial list of potential fuels and electrolytes.*

Hydrogen Fuel Cell Advantages

1. Efficiency is not subject to Carnot limit.
   - $\eta_{max,\ FC} > \eta_{max,\ Heat\ engine}$

2. Overall reaction is $2\ H_2 + O_2 \rightarrow 2\ H_2O$
   - No greenhouse gas emissions!

Fuel Cell Operation: Overview

- You will build your own hydrogen PEM Fuel Cell (PEMFC)!

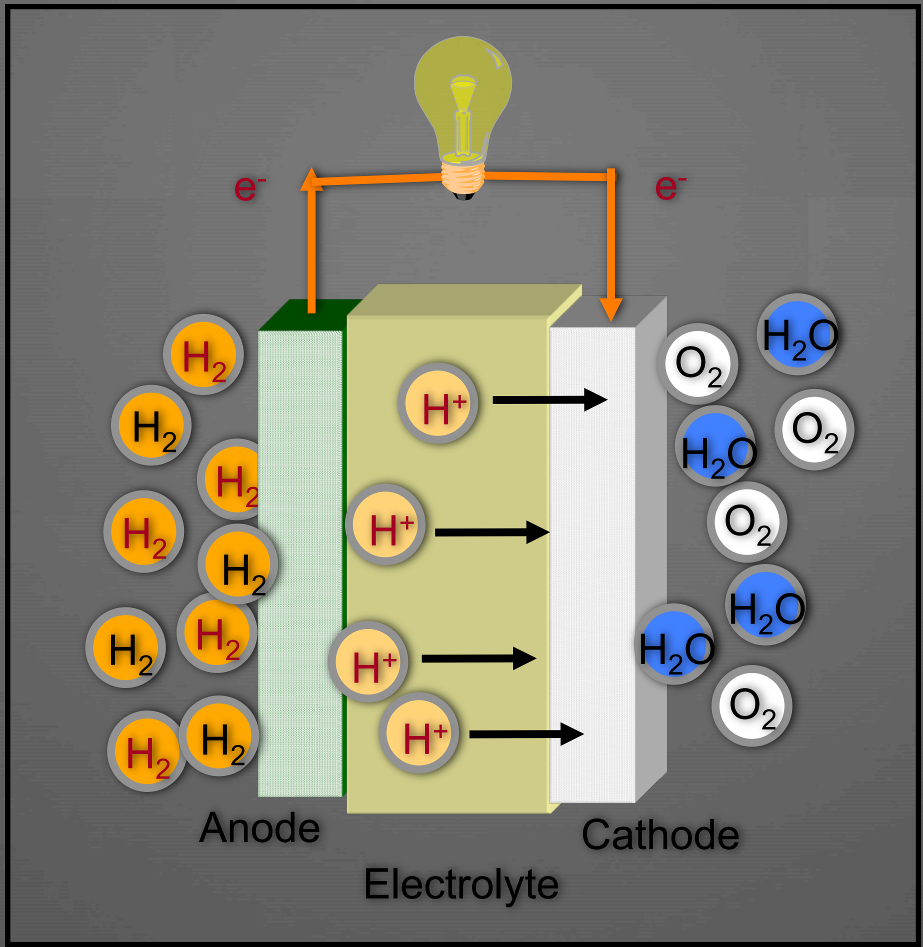


Figure from "Fuel Cell Efficiency" module in CACHE Modules on Energy in the Curriculum

Step 1: Hydrogen approaches Anode

- H_2 approaches the anode (negative terminal) of the fuel cell.

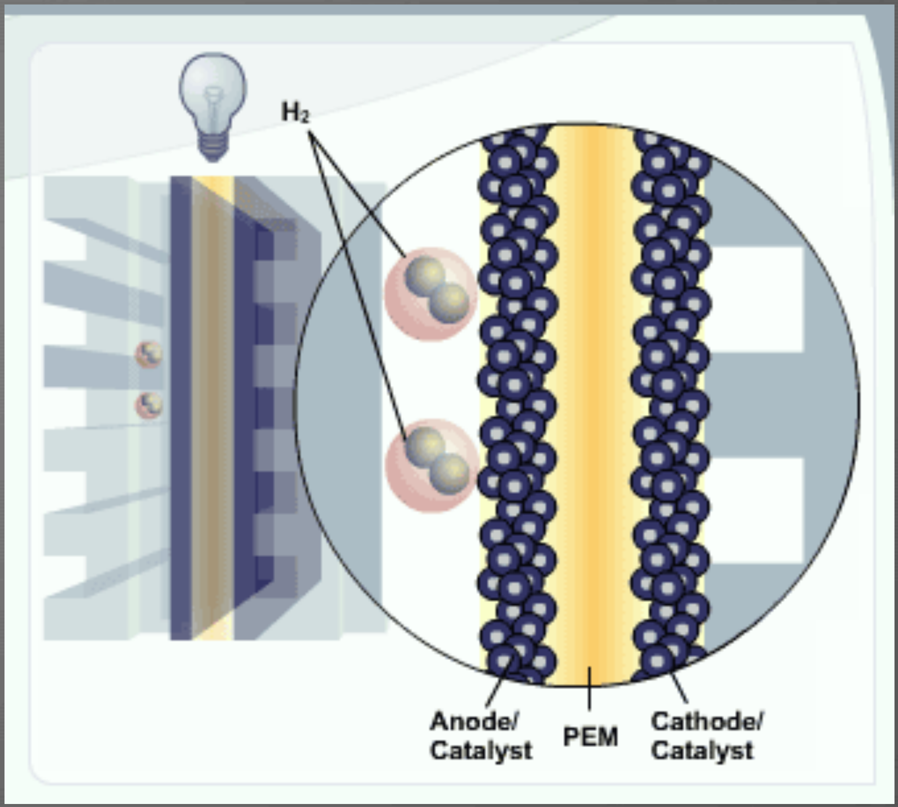


Figure from http://www1.eere.energy.gov/hydrogenandfuelcells/fc_animimation_process.htmlc

Step 2: H_2 is Oxidized to 2 H^+ and 2 e^-

- The H_2 is oxidized to 2 protons and 2 electrons, aided by the catalyst.

$H_2 \rightarrow 2\ H^+ + 2\ e^-$

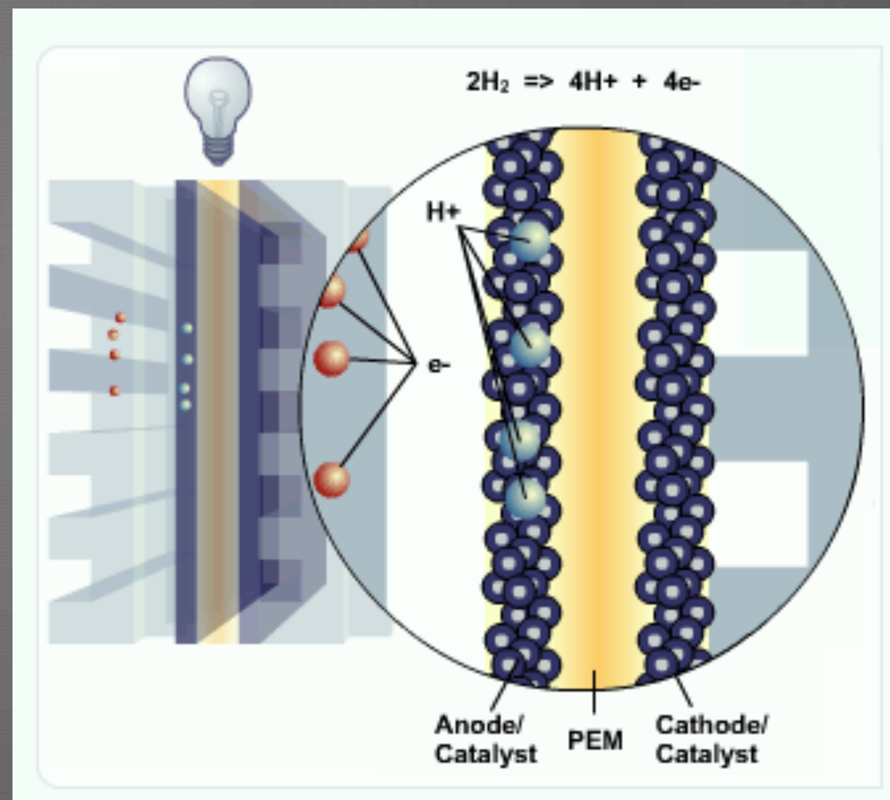


Figure from http://www1.eere.energy.gov/hydrogenandfuelcells/fc_animimation_process.htmlc

Step 3: H^+ passes through membrane, e- flows through circuit

- The electrons travel through the electrical circuit to the cathode (positive terminal) generating an electrical current.
  - The electrolyte prevents e^- from passing directly to cathode.
- The protons pass through the electrolyte to the cathode.

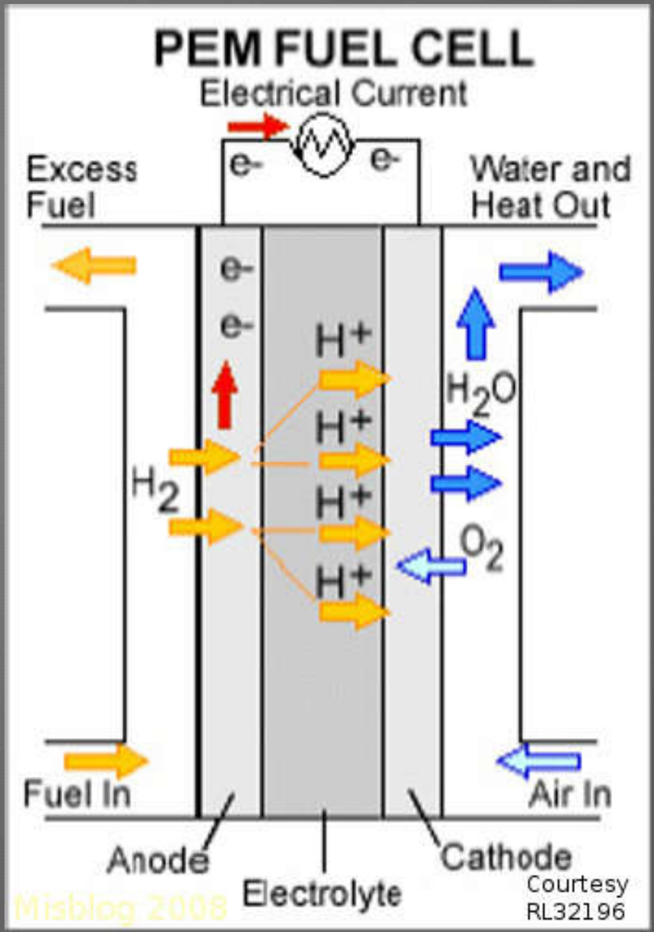
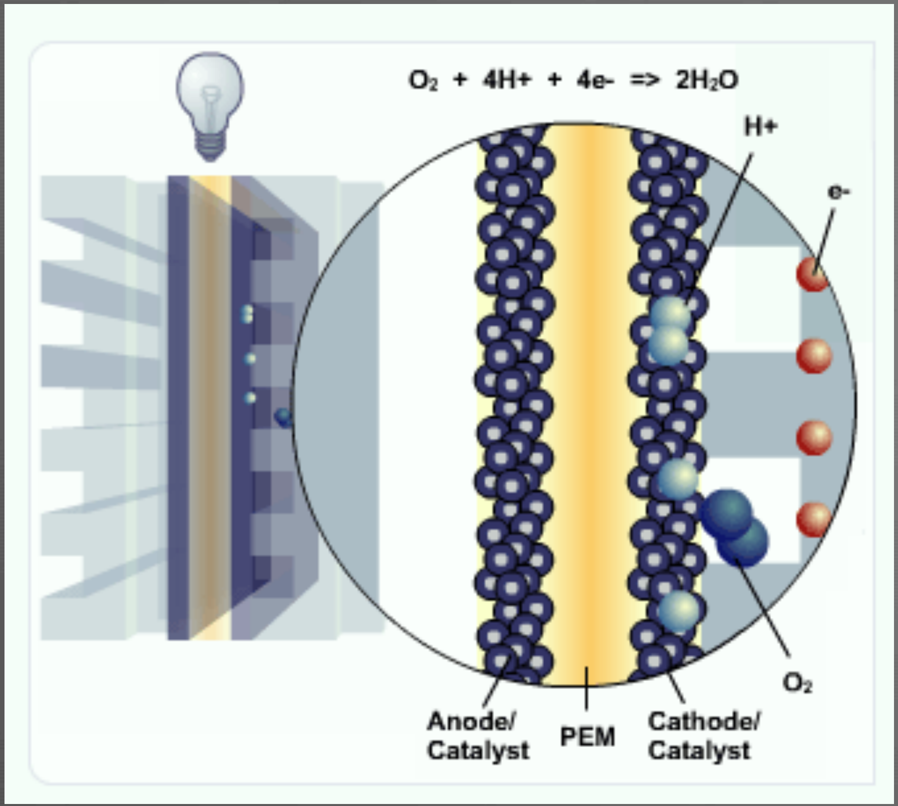
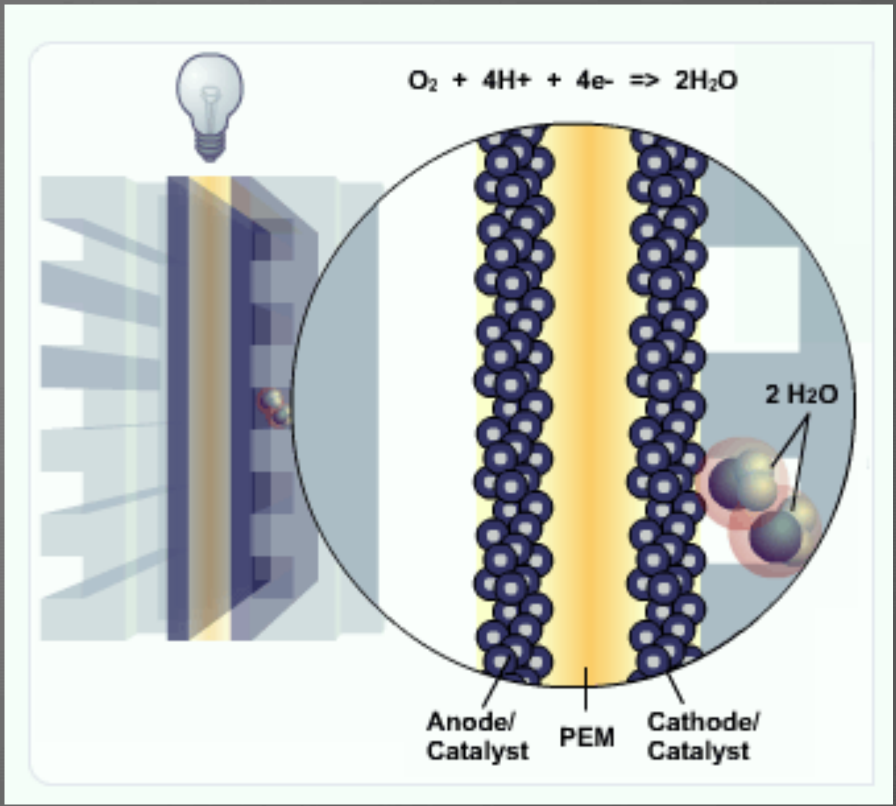


Figure from http://toocan.com/lunog/index.php/misblog/2010/02/08/time-to-stop-demonstrating-fuel-cell-tec

Step 4: $4H^+$ combine with O_2 and $4e^-$ to produce H_2O

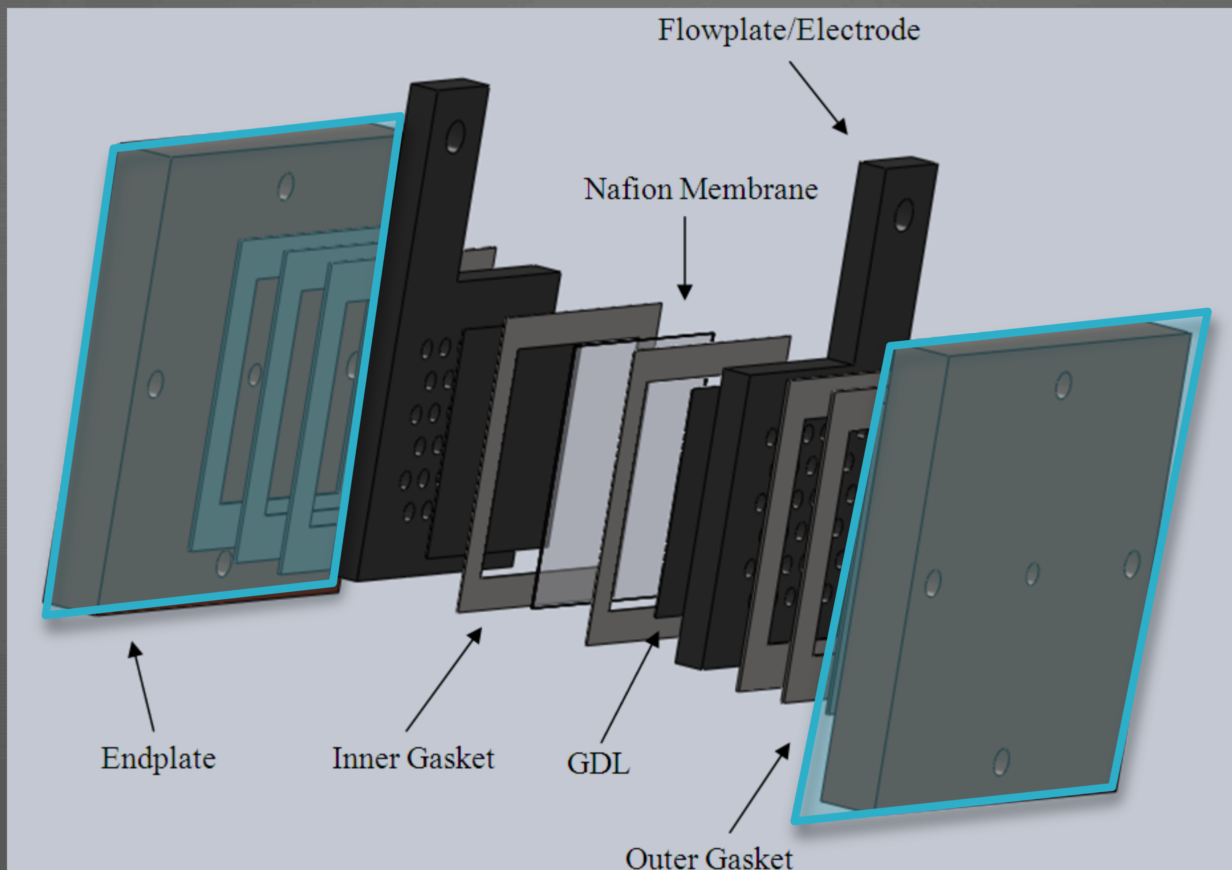




Figures from http://www1.eere.energy.gov/hydrogenandfuelcells/fc_animimation_process.htmlc

$$O_2 + 4\,H^+ + 4\,e^- \rightarrow 2\,H_2O$$

Fuel Cell Components



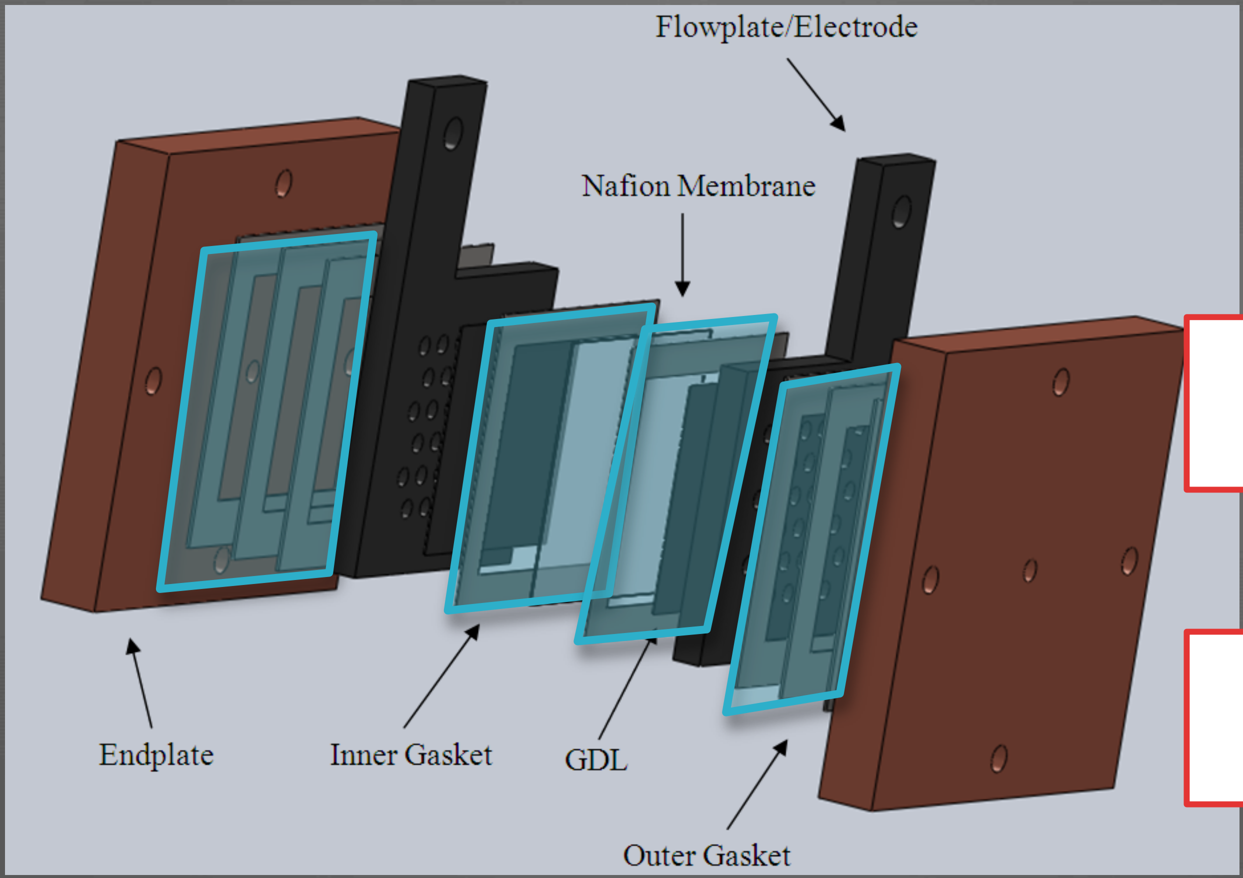
Endplates

Endplates

- **Endplates**:
  - Hold FC pieces together
  - Provide mechanical stability and strength for FC
  - Contain gas inlet/outlet ports
  - Must be electrically insulating

Endplates will be made of fiberglass.

Fuel Cell Components



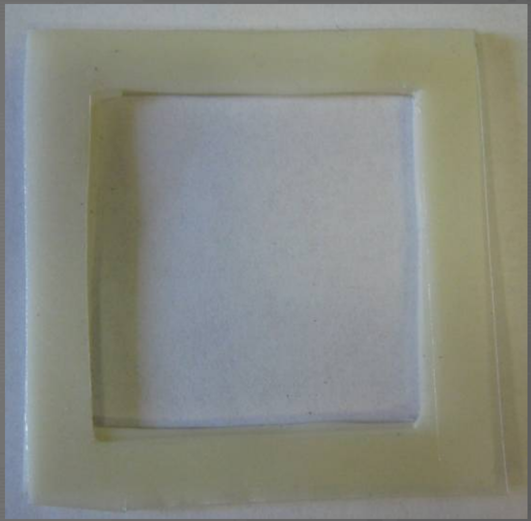
Outer Gaskets

Inner Gaskets

Inner and Outer Gaskets

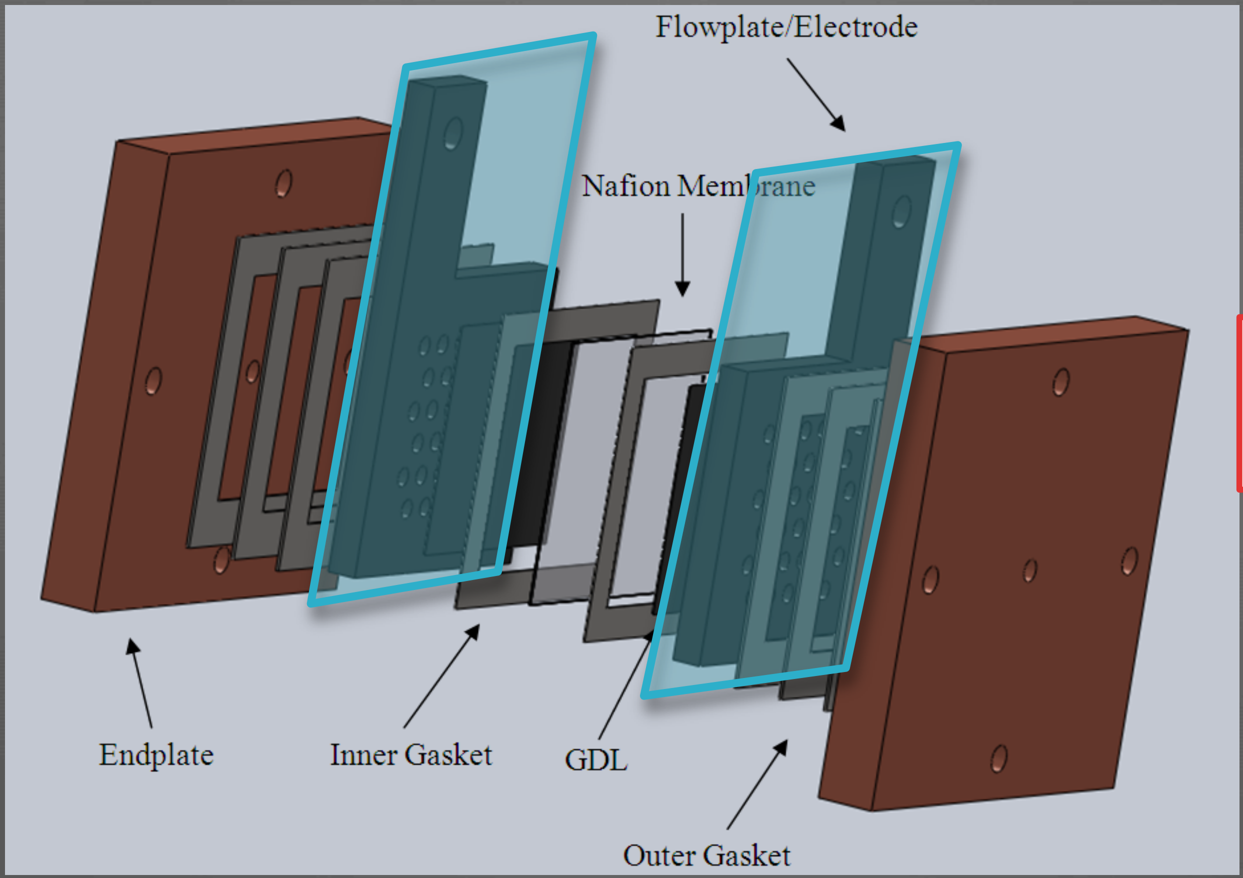
- Outer gaskets prevent leaks between endplates and flowplates.

- Inner gaskets prevent leaks between flowplates and Gas Diffusion Layers.



All of your gaskets will be made of silicone rubber.

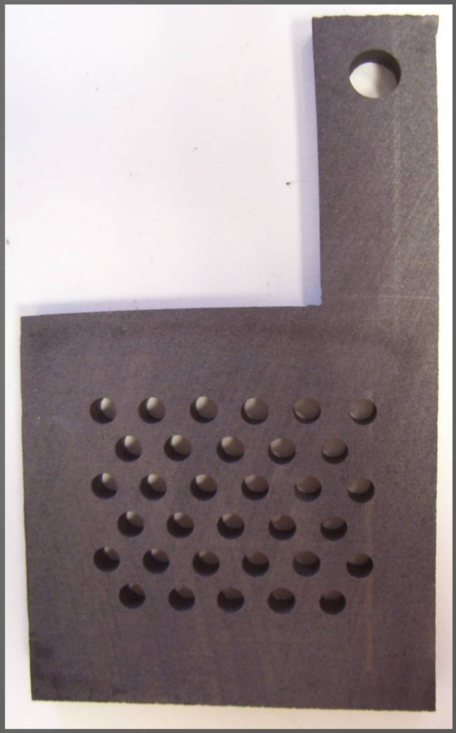
Fuel Cell Components



Flowplates /Electrodes

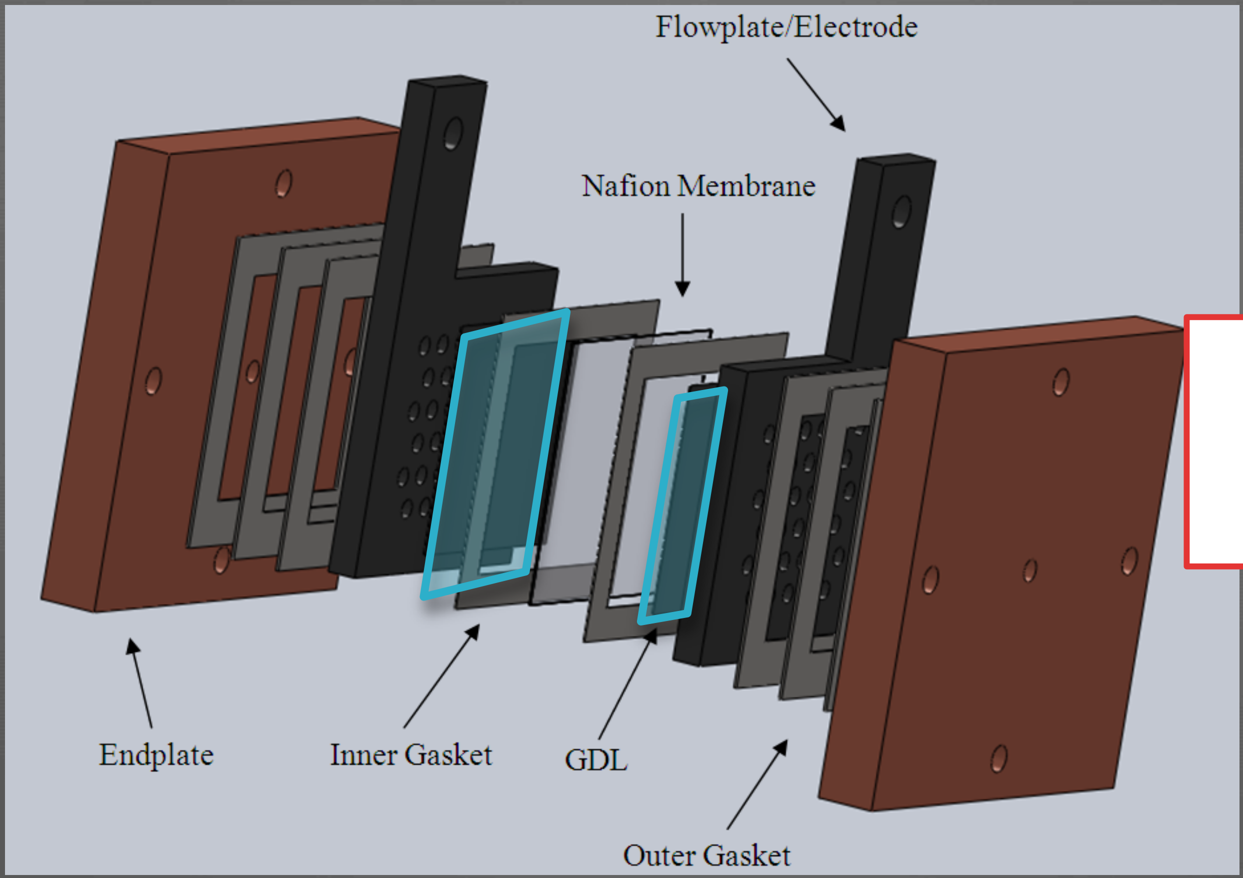
Flowplates/Electrodes

- **Flowplates/Electrodes**:
  - Distribute gas evenly across membrane surface
  - Must be electrically conducting to allow for current flow.



Your flowplates/electrodes are made of graphite.

Fuel Cell Components



Gas Diffusion Layers

Gas Diffusion Layers

- **Gas Diffusion Layers (GDLs):**
  - **Must be highly porous to allow even passage of hydrogen.**
  - **Coated with catalyst to accelerate reactions on anode and cathode.**

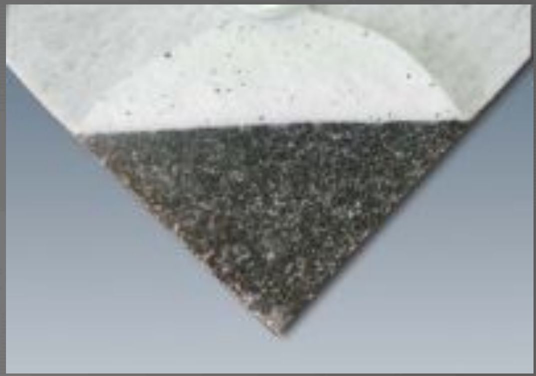
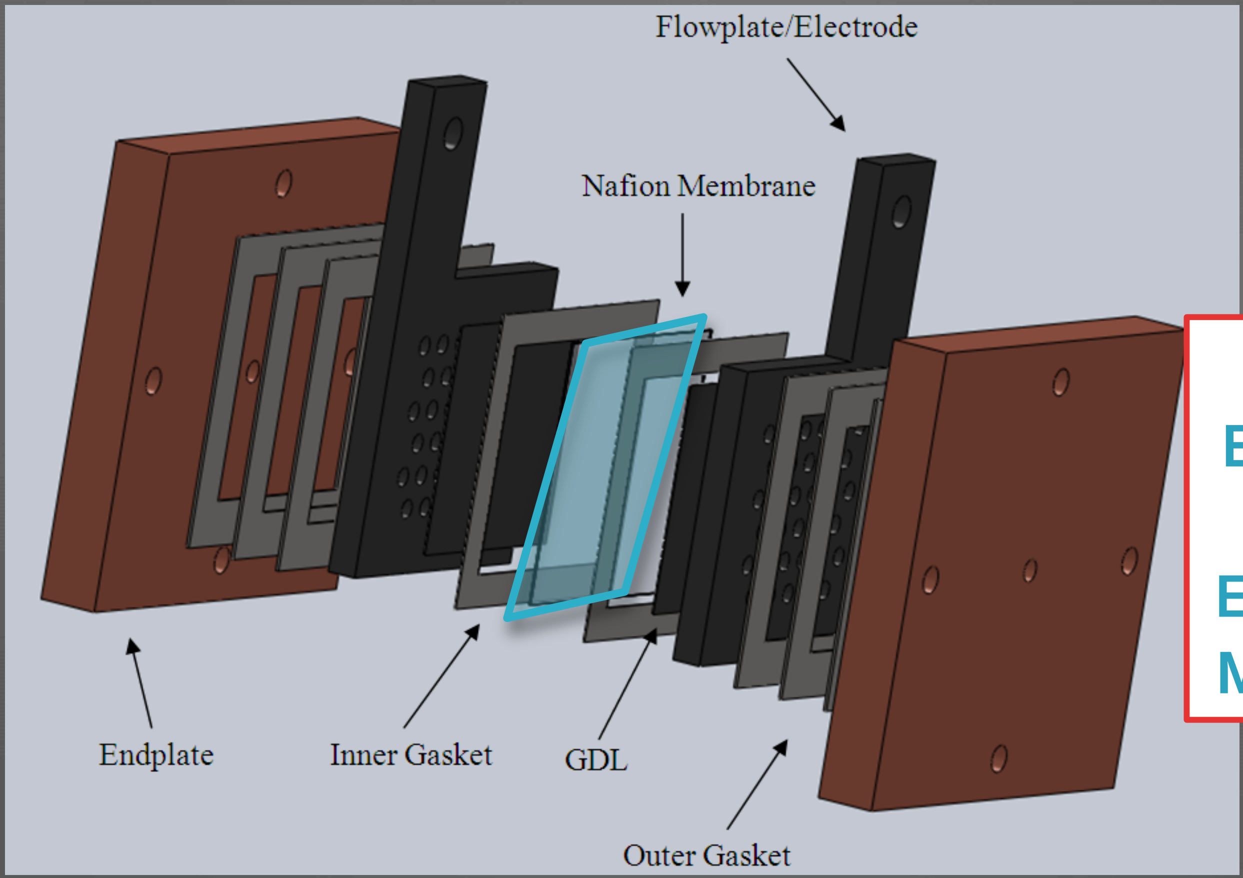


Figure from http://www.tradekey.com/product_view/id/820178.htm

Your GDLs are carbon paper which you will coat with a Platinum/Carbon catalyst.

Fuel Cell Components



Proton Exchange/ Polymer Electrolyte Membrane

Proton Exchange/Polymer Electrolyte Membrane (PEM)

- **PEM:**
  - **Selectively allows H+ but not e- to cross from the anode to the cathode, forcing electrons to flow through the circuit.**

Image from http://www.gizmodo.com.au/2008/05/20/

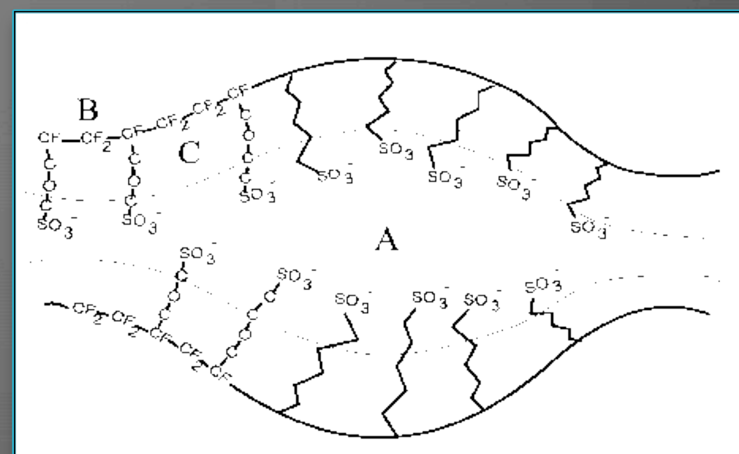


Figure from http://www.foa.se/surfbiotech/tt/Films.html

Your PEM is made of a clear polymer with the tradename Nafion 117 (DuPont).

Fuel Cell Challenges

- Depend on application, but for transportation key challenges are:
  - Weight (power density)
  - Reliability/Durability
  - Fuel source
    - Hydrogen usually obtained by fossil fuel reforming or electrolysis
    - Hydrogen is costly and difficult to transport and store
  - Cost
    - Catalyst (Pt, sometimes combined with rarer and even more expensive elements)
    - Electrolyte (Nafion is expensive!)