Hydrogen Basics

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Home Power is gearing up to use hydrogen fuel for cooking. We've been hoping to eliminate or at least reduce our propane use for a long time now and have been encouraged by the interest and enthusiasm in hydrogen that we've seen in our readers.

Hydrogen is not a source of energy; rather, it is a non-toxic means of storing and transporting energy. Any energy source can be stored in the form of hydrogen. Solar, wind and hydro power can be used to break down the molecular bonds which bind hydrogen in hydrocarbons and water. Hydrogen, unlike electricity, is efficiently transported over long distances (through pipelines, for example). It enables energy produced in areas where renewable energy resources are abundant to be safely transported to areas with high energy use. Part of hydrogen's virtue as an energy storage medium is the fact that energy stored in the form of hydrogen can be converted into different forms of usable energy without producing pollutants. Heat or electricity can be produced with water as the primary by-product.

Catalytic Combustion

Hydrogen can be recombined with oxygen to produce heat in the normal combustion process or it can be recombined in a fuel cell to produce electricity. In both cases the primary by-product is water. Burning hydrogen produces some nitrous oxides because of the high burning temperature. However, using a catalyst (such platinum or nickel) lowers the temperature and decreases the surface area of the reaction, which increases efficiency and reduces the nitrous oxides to a negligible amount. Pure catalytic combustion uses a catalyst to cause the hydrogen-oxygen recombination to occur without the input energy of a flame. There is a 100% efficient conversion of hydrogen to heat when temperatures are kept below 100 degrees Celsius or 212 degrees Fahrenheit.

Converting a propane stove to run on hydrogen is a fairly simple process. Low tech, inexpensive catalysts such as stainless steel wool (3% – 22 % nickel) work well and are easy to use. However, stainless steel wool is not as effective in eliminating nitrous oxides as more expensive catalysts. For more information on these operations see *Fuel from Water* by Michael Peavey. Also look in your local library under hydrogen.

The Electrolyzer

An electrolyzer is a device that uses electric current to lyse or split water (H_2O) into hydrogen and oxygen. (See Electrolyzer sidebar.) Electrolysis is currently the cheapest, simplest, and most efficient method of home scale hydrogen generation. Well-made and relatively inexpensive electrolyzer cells from Hydrogen Wind in Iowa are available. Each electrolyzer cell requires 2 Volts; the current determines how much hydrogen they produce. (see HP #22 and 26.)

How Much Hydrogen Would We Use?

We plan to use electrolyzers to produce hydrogen, but how much hydrogen do we need? Ideally we would like to supply the gas needs for the eight of us that live here on Agate Flat. That, however, is no small feat! In order to determine how much hydrogen we need to produce and store, we calculated how much hydrogen we would use on a daily basis. Here's how much hydrogen we would need to run the cookstove, our only gas appliance:

There are 82,000 British thermal units (BTU) per gallon of liquid propane. A 5 gallon tank of propane lasts us approximately twenty days. We therefore use:

$$\frac{82{,}000\ \text{BTU}}{\text{gal}} \times 5\ \text{gal} = 410{,}000\ \text{BTU every } 20 \text{ days}$$

$$\text{or } \frac{410{,}000\ \text{BTU}}{20\ \text{days}} = 20{,}500\ \text{BTU every day}$$

How much electricity do we need to run through electrolyzers to produce 20,500 BTU of hydrogen? We have a number for converting BTU into kilowatt-hours (kW-hr) of electricity but it assumes 100% efficiency. With the kind of electrolyzers we are looking at, we expect the efficiency to be about 50%.

$$1\ \text{BTU} = 2.9287 \times 10^{-4}\ \text{kW–hr}$$

$$\frac{20{,}500\ \text{BTU} \times (2.9287 \times 10^{-4}\ \frac{\text{kW–hr}}{\text{BTU}})}{0.5\ \text{efficiency}} = 12.0\ \text{kW–hr}$$

This means we would need 12 kW-hr input to the electrolyzers each day to produce hydrogen for our daily

ELECTROLYZER PHYSICS

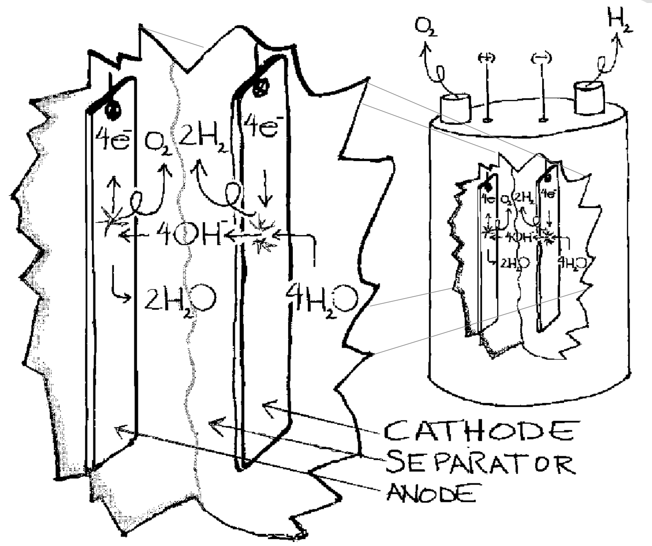
An electrolyzer is a device that uses direct current electricity to break the bonds holding together water, H_2O, into its components hydrogen, H, and oxygen, O.

An electrolyzer has three main components: an electrolyte, two electrodes and a separator. The electrolyte solution consists of distilled water and a salt, acid, or base, and is held in a chamber. The electrodes are pieces of metal which sit in the electrolyte and pass current through the electrolyte. The separator is a barrier that physically separates the electrodes from each other yet allows current to flow between them.

The Process

The following reactions occur when the electrolyte is a 30%solution of potassium hydroxide, KOH. If another electrolyte is used the results will be the same although the reactions will be different.

When DC electricity is connected to the two electrodes, current passes through the solution (H_2O and KOH), decomposing the chemical bonds of the H_2O molecules. Electrons enter into the chamber via the negative terminal, called a cathode, and cause a reaction. In this reaction four water molecules, $4H_2O$, are broken into eight positively charged hydrogen ions, $8H^+$, and four negatively charged oxygen ions, $4O^{2-}$. Since the four oxygen ions are unstable in this state, each one quickly re-attaches to one hydrogen ion, forming four hydroxyl ions, $4OH^-$. The four remaining hydrogen ions, $4H^+$, combine with four electrons at the cathode to form hydrogen gas, two molecules $2H_2$. This half reaction is:



$4e^- + 4H_2O \longrightarrow 4OH^- + 2H_2$

The negative hydroxyl ions that were generated at the cathode are attracted to the positive electrode, called the anode. The electrolyte increases the conductivity of the water, allowing the hydroxyl ions to be pulled to the anode. At the anode another reaction takes place in which the four hydroxyl ions give up four electrons and form oxygen gas, O_2, and two water molecules, $2H_2O$. These electrons leave the chamber via the anode to complete the circuit. The oxygen and hydrogen gas, kept separate by a barrier, bubble up through the electrolyte into separate pipes and off to their points of use or storage. This reaction looks like:

$4OH^- \longrightarrow O_2 + 2H_2O + 4e^-$

The overall result of the two reactions looks like this:

$2H_2O \longrightarrow O_2 + 2H_2$

cooking needs. This is a lot of electricity! There are a lot of us up here now, but we are going to need to find more efficient ways of our cooking and heating hot water if we hope to power our entire stove with hydrogen. We are planning on installing a solar hot water heater. We presently use our solar oven almost every sunny day and we are planning on building a larger one to further cut down on our propane use.

A Realistic Approach

We can begin by supplementing our propane use with hydrogen. The next question is how much hydrogen we can produce. *Home Power* will soon be adding two trackers to test. With our additional loads, this will add about 1.5 kW-hr surplus power per day. We use the following conversion factors to determine how many cubic feet of hydrogen (at atmospheric pressure, 1 atm.) 1.5 kW-hr will produce and how much energy in BTU this amount of hydrogen will give us.

$$1\ \text{ft}^3\ H_2\ (\text{at } 1\ \text{atm}) = 0.791\ \text{kW–hr}$$

$$\text{or } 1\ \text{kW–hr} = 12.6\ \text{ft}^3\ H_2\ (1\ \text{atm})$$

$$1\ \text{ft}^3\ (1\ \text{atm}) = 270\ \text{BTU}$$

Using the above conversion factors,

$$\frac{1.5\ \text{kW–hr}}{\text{day}} \times \frac{12.6\ \text{ft}^3\ (1\ \text{atm})}{\text{kW–hr}} \times 0.5\ \text{eff} = \frac{9.45\ \text{ft}^3\ H_2\ (1\ \text{atm})}{\text{day}}$$

$$\frac{9.45\ \text{ft}^3\ H_2\ (1\ \text{atm})}{\text{day}} \times \frac{270\ \text{BTU}}{\text{ft}^3\ H_2\ (1\ \text{atm})} = \frac{2551.5\ \text{BTU}}{\text{day}}$$

We will be able to produce 9.45 cubic feet of hydrogen at atmospheric pressure (or 2550 BTU hydrogen) each day from our 1.5 kW-hr/day surplus energy. This will only run our cookstove burner (assuming 10,000 BTU/hour) for a little more than 15 minutes.

Storage

Now that we have the hydrogen, how do we save it until we need it? Hydrogen storage can be complicated and costly. Hydrogen can be stored as a liquid, in a metal hydride, or as a pressurized gas. Liquid hydrogen at -253°C requires costly and complex storage containers and the energy required to liquify hydrogen is 20–40% of the energy being stored. Certain metals like magnesium, titanium, and iron absorb hydrogen when cooled and release it when heated. In these metals, hydrogen remains a gas but is confined in the spaces between molecules in the metal. When the metal is "charged" with hydrogen, it is called a metal hydride. Metal hydrides are the safest way to store hydrogen, especially in transportation applications, but are also more costly and complex than pressurized gas. Hydrogen can be stored as a gas at high or low pressures. High pressure systems allow smaller tanks but require expensive compressors. We are considering relatively low pressure storage options because we would like to keep our storage system as simple as possible.

To determine the size of our storage container, we've converted cubic feet into gallons.

$$9.45\ \text{ft}^3\ H_2\ (1\ \text{atm}) \times \frac{7.5\ \text{gal}}{\text{ft}^3} = 70.88\ \text{gal}\ H_2\ (1\ \text{atm})$$

The Ideal Gas Law

When we talk about storage, we also need to talk about the pressure. The above equation assumes we are storing the hydrogen at just above atmospheric pressure. Hydrogen, stored as a gas, follows the ideal gas law, $P_iV_i=P_fV_f$. The law states that the initial pressure times the initial volume of a gas is equal to the final pressure times the final volume of the gas.

Pressure in the ideal gas law must include atmospheric pressure. When we inflate a tire to 35 pounds per square inch (psi), we are actually inflating it to 35 psi above atmospheric pressure. Atmospheric pressure is the pressure per square inch exerted on us by the atmosphere above us. It varies according to elevation and temperature but is about 14.5 psi. Anything less than that is a vacuum; anything more is pressurized. So, the tire we inflated would actually be at 35 + 14.5 psi or 49.5 psi. The tires walls only "feel" 35 psi because atmospheric pressure presses on it.

We have 70 gallons of hydrogen at just above atmospheric pressure, at say 0.25 psi above atmospheric, or 14.75 psi. If we choose to store the hydrogen at 50 psi above atmospheric pressure or, 64.5 psi we can determine the resulting volume by applying the ideal gas law:

$$P_i \times V_i = P_f \times V_f$$

$$V_f = \frac{P_i \times V_i}{P_f} = \frac{14.75\ \text{psi} \times 70.88\ \text{gal}\ H_2}{64.5\ \text{psi}}$$

$$= 16.2\ \text{gal}\ H_2\ \text{at}\ 64.5\ \text{psi}$$

The 70 gallons of hydrogen we produce can be stored in a 16 gallon storage tank at 64.5 psi. The advantage of the higher pressure is the low volume storage tank. Hydrogen at 64.5 psi could be stored in a propane tank. Propane tanks, however, are expensive and a compressor might be necessary to increase the pressure of the hydrogen. Since hydrogen storage becomes more expensive and complicated as we increase the amount of hydrogen stored, we decided to start our system with only one day's worth of storage. Our options are to either store 16 gallons of hydrogen in an empty 10–20 gallon propane tank at 64.5 psi or store the 70 gallons of hydrogen in two 55 gallon drums at slightly greater than atmospheric pressure (see HP#26).

Hydrogen For Home Power Users

Hydrogen offers many possibilities for home power users. Indefinite, long term storage becomes possible with hydrogen. Many home power systems produce more power than can be used during only one season. PV's produce surplus power in the summer; micro-hydro systems produce surplus power in the winter. Hydrogen allows for the storage of the surplus energy produced during one season to be used in another. Hydrogen can be combusted to produce heat for cooking or space heating with no pollutants. It gives home power producers the option of eliminating the last of their fossil fuels. Hydrogen can also be added directly into an existing propane supply. Hydrogen bonds with propane and can be used in a propane appliances year-round, without any modifications, to conserve propane (see HP#22).

In the foreseeable future, we may see fuel cells become a cost-effective method of producing electricity with stored hydrogen. Hydrogen could then be used as an alternative to batteries which require proper maintenance and employ toxic heavy metals which eventually need to be disposed of or recycled.

This exercise has given us a good idea of what it will take to replace all of our propane use with hydrogen. It's brought home the importance of conservation; our solar oven and solar hot water heater will determine if our transition will be possible. There is little information on "home scale, home budget" hydrogen systems. We welcome any advice or experience.

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Fuel From Water by Michael A. Peavey, (ISBN 0-945516) Merit Products, Inc., Box 694, Louisville, KT 40201. Also available from Alternative Energy Engineering (see ad on page 5 of this issue).