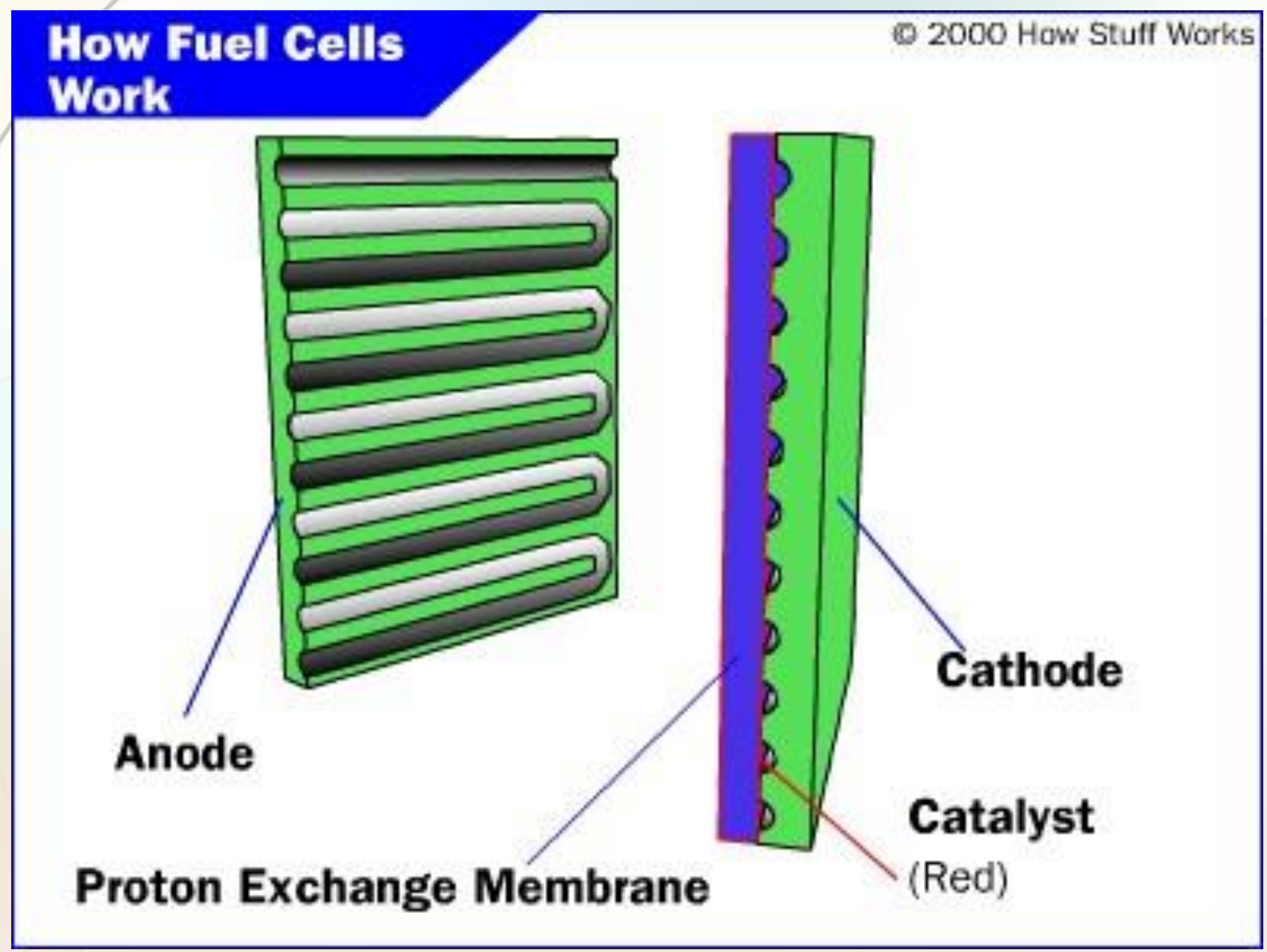
Fuel Cells

The Promise of Fuel Cells

- ***"A score of nonutility companies are well advanced toward developing a powerful chemical fuel cell, which could sit in some hidden closet of every home silently ticking off electric power."***
  - **Theodore Levitt, "Marketing Myopia,"** ***Harvard Business Review,*** **1960**

PEM Fuel Cell



https://www.youtube.com/watch?v=a4pXAmljdUA

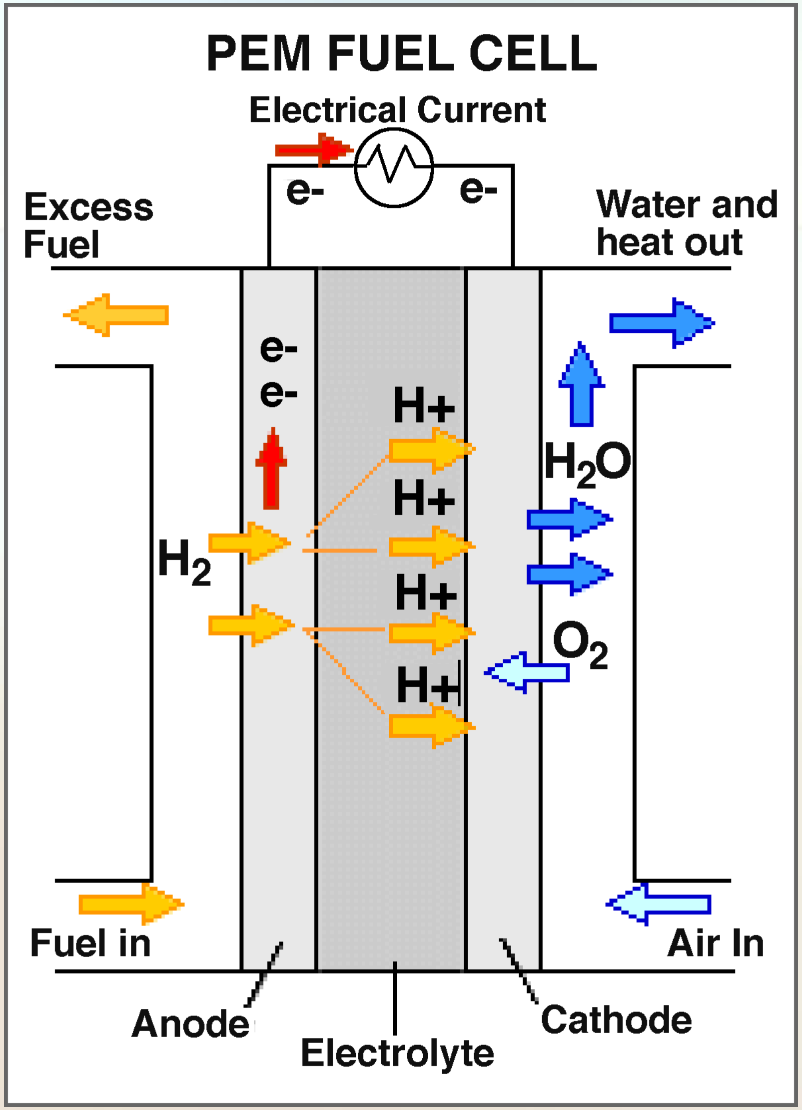
Parts of a Fuel Cell

- **Anode**
  - Negative post of the fuel cell.
  - Conducts the electrons that are freed from the hydrogen molecules so that they can be used in an external circuit.
  - Etched channels disperse hydrogen gas over the surface of catalyst.
- **Cathode**
  - Positive post of the fuel cell
  - Etched channels distribute oxygen to the surface of the catalyst.
  - Conducts electrons back from the external circuit to the catalyst
  - Recombine with the hydrogen ions and oxygen to form water.
- **Electrolyte**
  - Proton exchange membrane.
  - Specially treated material, only conducts positively charged ions.
  - Membrane blocks electrons.
- **Catalyst**
  - Special material that facilitates reaction of oxygen and hydrogen
  - Usually platinum powder very thinly coated onto carbon paper or cloth.
  - Rough & porous maximizes surface area exposed to hydrogen or oxygen
  - The platinum-coated side of the catalyst faces the PEM.

Fuel Cell Operation

- Pressurized hydrogen gas (H_2) enters cell on anode side.
- Gas is forced through catalyst by pressure.
  - When H_2 molecule comes contacts platinum catalyst, it splits into two H+ ions and two electrons (e-).
- Electrons are conducted through the anode
  - Make their way through the external circuit (doing useful work such as turning a motor) and return to the cathode side of the fuel cell.
- On the cathode side, oxygen gas (O_2) is forced through the catalyst
  - Forms two oxygen atoms, each with a strong negative charge.
  - Negative charge attracts the two H+ ions through the membrane,
  - Combine with an oxygen atom and two electrons from the external circuit to form a water molecule (H_2O).

Proton-Exchange Membrane Cell

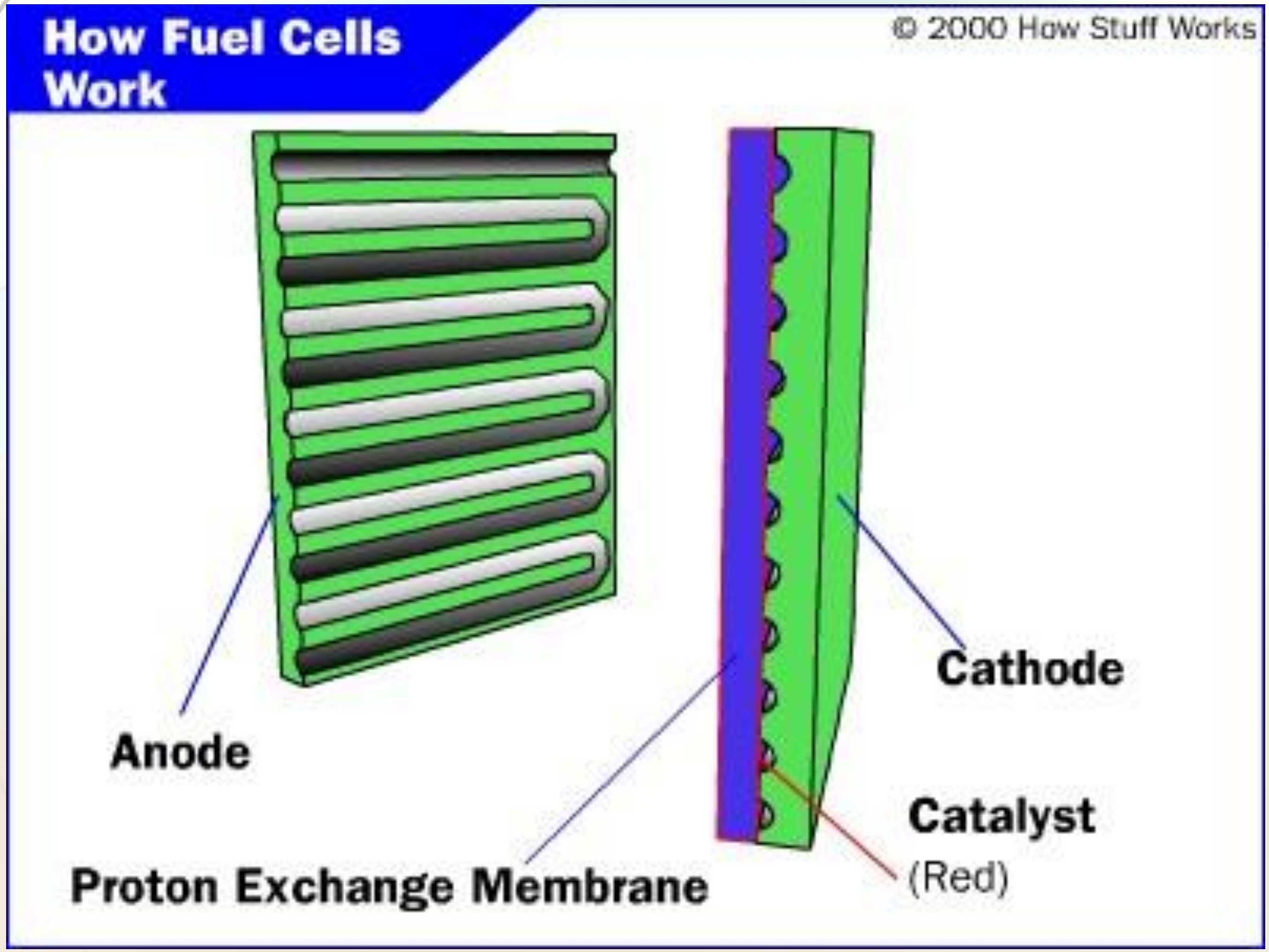


http://www.news.cornell.edu/releases/Nov03/Fuelcell.institute.deb.html

How a fuel cell works

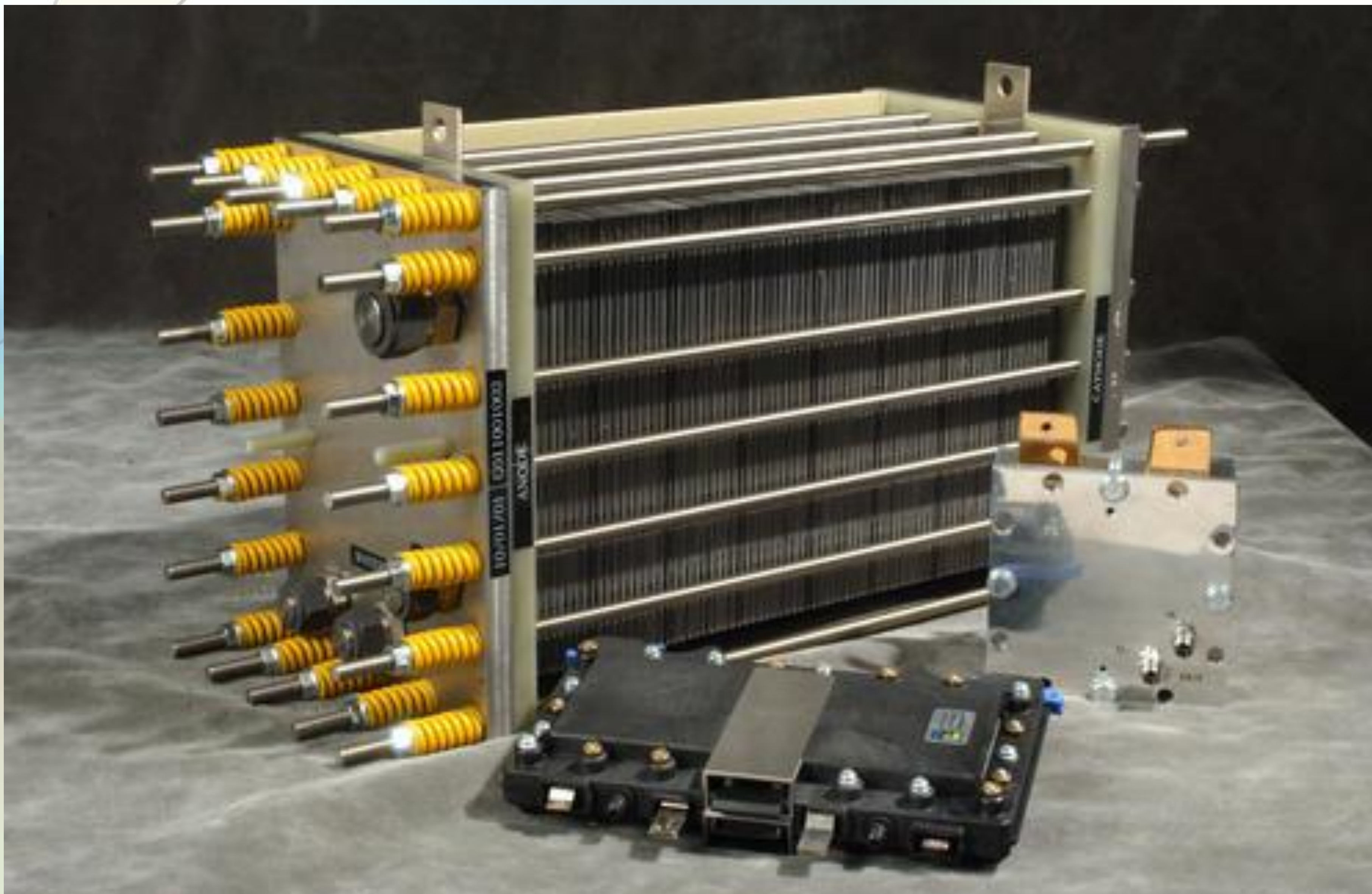
In the Polymer Electrolyte Membrane (PEM) fuel cell, also known as a proton-exchange membrane cell, a catalyst in the anode separates hydrogen atoms into protons and electrons.
The membrane in the center transports the protons to the cathode, leaving the electrons behind.
The electrons flow through a circuit to the cathode, forming an electric current to do useful work.
In the cathode, another catalyst helps the electrons, hydrogen nuclei and oxygen from the air recombine.
When the input is pure hydrogen, the exhaust consists of water vapor.
In fuel cells using hydrocarbon fuels the exhaust is water and carbon dioxide.
Cornell's new research is aimed at finding lighter, cheaper and more efficient materials for the catalysts and membranes.

PEM Fuel Cell Animation



Click on Diagram

Fuel Cell Stack



http://www.nrel.gov/hydrogen/photos.html

Hydrogen Fuel Cell Efficiency

- 40% efficiency converting methanol to hydrogen in reformer
- 80% of hydrogen energy content converted to electrical energy
- 80% efficiency for inverter/motor
  - Converts electrical to mechanical energy
- Overall efficiency of 24-32%

Auto Power Efficiency Comparison

Technology	System Efficiency
Fuel Cell	24-32%
Electric Battery	26%
Gasoline Engine	20%

http://www.howstuffworks.com/fuel-cell.htm/printable

Auto Power Efficiency Comparison

Maybe you are surprised by how close these three technologies are. This exercise points out the importance of considering the whole system, not just the car.

We could even go a step further and ask what the efficiency of producing gasoline, methanol or coal is.

Efficiency is not the only consideration, however. People will not drive a car just because it is the most efficient if it makes them change their behavior.

They are concerned about many other issues as well. They want to know:

Is the car quick and easy to refuel?

Can it travel a good distance before refueling?

Is it as fast as the other cars on the road?

How much pollution does it produce?

This list, of course, goes on and on. In the end, the technology that dominates will be a compromise between efficiency and practicality.

http://www.howstuffworks.com/fuel-cell.htm/printable

Other Types of Fuel Cells

- **Alkaline fuel cell (AFC)**
  - This is one of the oldest designs. It has been used in the U.S. space program since the 1960s. The AFC is very susceptible to contamination, so it requires pure hydrogen and oxygen. It is also very expensive, so this type of fuel cell is unlikely to be commercialized.
- **Phosphoric-acid fuel cell (PAFC)**
  - The phosphoric-acid fuel cell has potential for use in small stationary power-generation systems. It operates at a higher temperature than PEM fuel cells, so it has a longer warm-up time. This makes it unsuitable for use in cars.
- **Solid oxide fuel cell (SOFC)**
  - These fuel cells are best suited for large-scale stationary power generators that could provide electricity for factories or towns. This type of fuel cell operates at very high temperatures (around 1,832 F, 1,000 C). This high temperature makes reliability a problem, but it also has an advantage: The steam produced by the fuel cell can be channeled into turbines to generate more electricity. This improves the overall efficiency of the system.
- **Molten carbonate fuel cell (MCFC)**
  - These fuel cells are also best suited for large stationary power generators. They operate at 1,112 F (600 C), so they also generate steam that can be used to generate more power. They have a lower operating temperature than the SOFC, which means they don't need such exotic materials. This makes the design a little less expensive.

http://www.howstuffworks.com/fuel-cell.htm/printable

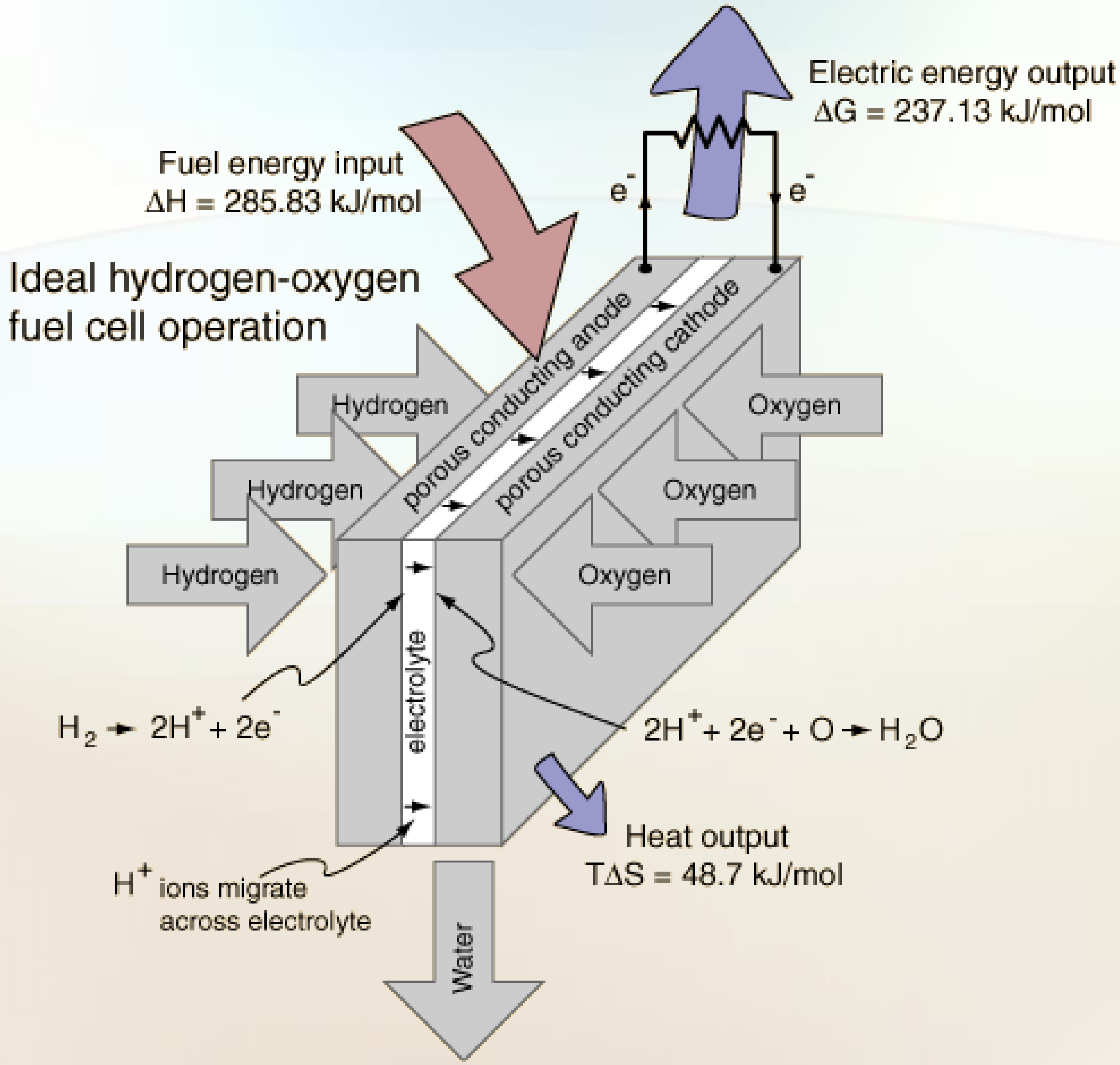
Advantages/Disadvantages of Fuel Cells

- **Advantages**
  - **Water is the only discharge (pure H_2)**
- **Disadvantages**
  - **CO_2 discharged with methanol reform**
  - **Little more efficient than alternatives**
  - **Technology currently expensive**
    - **Many design issues still in progress**
  - **Hydrogen often created using “dirty” energy (*e.g.,* coal)**
  - **Pure hydrogen is difficult to handle**
    - **Refilling stations, storage tanks, …**

Fuel Cells

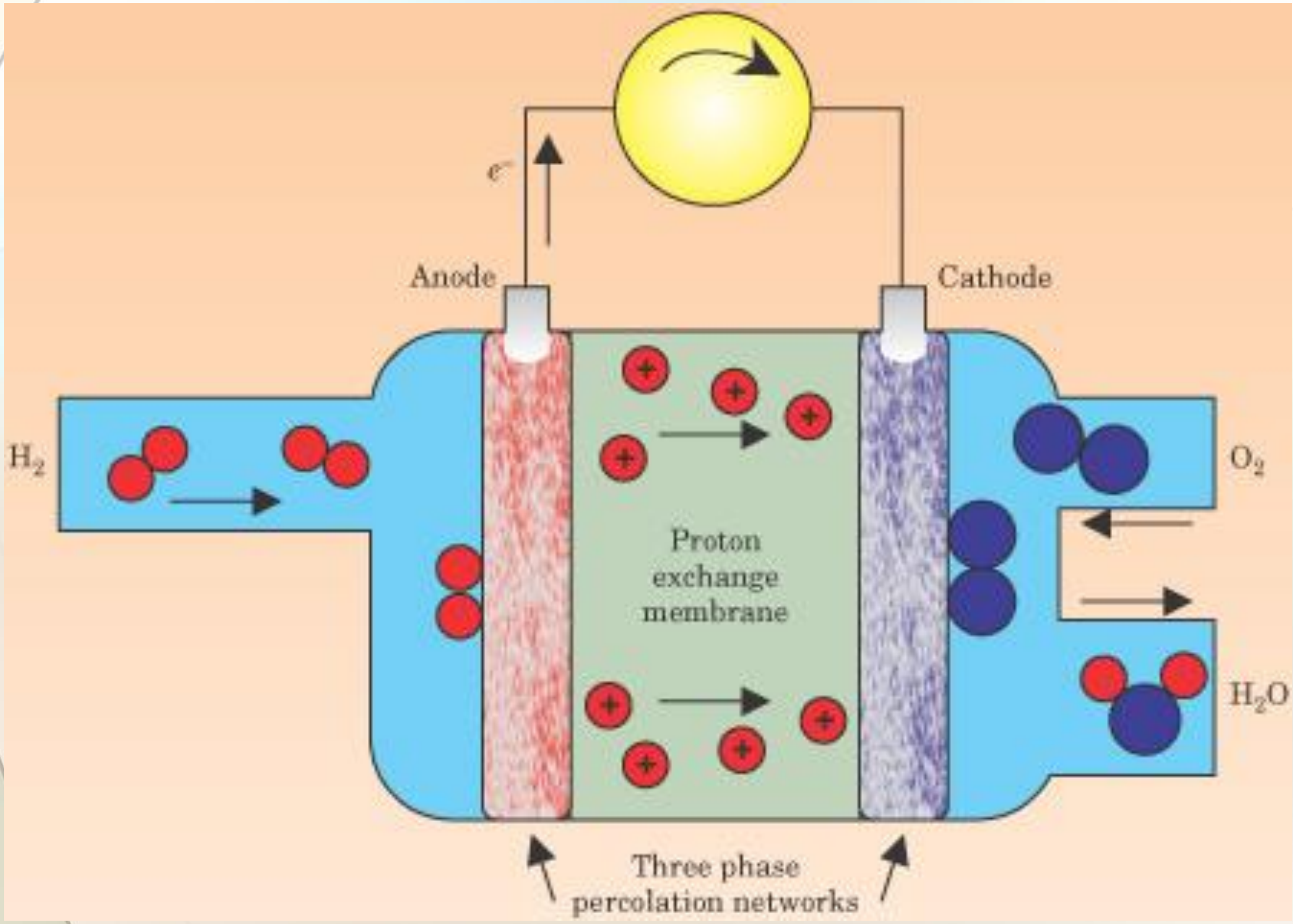
Extra Slides

Fuel Cell Energy Exchange



http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/electrol.html

PEM Fuel Cell Schematic



PEM Fuel Cell Schematic

Figure 5. In a proton–exchange–membrane fuel cell, hydrogen and oxygen react electrochemically. At the anode, hydrogen molecules dissociate, the atoms are ionized, and electrons are directed to an external circuit; protons are handed off to the ion–exchange membrane and pass through to the cathode.

There, oxygen combines with protons from the ion–exchange membrane and electrons from the external circuit to form water or steam.

The energy conversion efficiency of the process can be 60% or higher.