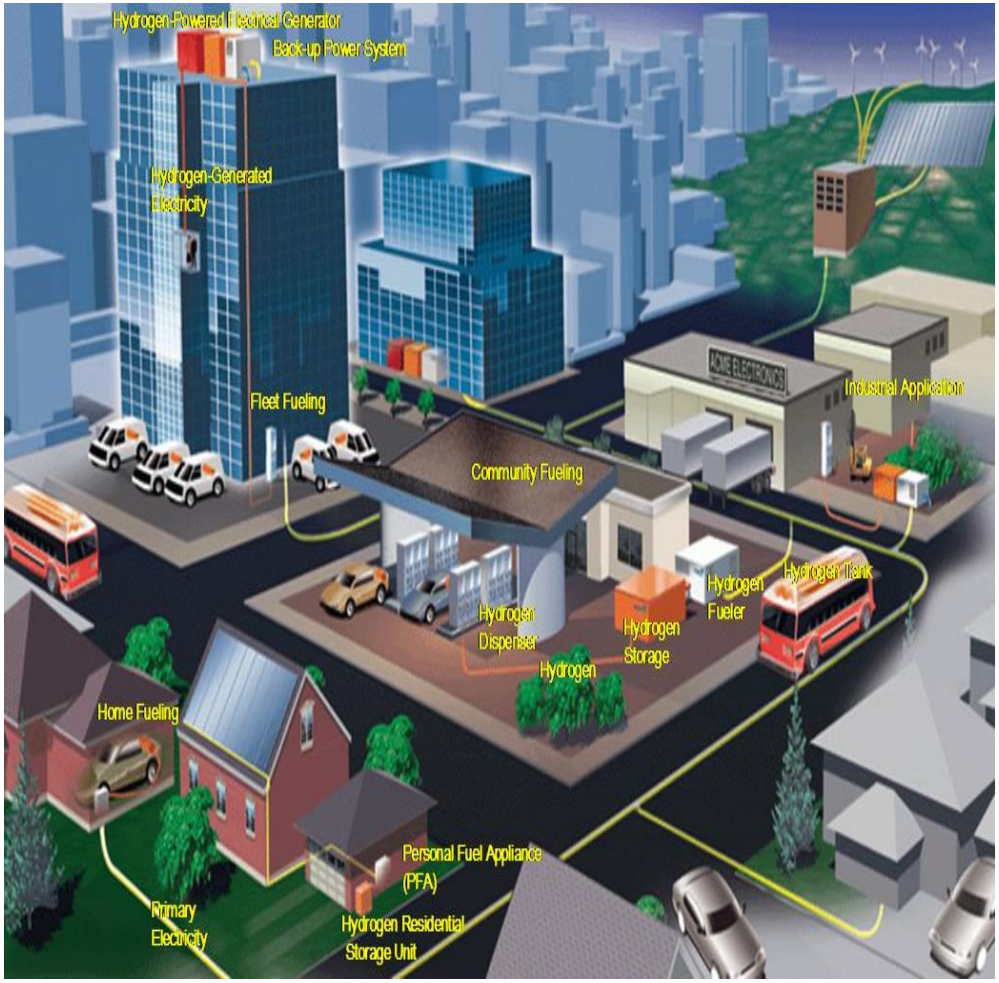
The Hydrogen Economy – The Future of Energy



Indian Institute of Technology (Banaras Hindu University), Varanasi, India
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Agenda

- A Hydrogen Vision of the Future
- What is Hydrogen Economy?
- Where do we get Hydrogen From?
- Hydrogen Fuel Storing and Transport
- Hydrogen Economy
- Problems with Hydrogen
- The Promise of Hydrogen
- Hydrogen Summary

A Vision of a Hydrogen Future

"I believe that water will one day be employed as fuel, that hydrogen and oxygen which constitute it, used singly or together, will furnish an inexhaustible source of heat and light, of an intensity of which coal is not capable. I believe then that when the deposits of coal are exhausted, we shall heat and warm ourselves with water. Water will be the coal of the future."

Jules Vernes (1870) *L´île mystérieuse*

What Is Hydrogen Economy?

- **Now: "Fossil Fuel Economy"**

  - Dependencies on foreign oil
  - Carbon dioxide = major pollutant & GHG
  - Without fossil fuels, economy at a standstill

- **What if we had a "Hydrogen Economy?"**

  - Clean: Hydrogen fuel cells' only byproduct is water
  - Economic independence: can be produced anywhere (even in homes)

What Is Hydrogen Economy?

The hydrogen economy is a vision (**Hydrogen is clean energy choice Hydrogen is flexible, affordable, safe, domestically produced, used in all sectors of the economy, and in all regions of the country)**.

It consists of an economic system in which energy is supplied by renewable resources.

In this “economy” hydrogen is the medium of energy storage and transport.

In other words: Solar, Wind, Hydro, biogas, etc.

National Vision to 2030 and Beyond*

Why Hydrogen ?

Technical reasons:

– Hydrogen has more energy per mass
– Technology can handle lighter fuels
– Too much carbon in the atmosphere already!

• Other forces:

– market in fuel cells
– visible urban pollution

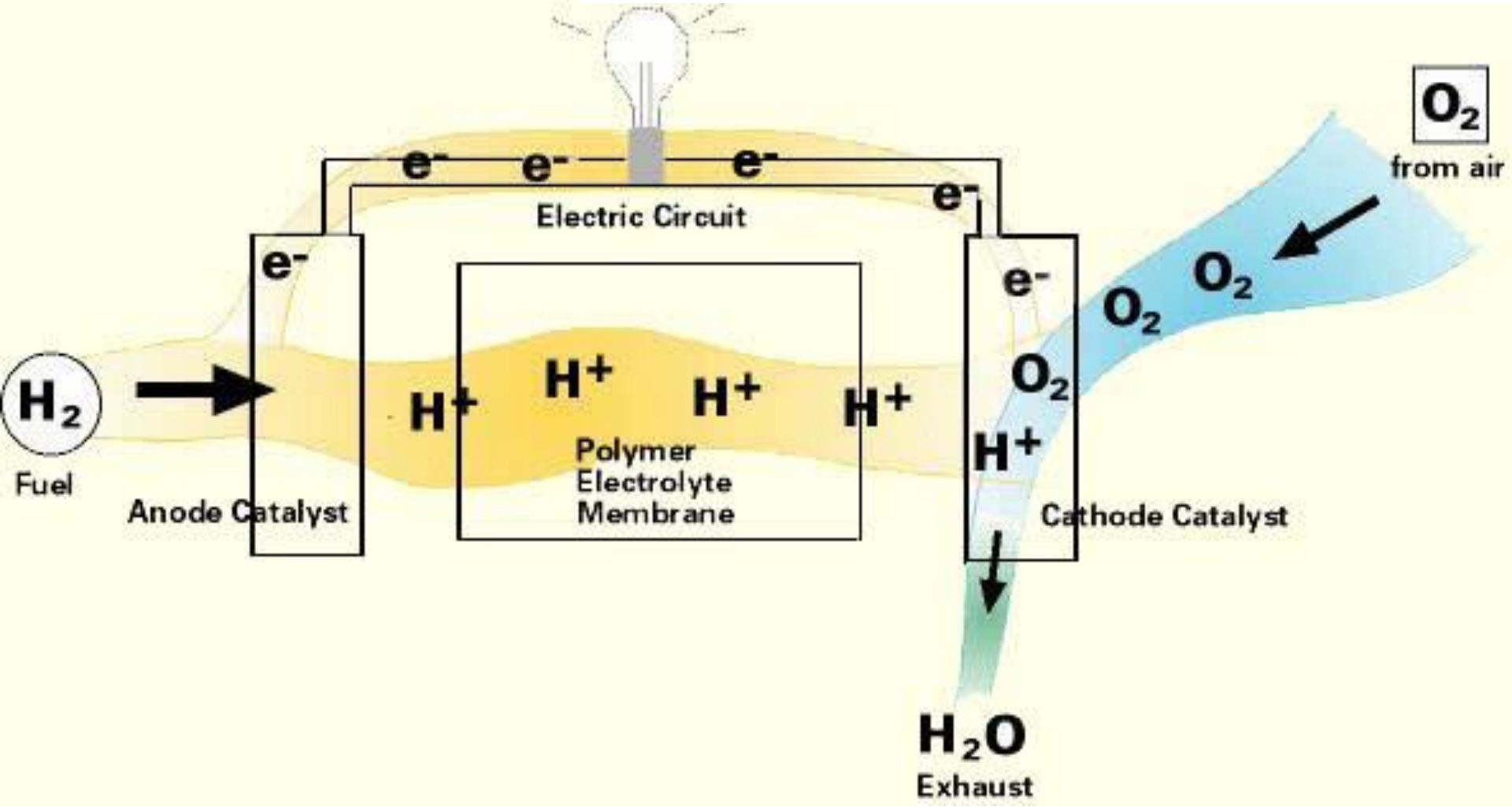
Where Do You Get Hydrogen?

Hydrogen can be extracted from fossil fuels, including gasoline, diesel, natural gas, propane or coal as needed, or **through electrolysis of water** using electricity from conventional power plants.

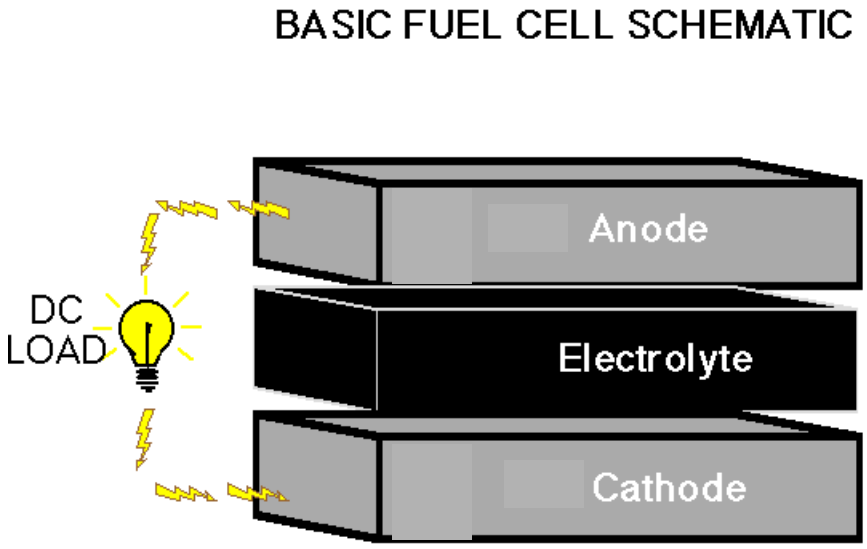
✓Hydrogen can be made from renewable resources - from water using electricity from solar. photovoltaic or wind or using direct processes.
✓From methane gas, landfills, waste treatment or biomass processing.

Fuel Cell

Where do we get the hydrogen from?



Fuel Cell



- All fuel cells have the same basic configuration - an electrolyte and two electrodes.

- Fuel cells are classified by the kind of electrolyte used.

- The type of electrolyte used determines the kind of chemical reactions that take place and the temperature range of operation.

Fuel Cell Type

PEMFC - Polymer Electrolyte Membrane Fuel Cells

(or Proton Exchange Membrane Fuel Cells)

DMFC - Direct Methanol Fuel Cells

AFC - Alkaline Fuel Cells

PAFC - Phosphoric Acid Fuel Cells

MCFC - Molten Carbonate Fuel Cells

SOFC - Solid Oxide Fuel Cells

Fuel Cell Type

Fuel cell type	Operating Temp (°C)	Effici-ency	Suitable applications			
			Domestic power	Small-scale power	Large-scale	Trans-port
PEMFC	50-120	40-50	√	√	X	√
AFC	50-90	50-70	√	√	X	√
PAFC	150-220	40-45	X	√	X	X
MCFC	600-650	50-60	X	√	√	X
SOFC	800-1000	50-60	√	√	√	X

Producing Hydrogen

How is Hydrogen Produced?

- Reforming fossil fuels
  - Heat hydrocarbons with steam
  - Produce H_2 and CO
- Electrolysis of water
  - Use electricity to split water into O_2 and H_2
- High Temperature Electrolysis
  - Experimental
- Biological processes
  - Very common in nature
  - Experimental in laboratories

http://www.howstuffworks.com/hydrogen-economy.htm

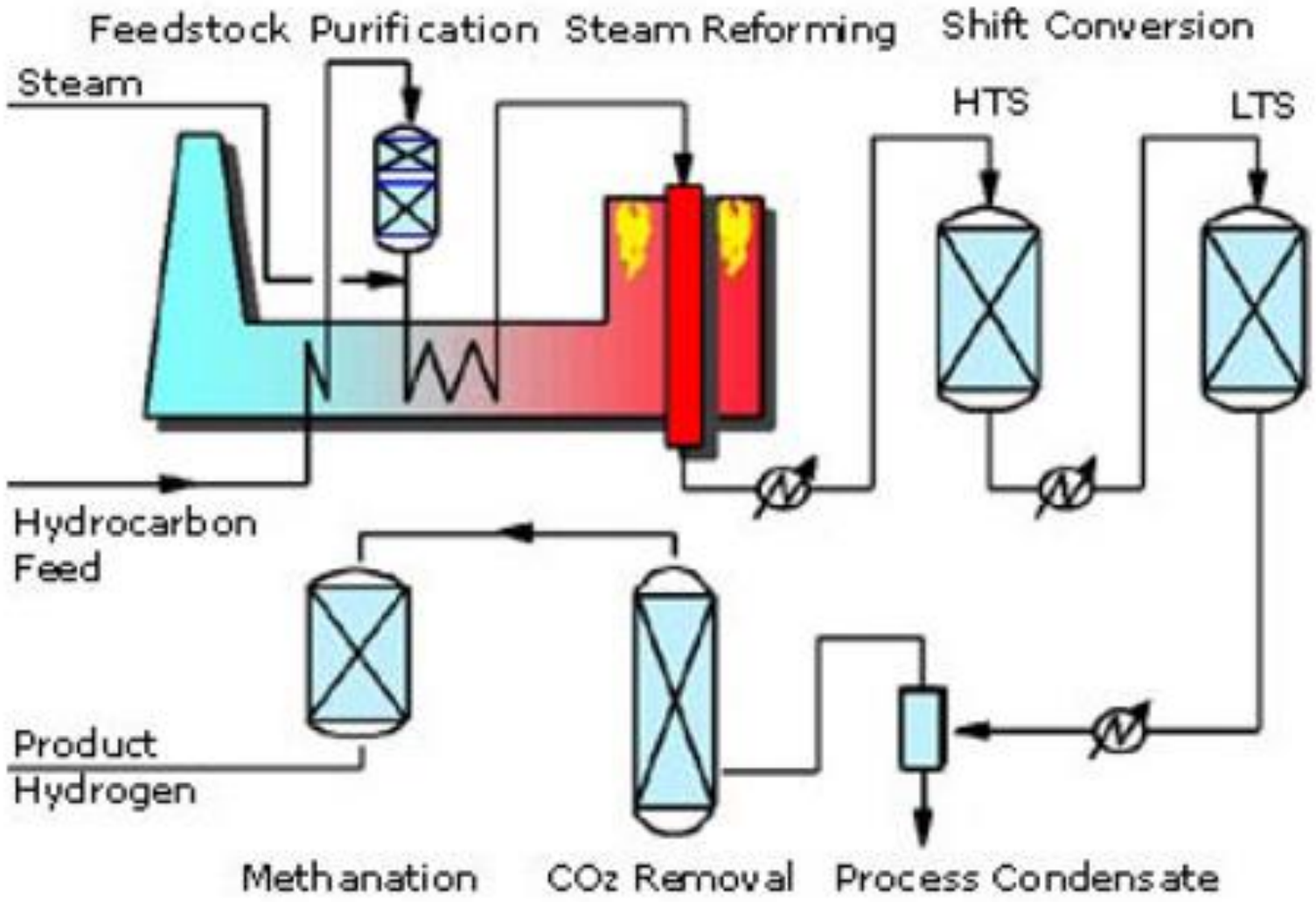
Steam Reforming

- From any hydrocarbon
  - Natural gas typically used
- Water (steam) and hydrocarbon mixed at high temperature (700–1100 °C)
  - Steam (H_2O) reacts with methane (CH_4)
  - $CH_4 + H_2O \rightarrow CO + 3\ H_2$ - 191.7 kJ/mol
- The thermodynamic efficiency comparable to (or worse than) an internal combustion engine
  - Difficult to motivate investment in technology

Fuel Cell

Hydrogen from steam reforming:

95% of the usage



HTS – High temperature shift

LTS – Low temperature shift

Hydrogen Steam Reforming Plants

Fuel Cell

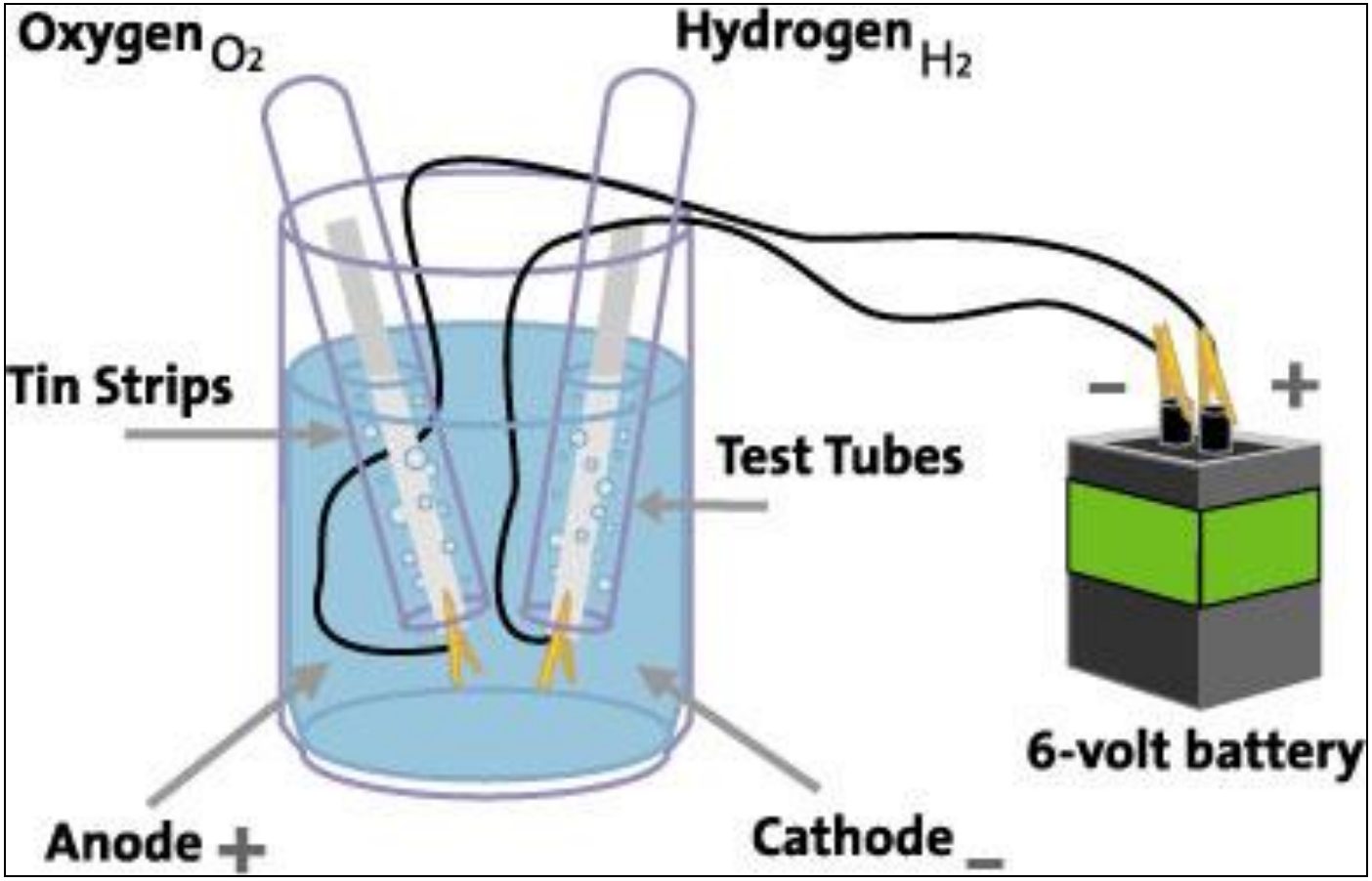
Hydrogen from electrolysis:

5% of the usage

Where does the power come from?

Wind
Solar PV and
Other renewable Energy Resources.

Electrolysis of Water (H_2O)

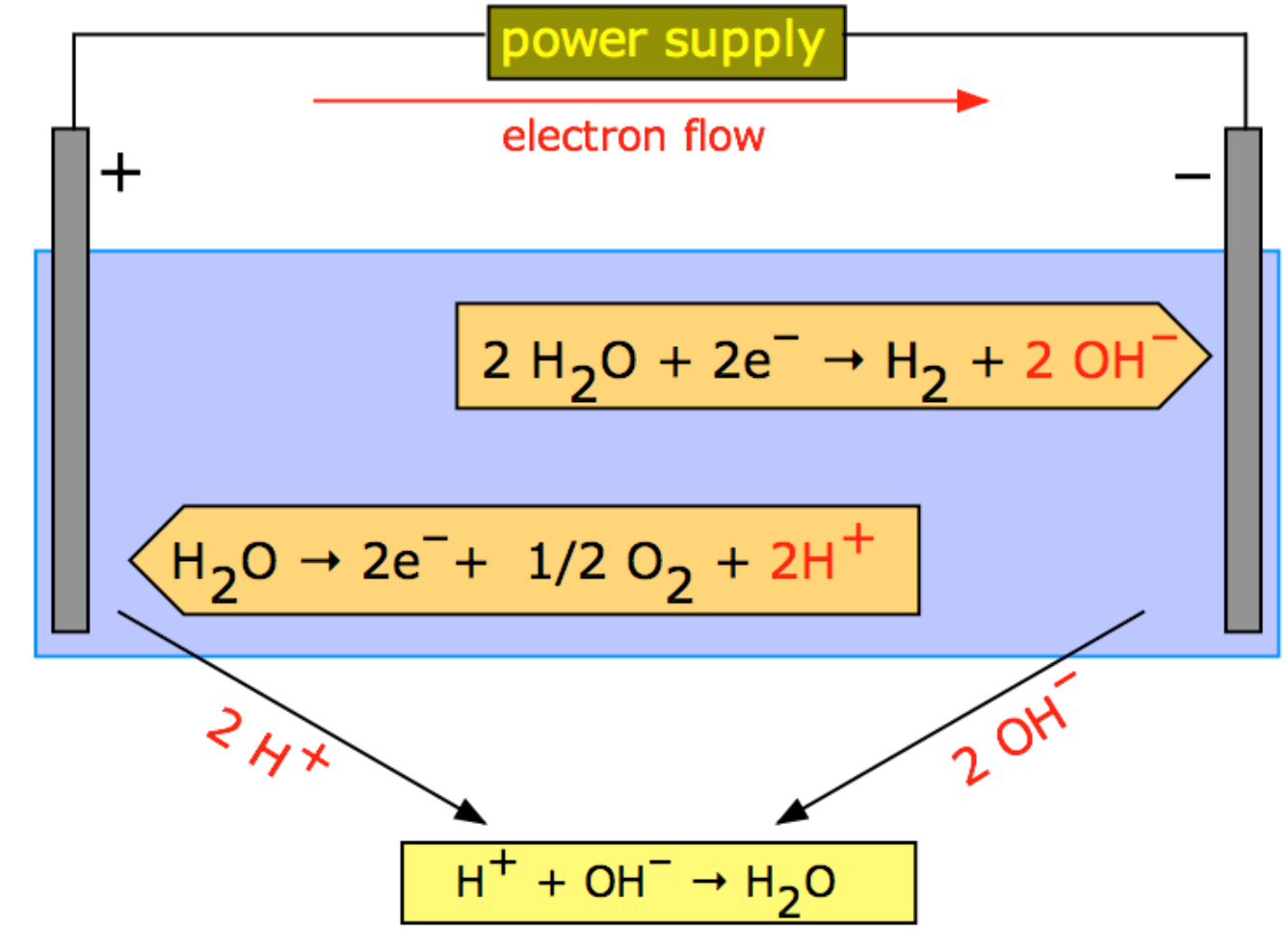


http://www.gm.com/company/gmability/edu_k-12/9-12/fc_energy/make_your_own_hydrogen_results.html

Fuel Cell

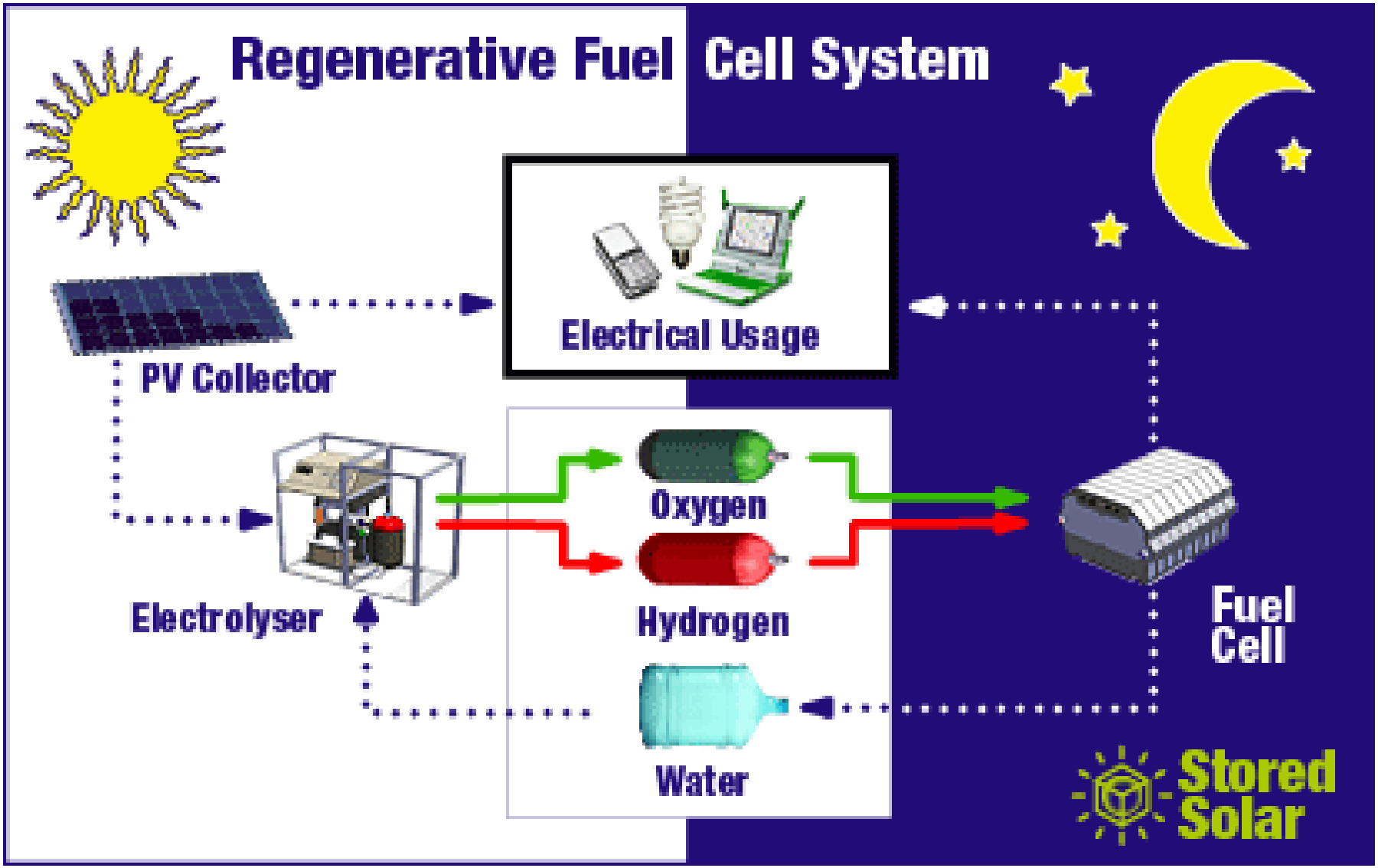
Hydrogen from electrolysis:

5% of the usage



net reaction: $2\ H_2O \rightarrow 2\ H_2 + O_2$

Regenerative Fuel Cell



Renewable Energy for Electrolysis

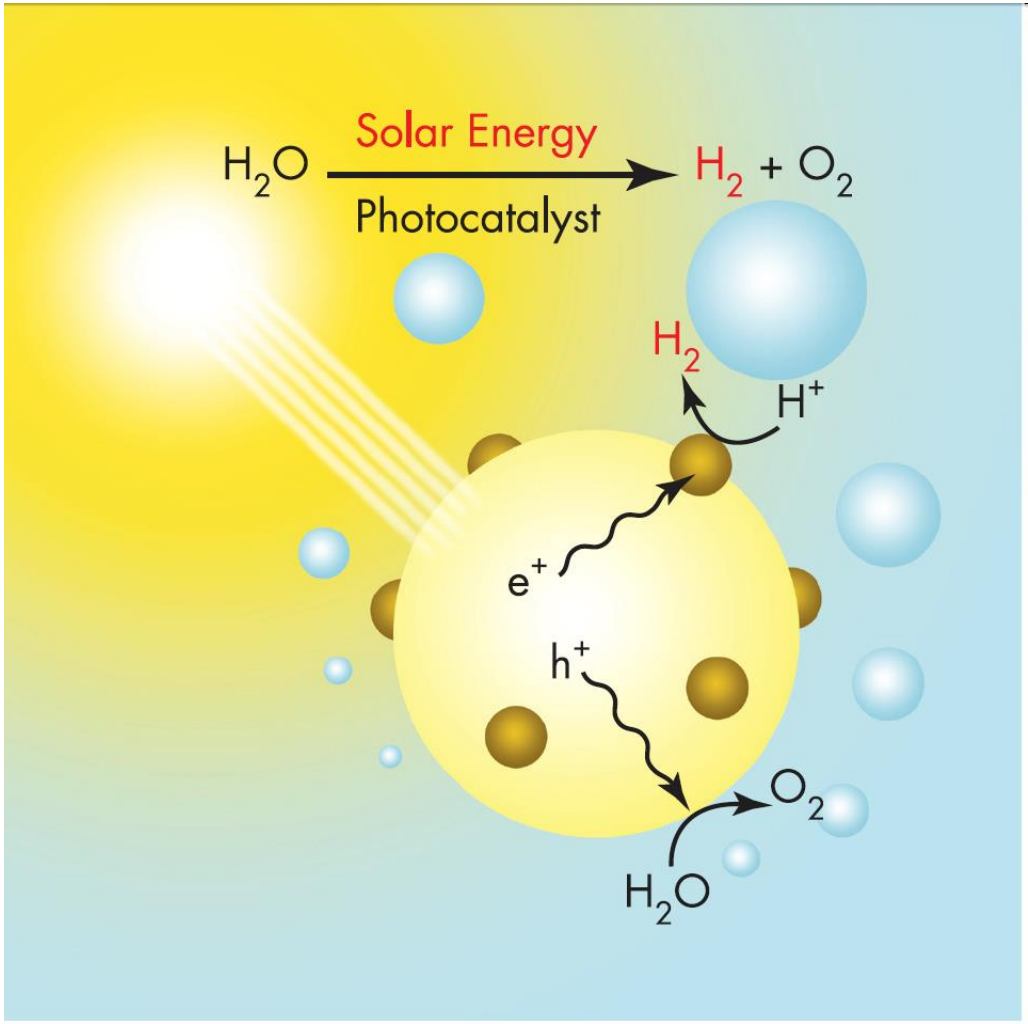
http://www.howstuffworks.com/hydrogen-economy4.htm

Fuel Cell

Hydrogen from water-splitting:

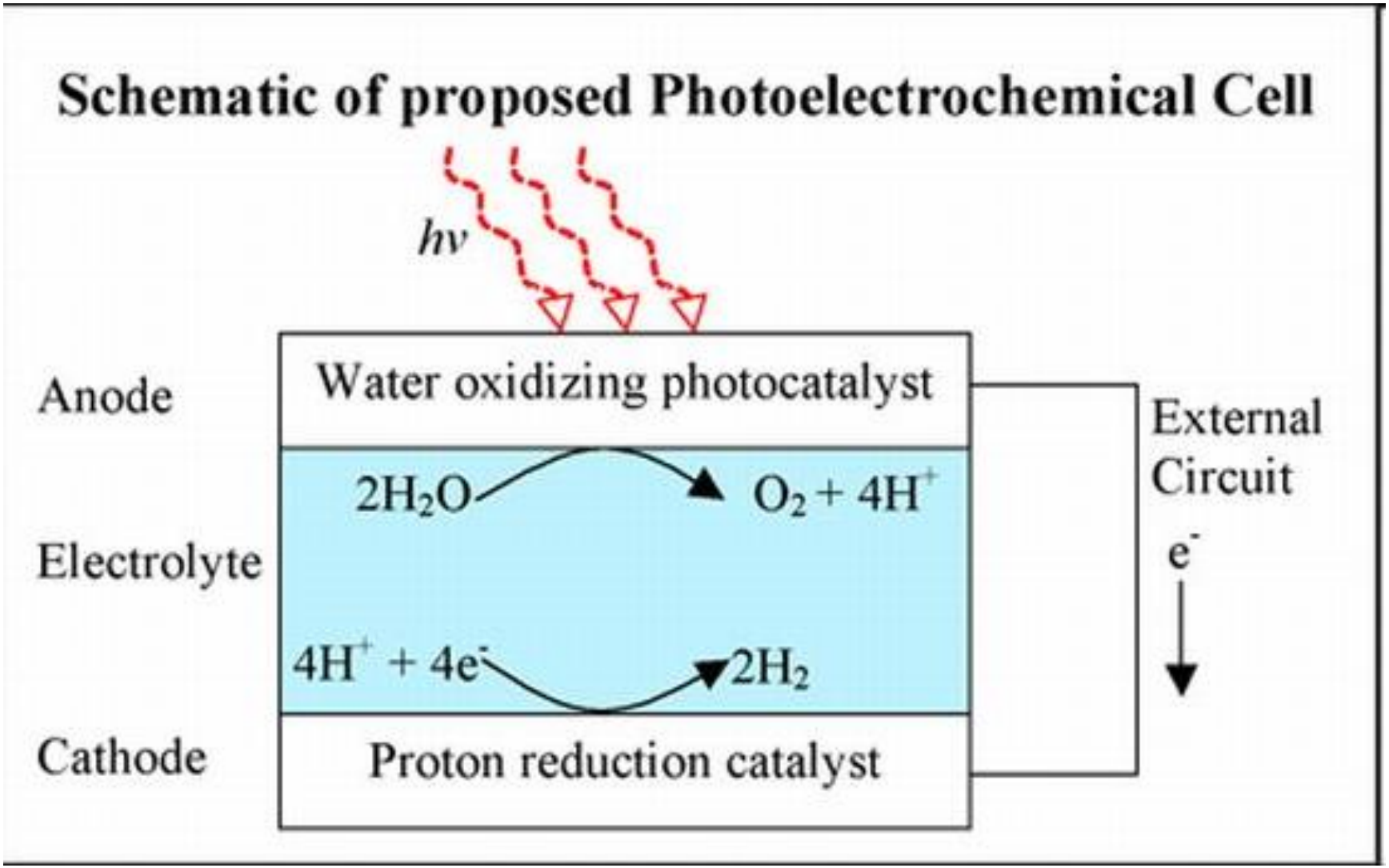
Solar water splitting is the process by which energy in solar photons is used to break down liquid water into molecules of hydrogen and oxygen gas.

Hydrogen produced through solar water does not emit carbon into the atmosphere.



Fuel Cell

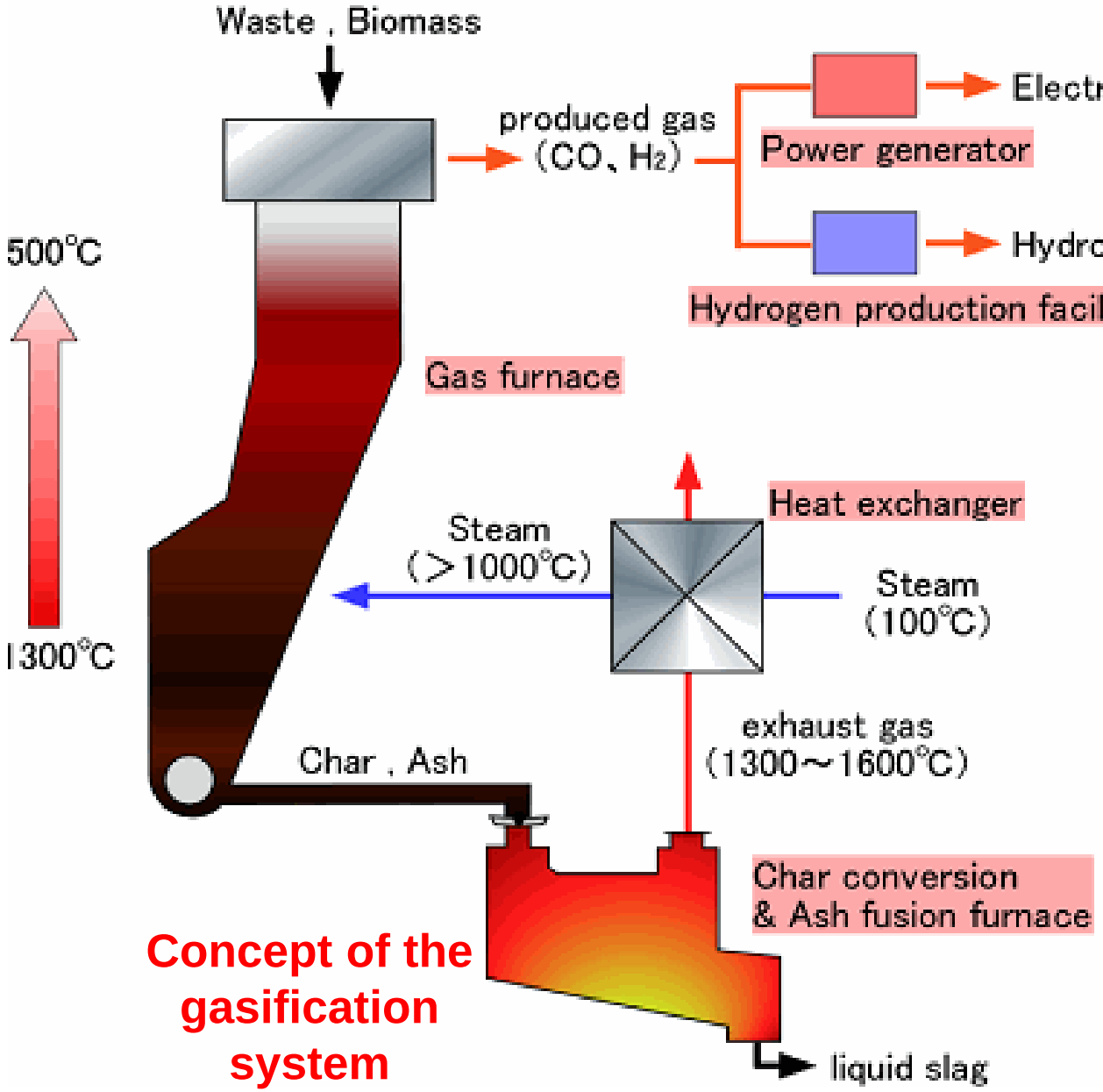
Hydrogen from water-splitting:



Fuel Cell

Hydrogen from waste:

HyPR-MEET
demonstration plant

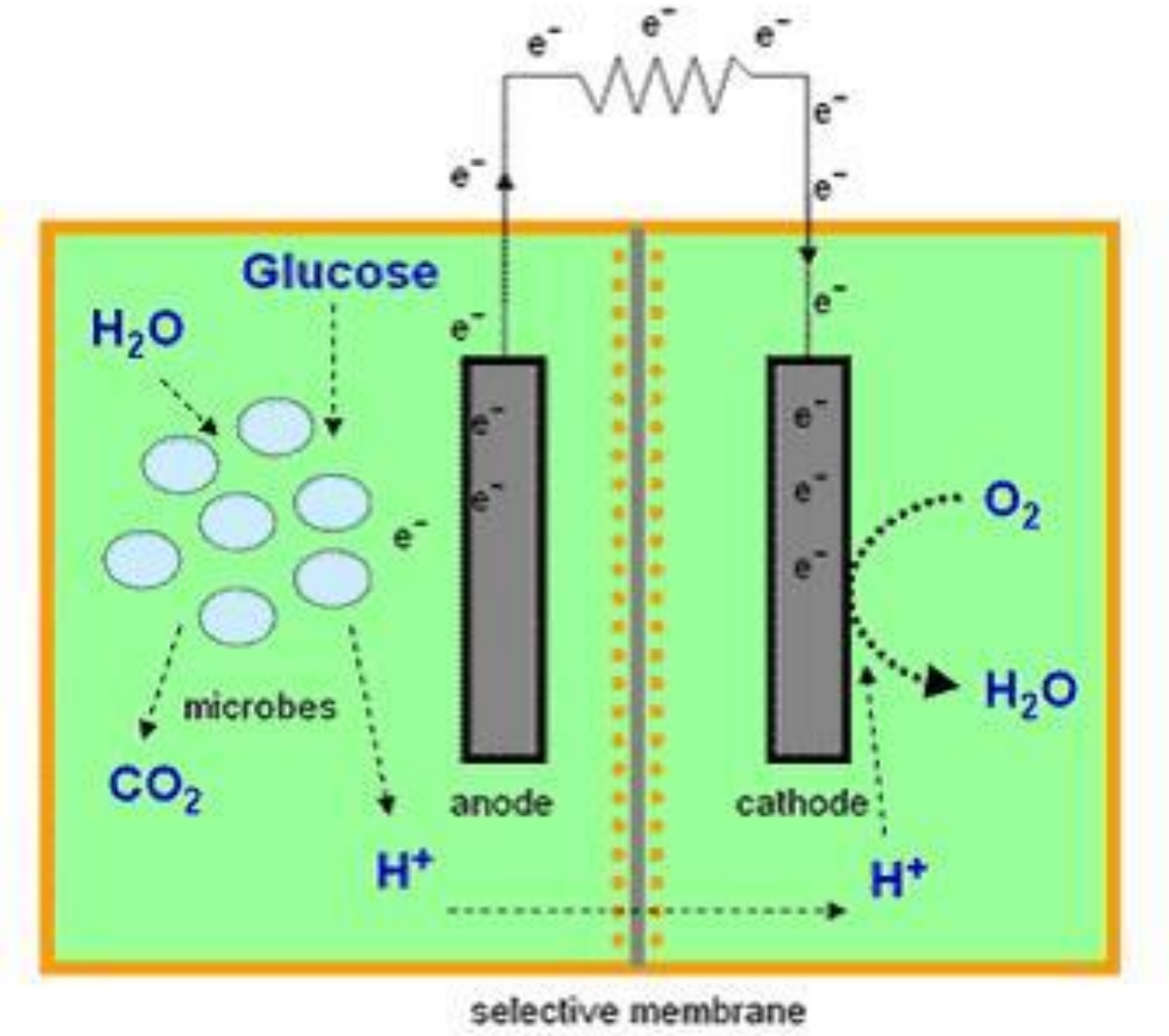


Concept of the gasification system

Biomass Electrolysis Module

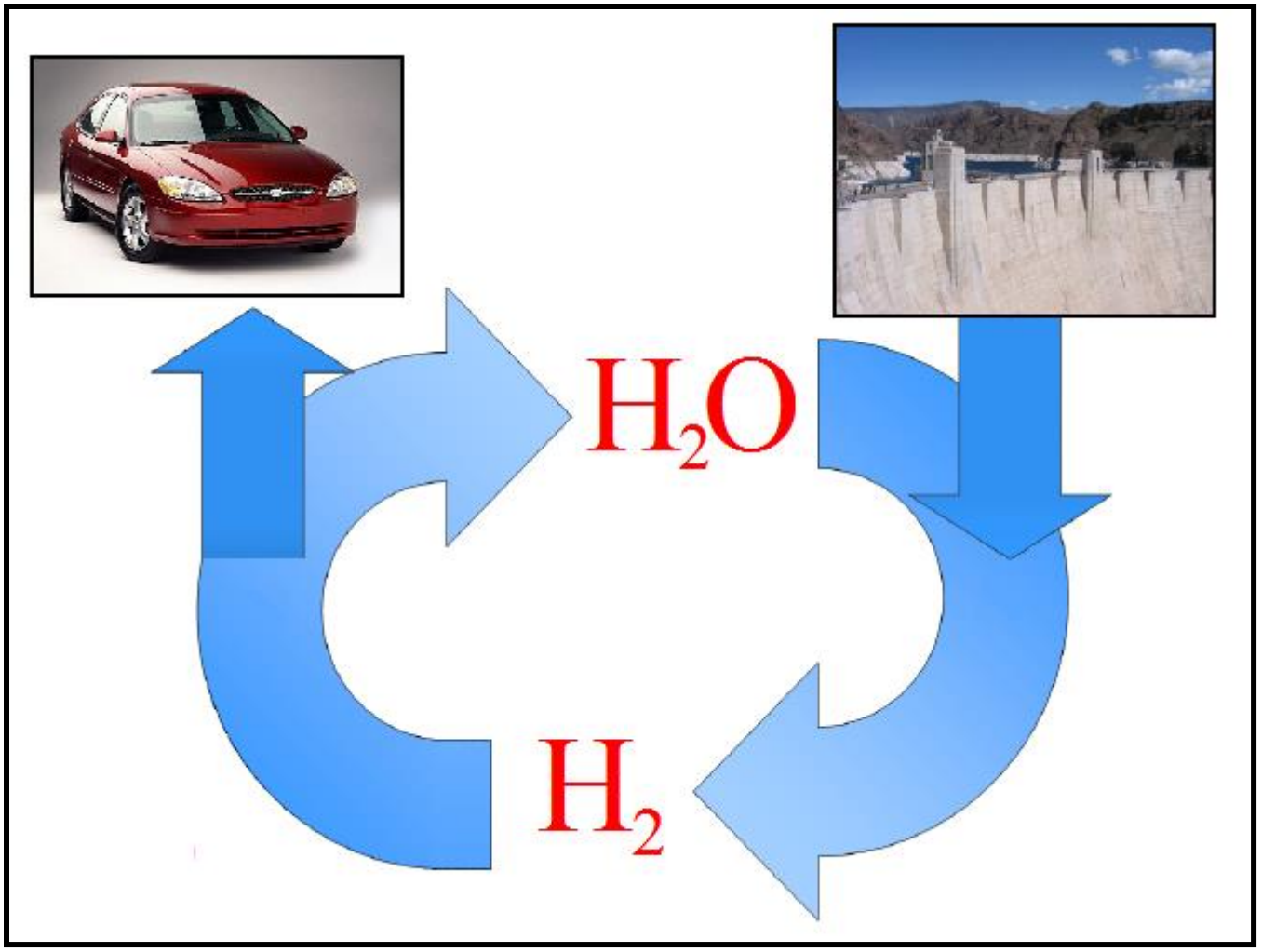
http://www.nrel.gov/hydrogen/photos.html

Microbial Fuel Cells



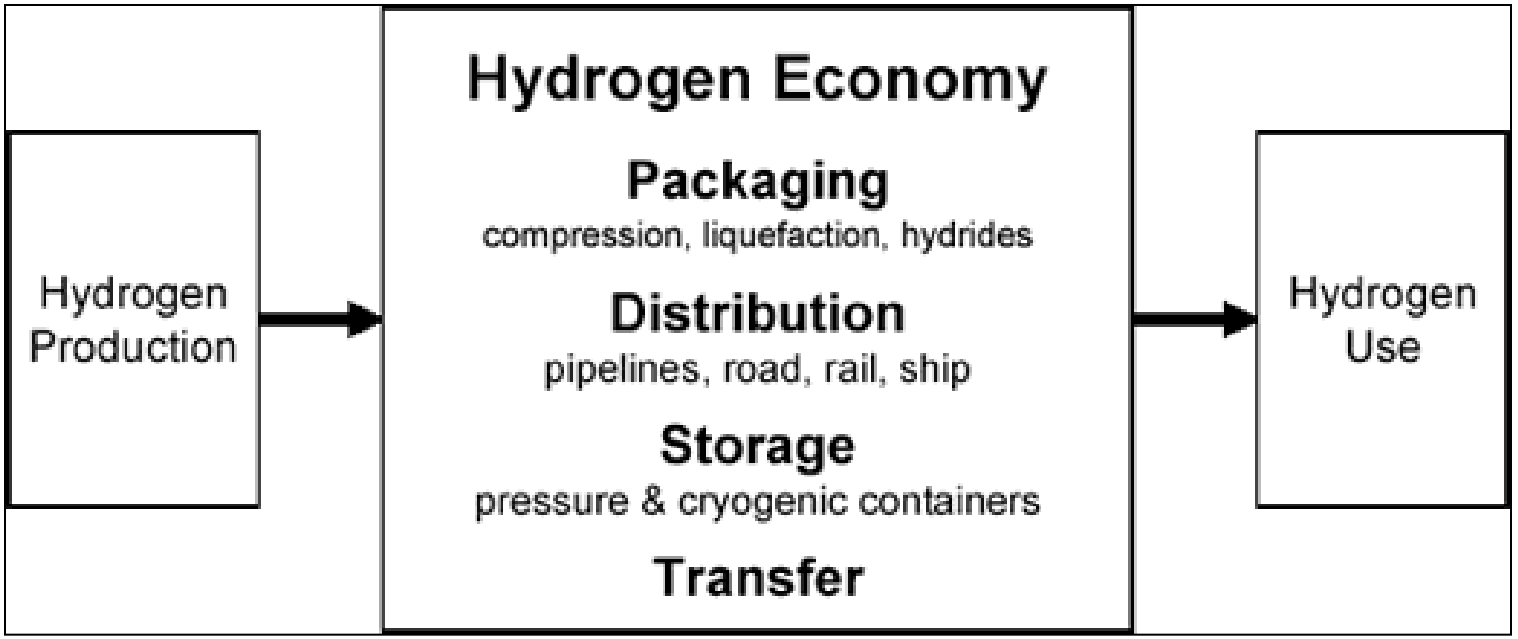
Source: http://parts.mit.edu/igem07/images/2/2d/Fuelcell.JPG

Hydrogen Energy Cycle



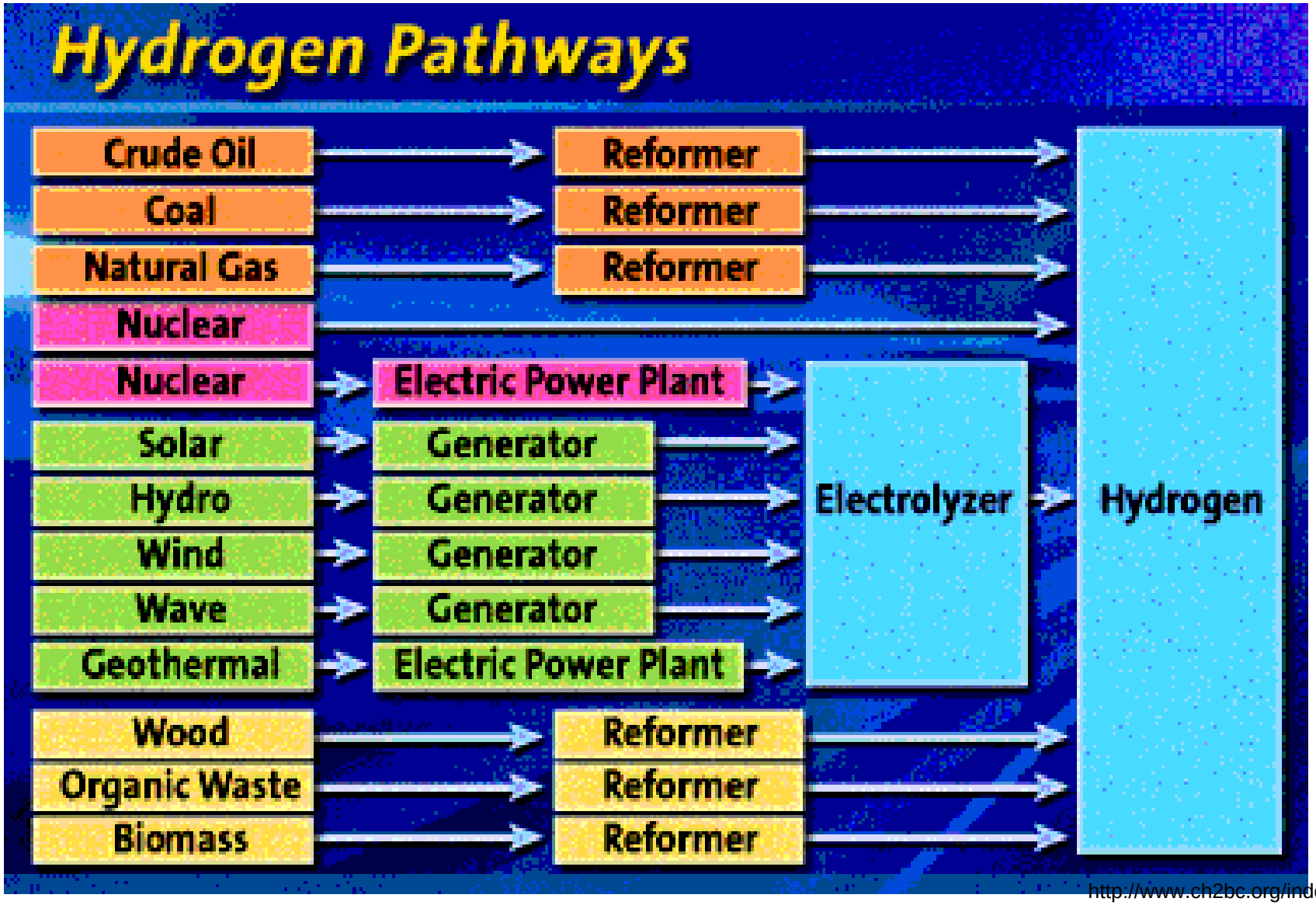
http://en.wikipedia.org/wiki/Hydrogen_economy

Operating the Hydrogen Economy



Bossel et al., *The Future of the Hydrogen Economy: Bright or Bleak?,* Oct 28, 2004
http://www.oilcrash.com/articles/h2_eco.htm

Hydrogen Pathways



http://www.ch2bc.org/index2.htm

Advantages of a Hydrogen Economy

- Waste product of burning H_2 is water
- Elimination of fossil fuel pollution
- Elimination of greenhouse gases
- Elimination of economic dependence
- Distributed production

http://www.howstuffworks.com/hydrogen-economy.htm

Issues with Hydrogen

- Not widely available on planet earth
- Usually chemically combined in water or fossil fuels (must be separated)
- Fossil fuel sources contribute to pollution and greenhouse gases
- Electrolysis requires prodigious amounts of energy

Technological Questions

- Where does hydrogen come from?
- How is it transported?
- How is it distributed?
- How is it stored?

http://www.howstuffworks.com/hydrogen-economy.htm

Direct Methanol Fuel Cell (DMFC)

- Operates at about 50-90^{o}C

- Efficiency is about 40%

- Used more for small portable power applications, possibly cell phones and laptops

Toshiba Corporation

Storing & Transporting Hydrogen

Storing the Hydrogen

Developing safe, reliable, compact and cost-effective hydrogen storage is one of the biggest challenges to widespread use of fuel cell technology.

Hydrogen Storage

- Storage a major difficulty with hydrogen
- H_2 has low energy density per volume
  - Requires large tanks to store
- H_2 can be compressed to reduce volume
  - Requires heavy, strong tanks
- H_2 can be liquefied to reduce volume
  - Boils at -423 °F (cryogenic)
  - Requires heavily insulated, expensive tanks
- Both compression and liquefaction require a lot of energy

Ammonia Storage

- H_2 can be stored as ammonia (NH_3)
- Exceptionally high hydrogen densities
- Ammonia very common chemical
  - Large infrastructure already exists
- Easily reformed to produce hydrogen
  - No harmful waste
- BUT
  - Ammonia production is energy intensive
  - Ammonia is a toxic gas

Metal Hydride Storage

- Metal hydrides can carry hydrogen
  - Boron, lithium, sodium
  - Good energy density, but worse than gas
- Volumes much larger than gasoline
  - Three times more volume
  - Four times heavier
- Hydrides can react violently with water
- Leading contenders
  - Sodium Borohydride
  - Lithium Aluminum Hydride
  - Ammonia Borane

Transporting Hydrogen

Storing & Transporting Hydrogen

- Store and Transport as a Gas
  - Bulky gas
  - Compressing H_2 requires energy
  - Compressed H_2 has far less energy than the same volume of gasoline
- Store and Transport as a Solid
  - Sodium Borohydride
  - Calcium Hydride
  - Lithium Hydride
  - Sodium Hydride

http://www.howstuffworks.com/hydrogen-economy.htm

Hydrogen Fueled Transport

Hydrogen-Powered Autos

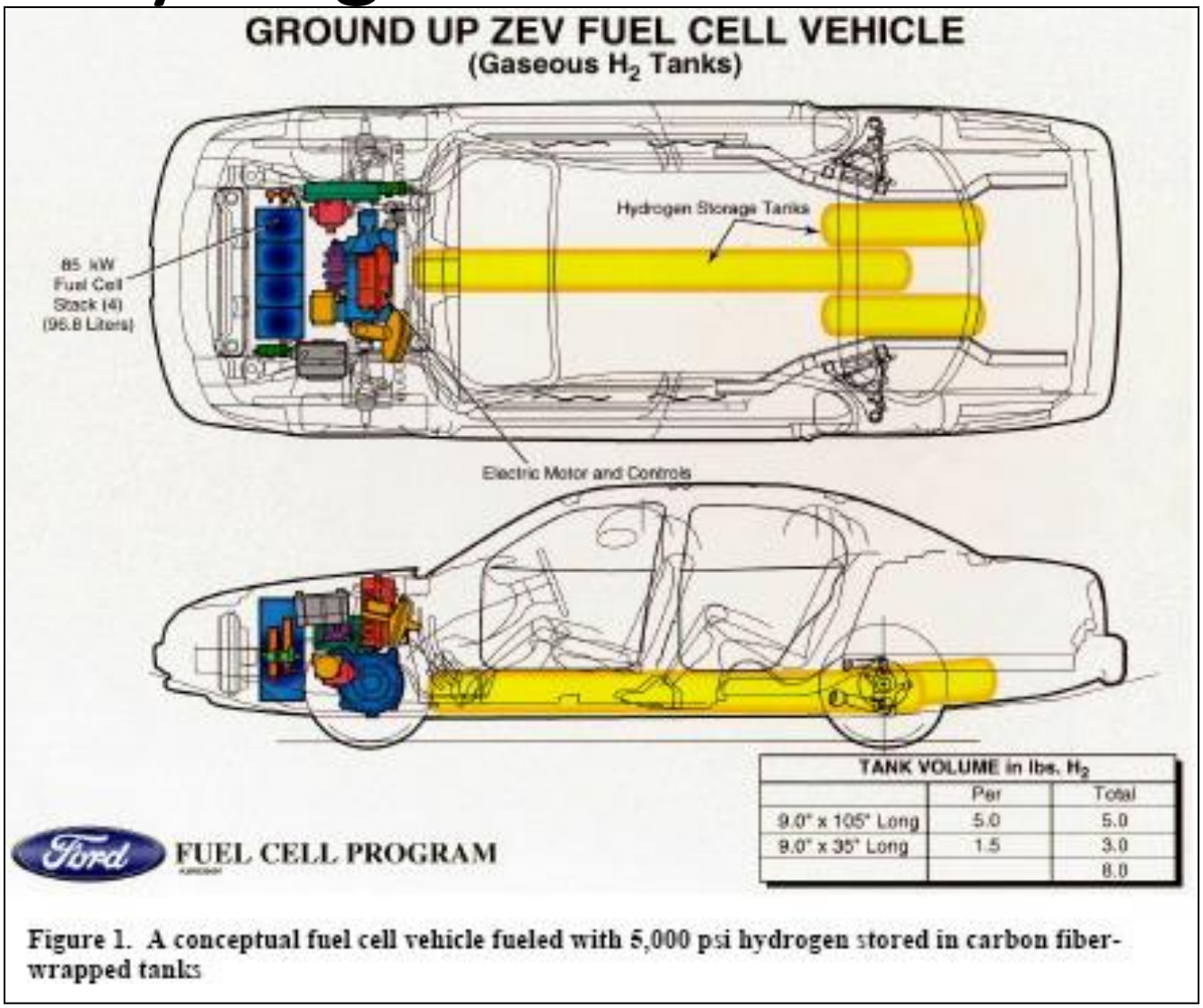


Figure 1. A conceptual fuel cell vehicle fueled with 5,000 psi hydrogen stored in carbon fiber-wrapped tanks

How can Fuel Cell Technology be used?

Transportation

- All major automakers are working to commercialize a fuel cell car.

- fuel cell buses are currently in use in North and South America, Europe, Asia and Australia

- Trains, planes, boats, scooters, and even bicycles are utilizing fuel cell technology as well

Hydrogen Fueling Station

Courtesy: Honda solar hydrogen station (FCX Clarity Car)

Hydrogen Fueling Station

Courtesy: Honda solar hydrogen station

Hydrogen Fueling Station

Courtesy: Honda Introduces Solar Hydrogen Station on Saitama Prefectural Office Grounds

Fuel cell SUV

Courtesy: Honda Introduces Solar Hydrogen Station on Saitama Prefectural Office Grounds

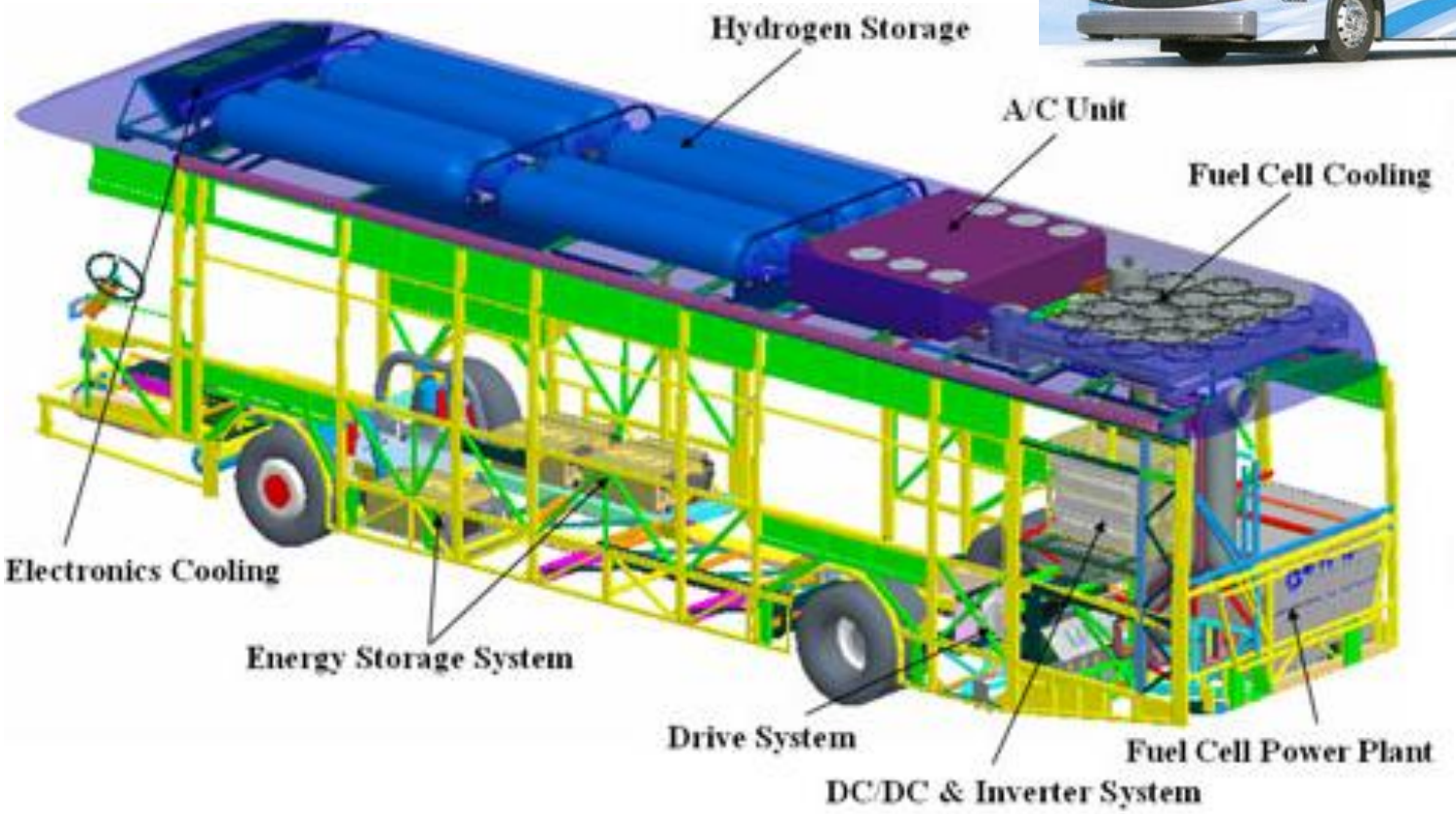
Hyundai ix35 fuel cell SUV with Malmö's famous Turning Torso in the background (Source: City of Malmö/Peter Adamsson)

Hydrogen-Powered Autos

http://planetforlife.com/h2/h2vehicle.html

Fuel Cell Technology For Buses

Fuel Cell Powered Buses:



28 litres of Hydrogen /100 km
(compared to 52 litres diesel /100 km)

Fuel cell BUS

Hydrogen fuel cell buses in London

[**London** Open Top **Bus** Tours]

Hydrogen-Powered Trucks

http://planetforlife.com/h2/h2vehicle.html

Fuel Cell Technology for Planes

Boeing Flies First Ever Hydrogen Fuel Cell Plane:

The experimental airplane climbed to an altitude of 1,000 m above sea level using a combination of lithium-ion battery power and power generated by hydrogen fuel cells.

After reaching the cruise altitude, batteries were disconnected, and the plane flew straight and level at a cruising speed of 100 km/h for about 20 min on power solely generated by the fuel cells.

http://www.treehugger.com/aviation/boeing-flies-first-ever-hydrogen-fuel-cell-plane.html

Fuel Cell Technology Aircrafts

First Commercial Fuel Cell Powered Aircraft:

Airbus and the German Aerospace Center (DLR) presented the first commercial aircraft powered by fuel cells at the ILA Berlin Air Show 2008. The fuel cells cannot replace the plane's jet engines for powering the heavy plane through the air.

Fuel cells replace the auxiliary power units which meet the plane's power demands when the plane is on the ground.

Hydrogen-Powered Aircraft

Hydrogen powered passenger aircraft with cryogenic tanks along spine of fuselage. Hydrogen fuel requires about 4 times the volume of standard jet fuel (kerosene).

http://planetforlife.com/h2/h2vehicle.html

http://aix.meng.auth.gr/lhtee/projects/cryoplane/

Fuel Cell Technology For Powered Trains

Fuel Cell Powered Trains:

Visit http://hydrail.org/

Hydrogen-Powered Rockets

http://planetforlife.com/h2/h2vehicle.html

Nanotechnology in Fuel Cells

- The researchers believe that the improvement is due to a more efficient transfer of electrons than in standard catalysts.

- Increasing catalyst surface area and efficiency by depositing platinum on porous alumina

- Allowing the use of lower purity, and therefore less expensive, hydrogen with an anode made of platinum nanoparticles deposited on titanium oxide.

http://www.understandingnano.com/fuel_cells-platinum-reactivity-lattice-strain.html

Problems with Hydrogen

Environmental Concerns

- 48% of hydrogen made from natural gas
  - Creates CO_2 – a greenhouse gas
- Hydrogen H_2 inevitably leaks from containers
  - Creates free radicals (H) in stratosphere due to ultraviolet radiation
  - Could act as catalysts for ozone depletion

Hydrogen Economy

The vision of the hydrogen economy is based on two
expectations:

(1) that hydrogen can be produced from domestic energy sources in a manner that is affordable and
environmentally benign, and

(2) that applications using hydrogen—fuel cell vehicles, for example—can gain market share in competition with the alternatives.

http://www.nap.edu/catalog/10922.html

"HYDROGEN – The New Source of Power"

Hydrogen = "Currency of the Future"
HYDROGEN Revolution
Roadmap to the Hydrogen Economy
Why Hydrogen as a Transportation Fuel

- Will Hydrogen be an alternative fuel or the mainstream fuel ?
- Short term and Long term Infrastructure
- Speculation on Timescales

Hydrogen Economy Schematic