



HYDROGENICS

Changing power ...Powering change

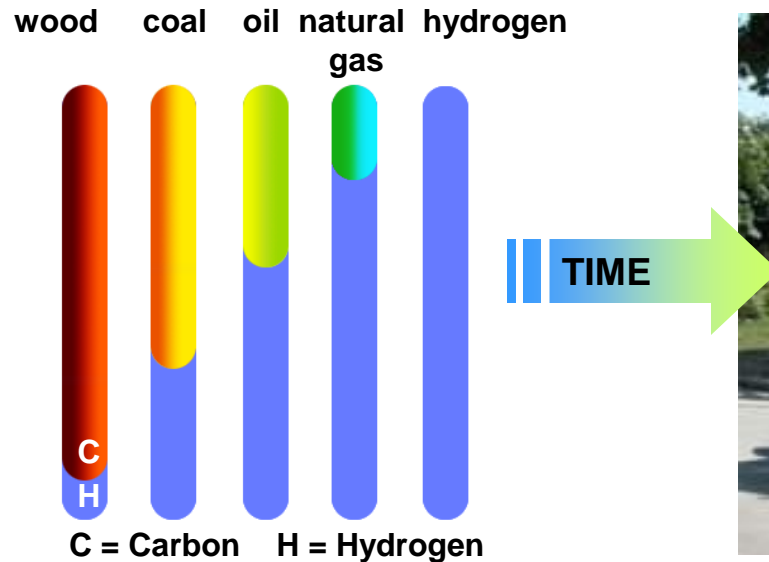


Introduction to Hydrogen and Fuel Cells



Transition to a Hydrogen Future

- The carbon content in fuels contributes to air pollution
- Carbon content in fuels has decreased over time
- Hydrogen is the ultimate zero-carbon fuel
- Fuel cells are the ultimate engine for that fuel



“The Stone Age did not end for a lack of stones”



Driving Forces

Hydrogen Energy can help meet global priorities

- **Energy Security**

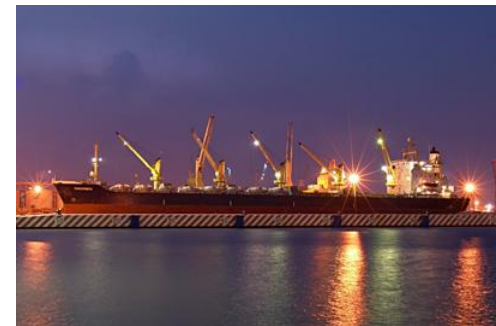
- Reduced dependence on foreign oil
- Lower price volatility

- **Urban Air Quality**

- Lowers or eliminates smog and particulate emissions

- **Greenhouse gas emissions**

- enables a connection to renewable and clean energy sources



Benefits of Fuel Technology

- Clean...potentially zero emissions
- Efficient, especially with combined heat
- A means to sustainable energy
- Fuel flexibility = use of regional resources
- Point of use power generation = reliability
- No moving parts = low maintenance
- Scalable = multi-application
- Modular = production & installation advantages = cost savings
- Design freedoms





The Markets for Fuel Cells

The power market is by far the largest commercial market in the world

Three major power markets:

- **Transportation**
- **Stationary / distributed generation**
- **Portable**
 - Transportable generators
 - Micro-portables

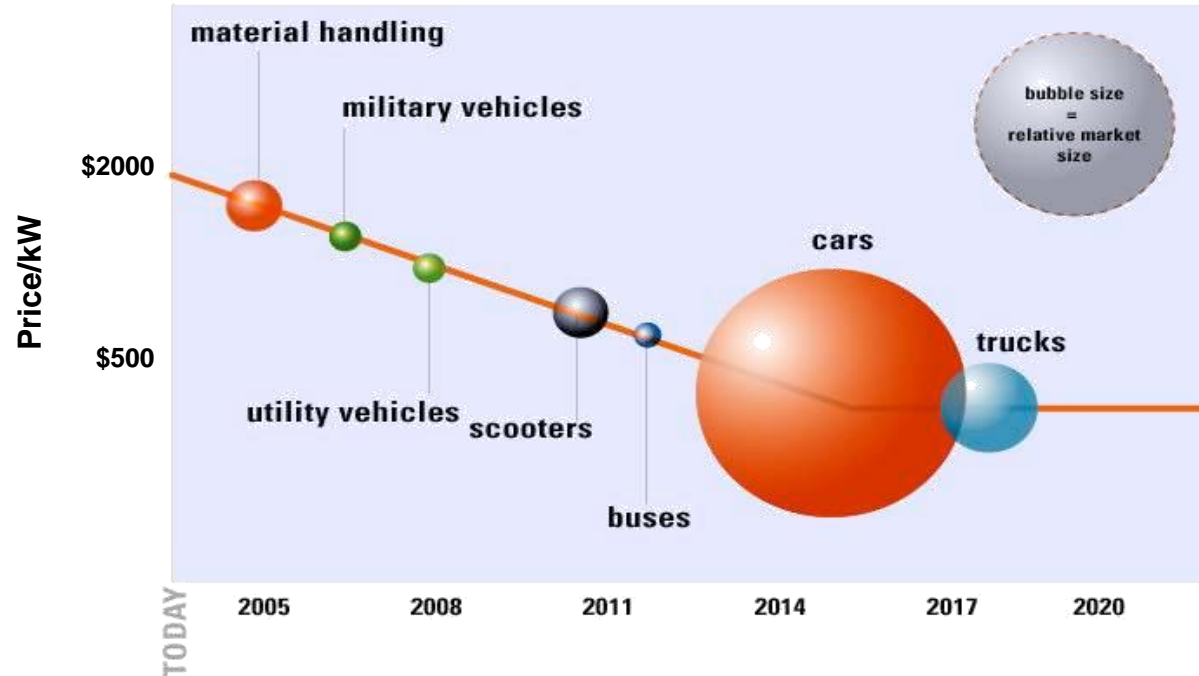


Each of these markets has premium segments that will emerge for fuel cells earlier than the larger 'mass markets'

- Dependent on relative price points and fueling infrastructure



Light Mobility Applications for Fuel Cells Precede Large Automotive Markets



Adoption in pre-automotive markets driven by

- Centralized refueling for captive fleets
- Operating and maintenance advantages



A Chance to Think Differently

- Don't just think about applications as they are TODAY.
- THINK about applications that could be.
- GM's AUTOmomy offers new vehicle architecture using fuel cell technology





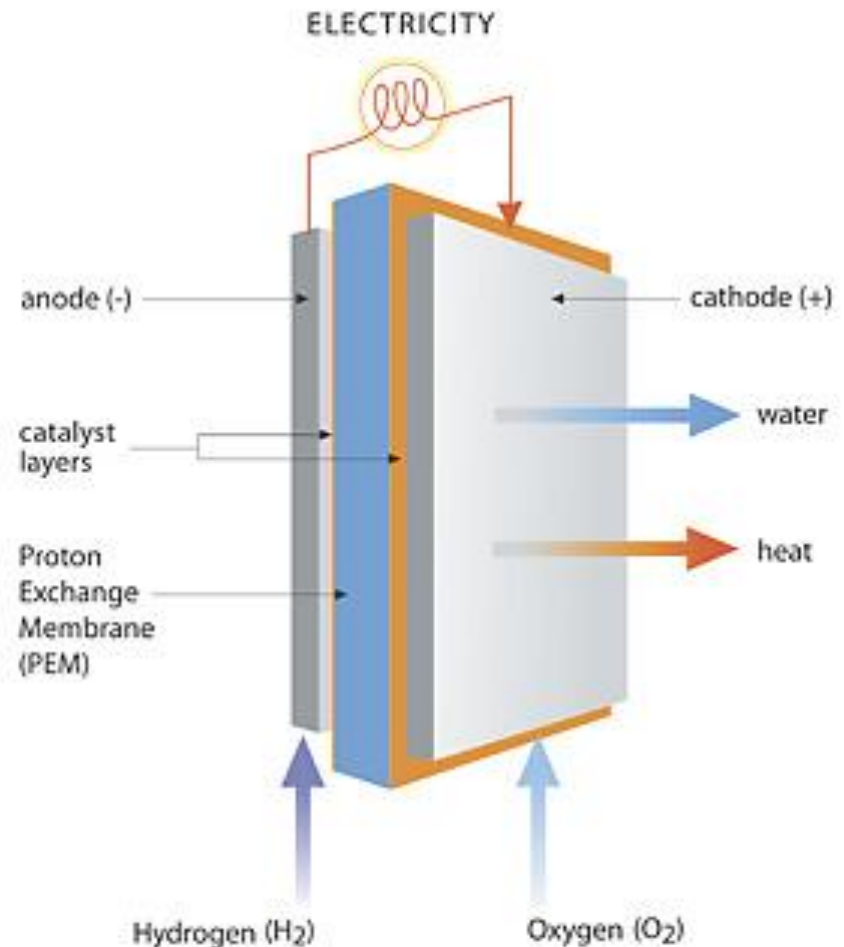
A Brief History

- 1839: William Grove, amateur physicist, discovered the principle of the fuel cell
- 120 years later NASA first demonstrated an application of fuel cells to provide power during space flight
- Commercial potential started to be realized in the 1960's
- Research significantly accelerated in the mid 1980's with the advent of PEM technology
- Reduction in technology barriers over the last 10 years has resulted in significant increase in commercialization activities and investment



What Is A Fuel Cell?

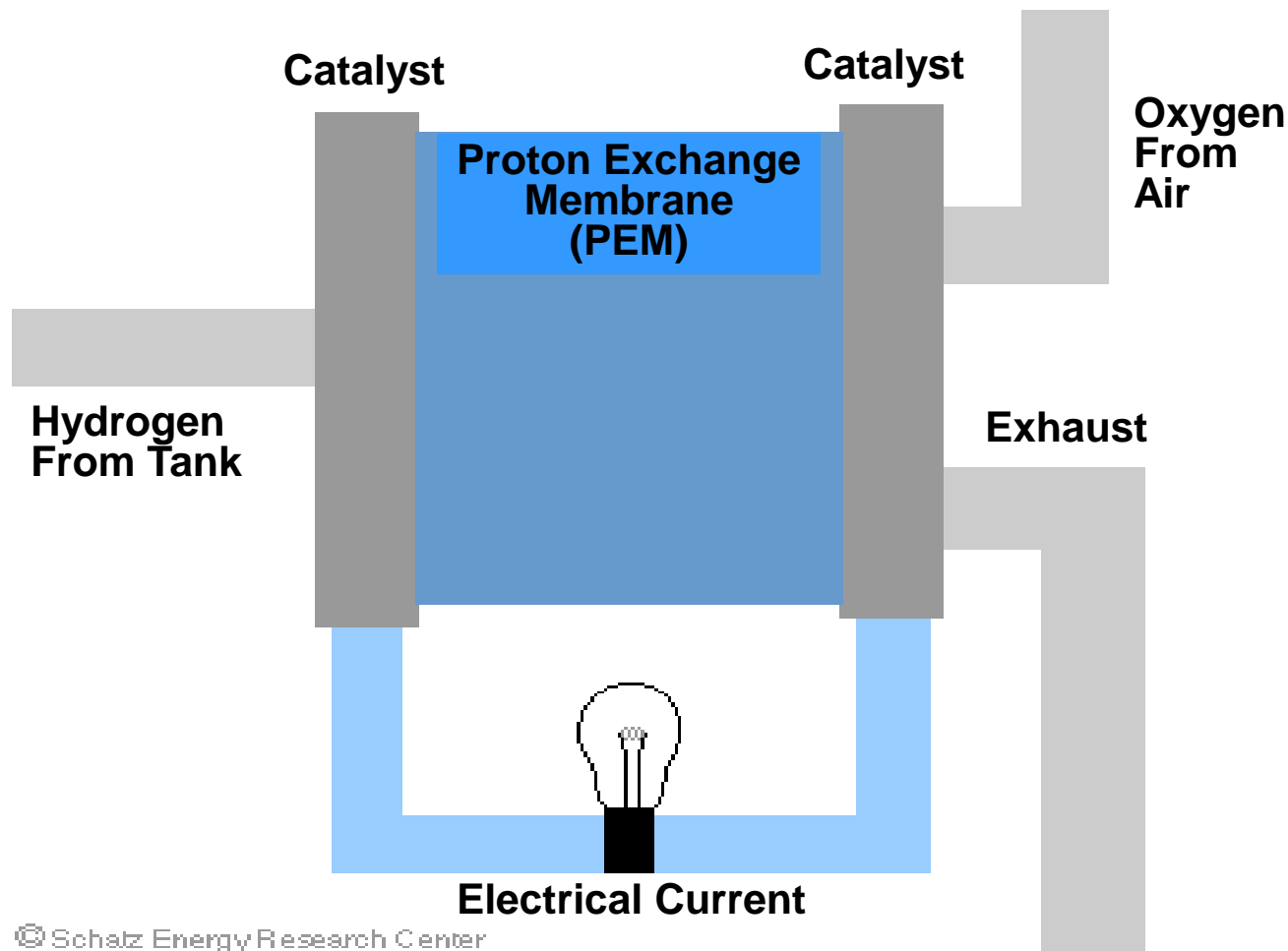
A fuel cell is a highly efficient electrochemical conversion device that produces DC electricity, water and heat using hydrogen as fuel and oxygen in the air.



Membrane Electrode Assembly = membrane + electrodes (incl catalyst)



How a Fuel Cell Works



© Schatz Energy Research Center

- A single cell provides 1.16 volts in ideal open circuit conditions.
- The current is determined by the active area of the cell.



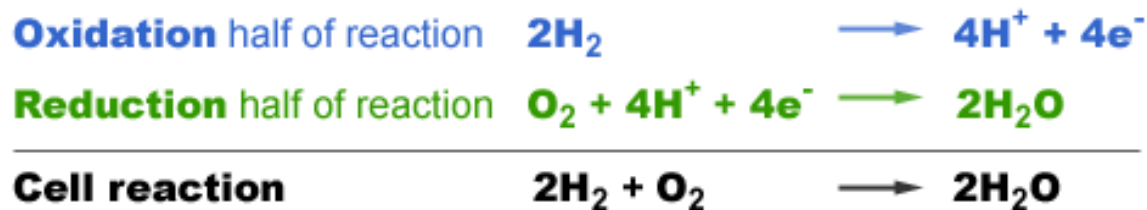
Polymer Electrolyte Membrane (PEM)

- The **PEM** is an unusual electrolyte because negative ions are rigidly held and only the positive ions are mobile, therefore the hydrogen ions move in one direction only from anode to cathode
- The **PEM** does not conduct electrons therefore forcing them to travel through an external wire to the other side of the cell to complete the circuit



The Electrodes

As with all electrochemical reactions there is an oxidation half-reaction at the anode and a reduction half-reaction at the cathode



Platinum catalyst is used at both electrodes to increase the rates of each reaction



The Flow Fields

Serve a dual purpose:

- **Flow distribution**
 - Reactant gases
 - Water
(supply to the membrane and removal from the cathode)

- **Current collection**

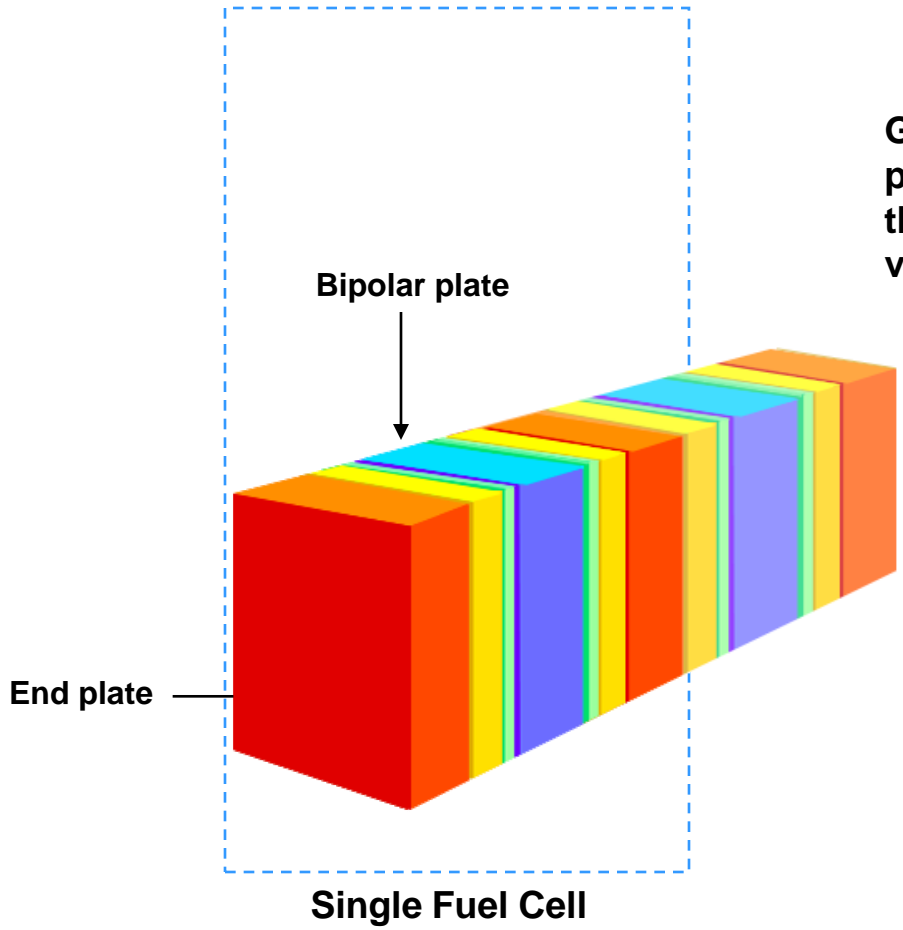
Considerable IP registered for unique designs including flow pattern, channel depth and width





The Fuel Cell Stack

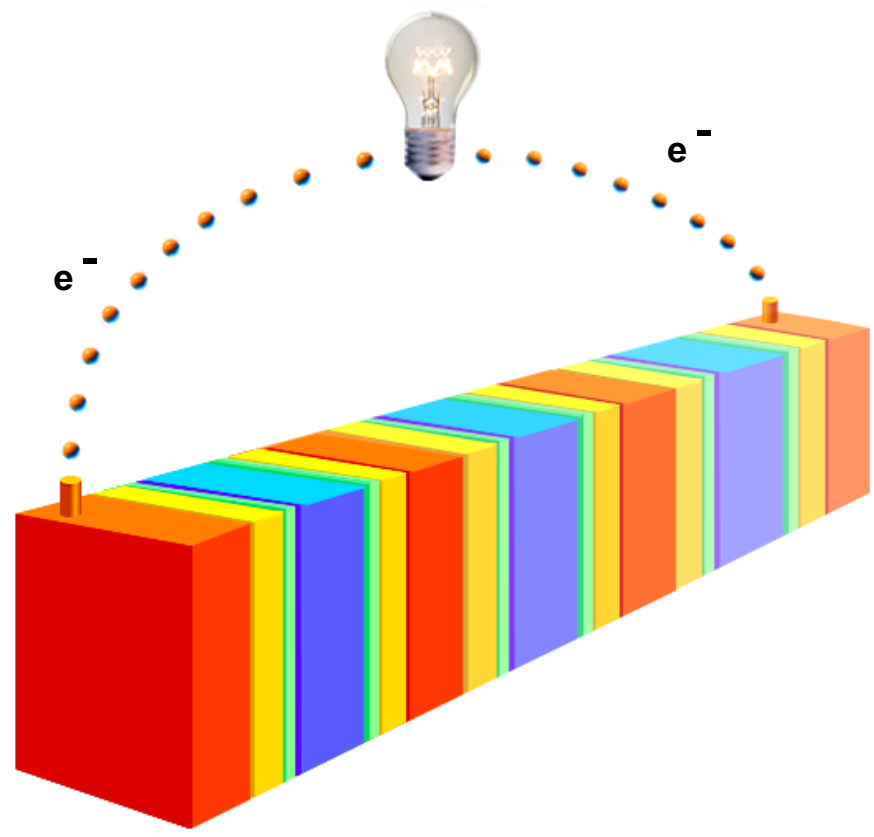
To meet the power requirements of any practical application individual cells must be assembled into a stack configuration.



Gas-impermeable bipolar plates are used to decrease the overall weight and volume of the stack



The Fuel Cell Stack



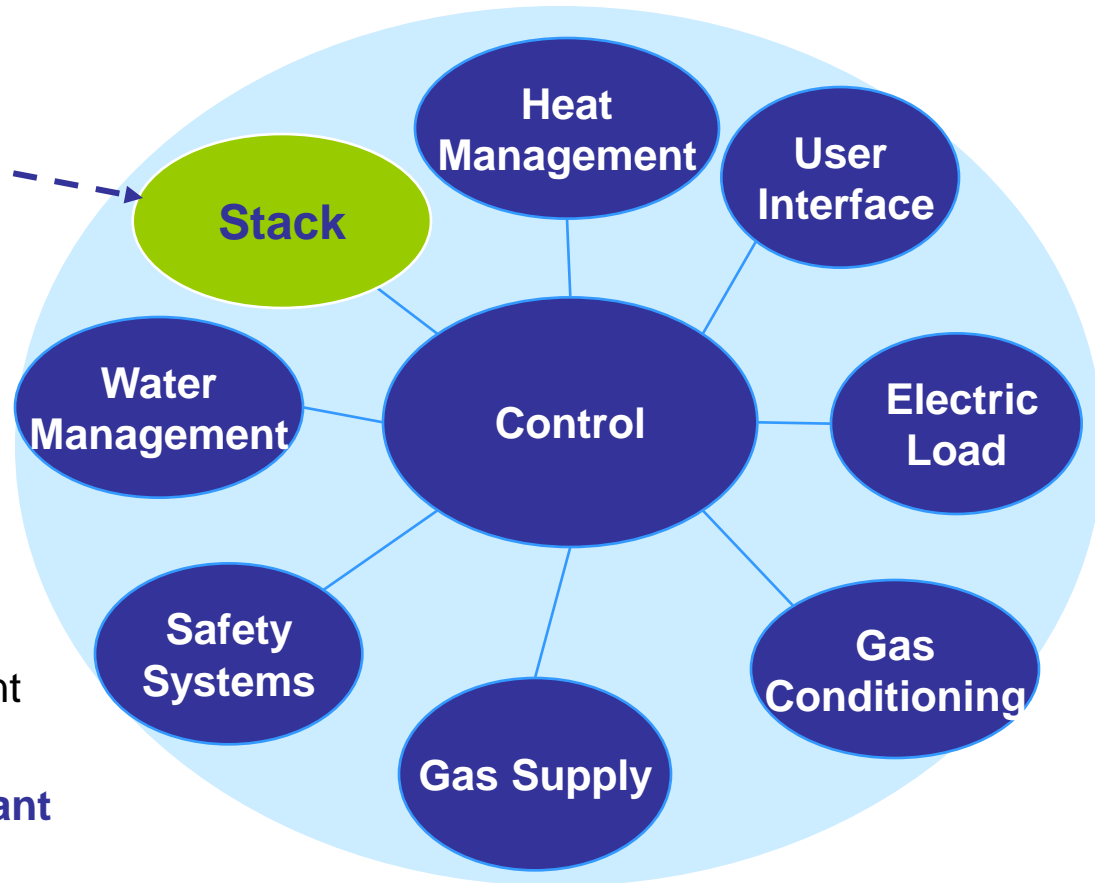


What is a Fuel Cell System?

Not just a stack!!!



Fuel Cell System

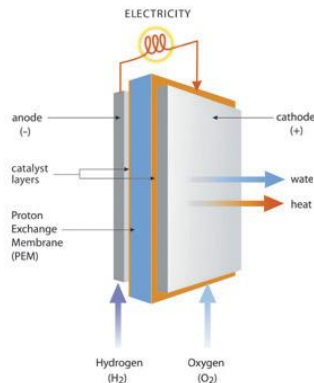


- Achieving usable power requires sophisticated controls
- Numerous inter-dependent components and sub-systems = **Balance of Plant**

Fuel Cell Power

Core Competency From Cells to Solutions

The PEM Fuel Cell



Single cell by-products are heat and water

The Fuel Cell Stack



Multiple cells layered to create a stack

The Fuel Cell Power Module



- Heat and water management
- Gas humidification
- Software & hardware controls
- Power conditioning
- Fuel management

The Fuel Cell Power Pack



- Power Module
- Electrical Storage Device
- Hybrid control hardware & software
- Thermal mgmt.
- H₂ storage



The Challenges of Fuel Cell Adoption

■ **Hydrogen fuel infrastructure**

- different hydrogen generation technologies available
- difficult to invest capital cost prior to market demand
- codes and regulations

■ **Hydrogen storage**

- storage technologies need further development to achieve greater capacities at acceptable pressures

■ **Fuel cells**

- high costs related to low initial volumes (materials, manufacturing)



Fueling the Fuel Cell

- **PEM fuel cells require hydrogen as fuel**

- **Hydrogen is the most abundant element on the earth however it is always combined with other elements**
 - In water (H₂O)
 - In hydrocarbons, eg. natural gas





Industrial Hydrogen

The merchant hydrogen market has been going strong for several decades and is estimated at more than US\$5 Billion/year

Industrial hydrogen applications include:

- Power generation (Generator cooling)
- Electronics and float glass manufacturing
- Food and beverage
- Pharmaceuticals
- Steel industry
- Aerospace (NASA, Ariane, etc)
- Petrochemical and refinery





Electrolysis

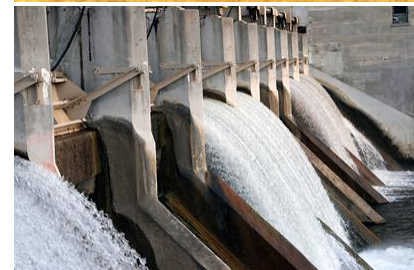


This is essentially the fuel cell process
in reverse

Where does the electricity come from?

- **The grid (off peak power)**
- **Renewable sources**
 - Solar power
 - Wind power
 - Hydroelectricity

In other words fuel cell technology can be integrated
with other clean power technologies to great benefit





Understanding H₂ Properties

Understanding differences between hydrogen and other fuels is key in order to use it in power and transportation applications

- **Hydrogen properties are substantially different from other fuels (like methane, propane and gasoline):**
 - Colorless, odorless, no taste
 - Buoyancy – it is the lightest of all elements so it rises and diffuses very rapidly, effectively diluting the hydrogen very quickly in an open environment
 - Highest energy per unit weight of any fuel
 - Wide flammability range
 - Low ignition energy
 - No toxic combustion products
 - Small molecular size allows it to leak very easily through cracks, joints, or porous materials



Comparison with other Fuels - LFL

Fuel Leak Simulation, Dr. Michael Swain, University of Miami

Time: 0 min,
3 sec. Ignition of
both fuels occurs.

Hydrogen flow
rate 2100 SCFM.

Time: 1 min,
0 seconds
hydrogen flow
is subsiding



Gasoline
flow rate
680 cc/min.

Hydrogen

Low heat radiation

Gasoline

High heat radiation



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Hydrogen Refueling

- Main components of a typical H₂ refueling system include:

H₂ storage tanks



H₂ dispenser





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H₂ Dispenser Overview

- The hydrogen dispenser provides the same functions as a conventional gas pump, except that it only fuels vehicles that are powered by hydrogen gas
- The dispenser unit controls pressure and amount of hydrogen delivered to the vehicle
- Automatically stops filling the tank once it is full
- Dispenser can be located indoors or outdoors

