A2 LEVEL

Environmental Technology

Hydrogen Fuel Cell Opportunities

For first teaching from September 2014

For first award in Summer 2015

FACT FILE

environmental technology

Sustainability and Future Development

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environmental technology

Sustainability and Future Development
Fact File 1: Hydrogen Fuel Cell Opportunities

Specification Content

Students should be able to:

- explore the key points of hydrogen chemistry with particular emphasis on those properties that relate to its extraction and use as a fuel, including reactivity and density;
- outline the bulk production of hydrogen by the following methods:
  - steam reforming of fossil gases;
  - electrolysis of water;
  - photocatalytic water splitting;

(to include simple equations only);
- describe the process of energy conversion that occurs in the most common forms of hydrogen fuel cells:
  - Polymer Electrolyte Membrane (PEM);
  - alkaline;
  - phosphoric acid;
  - molten carbonate;
  - solid oxide;

(to include redox reactions involved);
- demonstrate the operation of a fuel cell, using a scale model;
- demonstrate an understanding of a range of applications of hydrogen fuel cells to include:
  - stationary generation as back up or in remote locations;
  - stand-alone power supplies for telecommunications installations; and
  - transport, including cars, buses, trains, boats, or portable power generators;
- discuss the challenges presented by using hydrogen as an energy source, for example production costs, transport issues and safe storage;

Course Content

Hydrogen Bulk Production

Hydrogen is a very versatile energy carrier and can be used in almost every situation where energy is needed to do work.

It can be burned in oxygen in an internal combustion engine, or it can be used to generate useful electrical energy.

With hydrogen having only 1 electron in its outer shell it is extremely reactive. Therefore it is rarely found on its own, but combined in compounds with other elements such as water. This helps to explain why, despite hydrogen being the most abundant element in the universe; it is relatively rare on Earth. Hydrogen is colourless, has no odour and is extremely flammable. It was associated with the famous explosion of the Hindenburg airship.

The energy density per unit volume of both liquid hydrogen and compressed hydrogen gas at any practicable pressure is significantly less than that of traditional fuel sources, although the energy density per unit fuel mass is higher.

More information about the chemistry of hydrogen can be found at http://chemistry.about.com/od/elementfacts/a/hydrogen.htm

In order to provide a source of hydrogen, to use as a fuel, the following methods can be used to remove hydrogen from other compounds:

Steam reforming of natural or fossil gas

Natural gas in the form of methane will release hydrogen when exposed to superheated steam. Since natural gas is readily available through an existing gas delivery infrastructure, this method is responsible for a large percentage of overall production of hydrogen

The process requires:

- A supply of methane
- Temperatures of 700oC to 1000oC
- Steam
- Pressure of 3 – 25bar
- A catalyst

The reaction steps are:

1. $CH_4 + H_2O \rightarrow CO + 3H_2$ The high temperatures and pressure are needed for this step.
2. $CO + H_2O \rightarrow CO_2 + H_2$

Electrolysis of water

In this method an electric current is passed through the water, which may be fresh water or seawater, causing it to split into hydrogen and oxygen. The current is passed through electrodes submerged in the water. The reaction occurring at the electrode is:

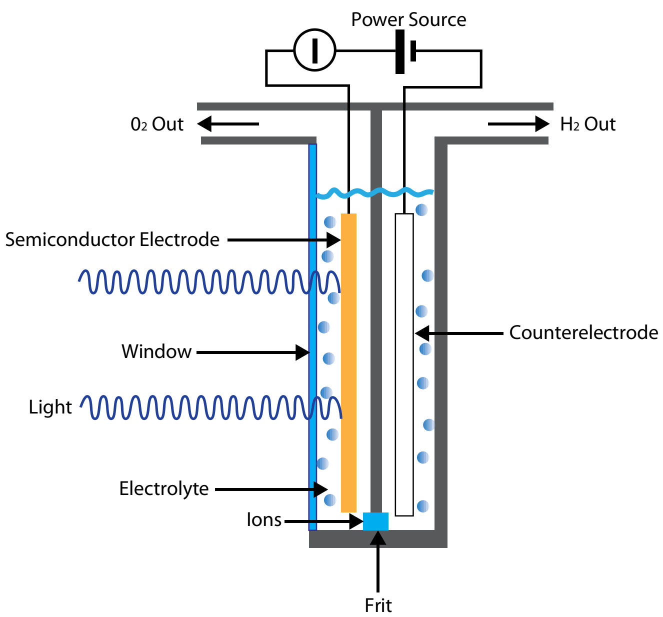
$$2H_2O + 2e^- \rightarrow H_2 + 2OH^-$$

If seawater is used then potentially poisonous chlorine gas is produced which must be safely vented or liquefied and stored as a potentially useful gas in other processes.

Photocatalytic water splitting

Water can also be split directly by sunlight in the presence of a semiconductor catalyst. The water is passed over the semiconductor with light shining directly on to it. The semiconductor material catalyses the water splitting reaction as follows:

$H_2O \rightarrow \frac{1}{2}O_2 + 2H^+$	reaction at the semiconductor electrode
$2H^+ + 2e^- \rightarrow H_2$	reaction at the counter electrode



An interesting version of this method involves the semiconductor catalysts being formed as spheres which float in the water. As the sun hits the water the hydrogen gas is then taken off, compressed and stored.

Hydrogen Fuel Cells

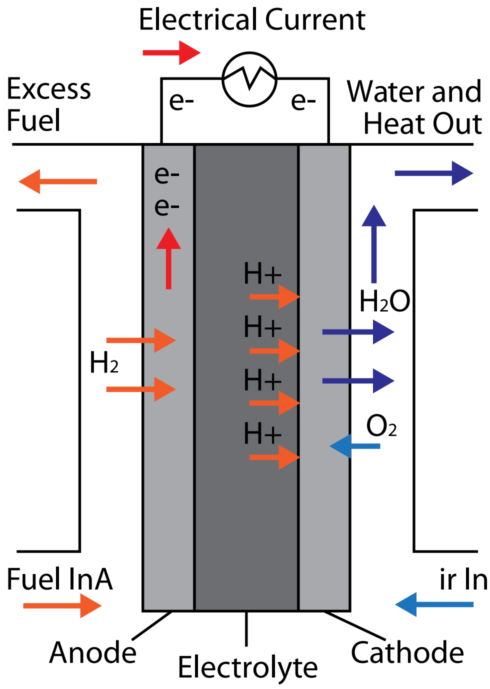
The hydrogen fuel cell is an energy conversion device where the chemical energy stored within the hydrogen molecule (H_2) can be turned into electric current.

Main advantages include;

- The only by-products are water and some heat, which can in fact be useful;
- Typically fuel cells are around 60% efficient which is about twice as efficient as a conventional internal combustion electricity generation;
- They are silent running; and
- With few moving parts they are reliable and present low maintenance costs.

The diagram shows the reactions occurring in a typical fuel cell.

PEM FUEL CELL



- The electrolyte material lies between a selectively permeable anode and cathode.
- The anode layer allows hydrogen gas through to meet the electrolyte layer.
- When the hydrogen gas hits the anode a reduction reaction occurs and H^+ ions (protons) are formed

  $H_2 \rightarrow 2H^+ + 2e^-$
- These electrons then flow in a circuit and are used to do work such as operate a motor, a pump or lights for example.
- The protons pass on through the selectively porous

electrolyte membrane (PEM) and arrive at the cathode to be met there by oxygen gas from the air.

- Now the electrons generated at the anode have come back through the circuit and arrive at the cathode.
- The electrons, the oxygen gas and the protons react to form water in an exothermic reaction:

  $4H+ + 4e\sim + O2 \longrightarrow 2H2O$

- If the heat is not absorbed to be used then the water will be emitted as steam. If the heat is removed the water is emitted at liquid water.

A single reaction sequence as shown here will only produce small amounts of electricity at a very low voltage. Many applications connect multiple arrays together in stacks. The greater the power needed the bigger the stack.

Pupil Activity

All fuel cells operate on basically the same principle with electrodes separated by an electrolyte.

You should research the five types of fuel cell in most common use listed below using the links;

www1.eere.energy.gov/hydrogenandfuelcells/fuelcells/fc_types.html

www.bluffton.edu/courses/TLC/MontelA/Montel/Alternative_Energy_Website/Fuel_Cell.htm

www.slideshare.net/guest0c2139/hydrogen-fuel-cells

- Polymer electrolyte membrane (PEM);
- alkaline;
- phosphoric acid;
- molten carbonate;
- solid oxide

Draw an annotated diagram for each and present the following information:

The electrolyte used	Process of energy conversion
Redox reactions involved	Efficiency
Range of applications	Key advantages & disadvantages

Applications for hydrogen fuel cells

As the technology of fuel cells develops there is an ever increasing range of applications where they can be used;

- generation of electricity as a back up to traditional methods in case of emergency;
- use as a source of power in remote locations where a mains supply is not available;
- stand-alone power supplies for installations such as telecommunications providers where no mains supply is available;
- use as a power supply for modes of transport such as cars, buses, trains or boats; and
- as portable power generators.

The main challenges presented by production, storage and transportation of hydrogen gas

Production Concerns

- In gas reforming the key concern is that using a fossil fuel as the gas has its own limitations in terms of the fact that it is not renewable. If a renewable form of methane can be obtained as biogas for example then this issue could be largely solved.
- As far as production is concerned the energy requirement of the production process is a major consideration for all types, particularly the electrolytic splitting of water. The electricity needed for the process is the main expense. Therefore unless the electricity can be produced by a renewable method, then the actual manufacturing process will have a large carbon footprint.
- All of these methods will be limited by economic feasibility. Unless they can operate at a cost which allows an amount of hydrogen gas equivalent in energy to a gallon of petrol or diesel to be economically comparable then significant usage will not occur.

Storage & Transportation Concerns

- Any gas will occupy a considerable volume. Since Hydrogen has such low density, it needs to be compressed and liquefied under significant pressure in order to make storage feasible. Pressurised vessels need expensive pumping and compression technology to keep the gases contained in the correct conditions. This adds expense to already expensive tanks.
- With the extremely explosive nature of Hydrogen the tanks for storage must be very strong, have thick walls and have very high quality welds and seals. All of which makes the storage vessels very expensive to build and maintain.

- Hydrogen must be maintained at -253oC to keep it liquefied. With cryogenic cooling apparatus for the storage tanks comes even more expense.
- Very little piped infrastructure exists for hydrogen delivery by pipeline. Even in the US there is only 1200 miles of pipeline. Therefore bulk delivery of hydrogen will be by specialised cryogenically chilled truck or barge.
- Due to the low density of hydrogen, even in its liquid state, it contains a smaller amount of useable energy than LPG or petrol. Therefore a gallon equivalent of hydrogen would still be more expensive than its competitors.
- Transportation and storage require vessels to be double hulled for safety making them very heavy. Therefore the actual fuel used by the transportation method will itself be significant in getting the hydrogen from producer to delivery site.
- The low temperatures of hydrogen liquid can make welds brittle. Therefore all delivery vessels or pipelines must undergo regular and expensive weld inspection.

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