# SOLAR POWERED HYDROGEN FUEL CELLS

## Table of Contents



## 1. Fuel Cell Uses - Present and Future[1]

There can be few inventions that have taken as long to go from first demonstration to widespread commercial use as the fuel cell. Although first demonstrated in 1839 by barrister-cum-inventor William Grove, the fuel cell had to wait till the U.S. space program of the 1960s before being used to produce useful power. The fuel cell has been a huge success in the space program, and is used in all the U.S. manned space vehicles. As well as providing the electrical power, fuel cells also provide water for drinking, cooking and cooling!

Fuel cells are now beginning to be used in more ordinary applications, though they are still not in widespread use. They are expensive, and most current applications are for research or where a subsidy has been secured because of their particularly benign environmental properties. Nevertheless, in recent years encouraging progress has been made, and the environmental benefits of fuel cells should soon be much more widely available without the need for massive subsidy.

## 2. Introduction

With the possibility of traditional energy sources becoming less affordable due to worldwide upswings in demand, finding alternate sources of energy has become a pressing need. Hydrogen fuel cell power has become a popular possible alternative because of its "clean" waste product: pure water. While the waste of a hydrogen-powered motor is much more desirable than that of our current fossil fuels based systems, one must acknowledge the fact that there is perhaps more "dirty" energy being used to create hydrogen than in refining gasoline. Hydrogen fuel cells, as they currently exist, rely upon fossil fuel-generated electricity to make the hydrogen necessary for the cell's power-creating reaction. In fact, it is currently more costly in terms of dollars spent and harmful effect on the environment to create hydrogen using the current methods than to simply use fossil fuel generated electricity. In this paper we examine the possibility of using solar energy to create the hydrogen for the fuel cells – thus making the entire hydrogen fuel cell energy process a clean technology.

This paper will discuss:

- The current state of both solar power and hydrogen fuel cell technology
- The status of research combining the two technologies
- The necessary steps and applications that would catapult this combination of technologies from an emerging innovation to a widely adopted product.

[1] Electro-Chem-Technic. Cited on May 1, 2005. Cited from http://www.ectechnic.co.uk/applications.html

## 3. The Basics

### *Hydrogen Fuel Cell*

There are several types of hydrogen fuel cells that use different materials. For our purposes, we will examine the technology that most affects the automotive industry. The figure below can help illustrate the process:

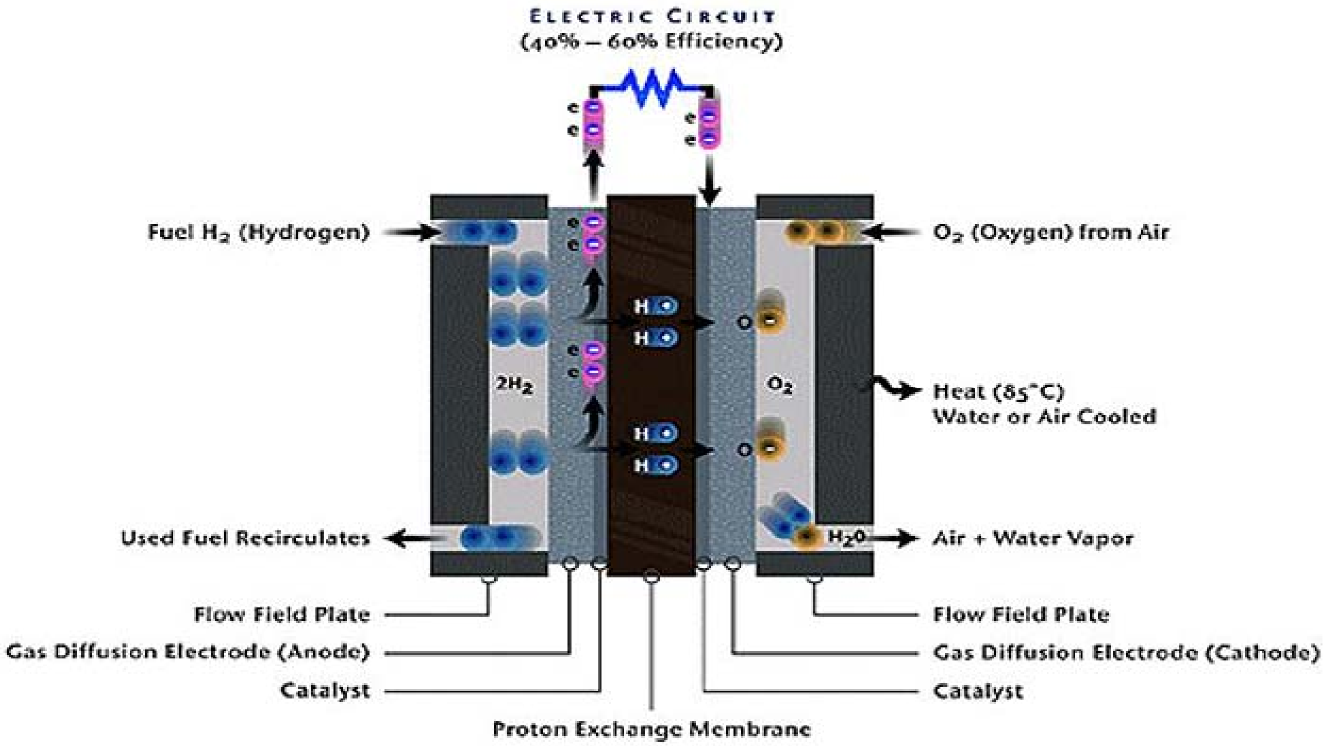



**Figure 1: Hydrogen Fuel Cell**
*Source: http://www.deh.gov.au/minister/env/2004/mr17aug204.html*

A hydrogen fuel cell requires hydrogen and oxygen as inputs, and has water and electricity as outputs. The cell itself also requires two electrodes (an anode and cathode), which are placed next to a catalyst (typically made from a precious metal such as platinum). The catalyst surrounds a Proton Exchange Membrane (PEM), a plastic-like material that allows protons to cross over from one side to another, but not electrons. Hydrogen atoms enter the cell and are split as they pass through the anode. The Hydrogen atoms are forced through the catalyst, which strips away the electrons, sending them through a circuit, while the hydrogen protons pass through the PEM. At the same time, oxygen from the outside air has come into the fuel cell and been attracted through the cathode, splitting it from its normal state ($O_2$) into pure oxygen atoms which are then attracted to the hydrogen atoms to form $H_2O$ – pure water.

The Positives

The process doesn't emit any greenhouse gases - just heat, water, and electricity. Unlike a traditional internal combustion engine, which must burn fuel to create heat then convert the heat to mechanical energy, fuel cells extract electricity at an atomic level. They are therefore much more fuel efficient than traditional internal combustion engines, which typically can achieve about 30% fuel efficiency, whereas fuel cells can achieve up to 90% fuel efficiency.[2]

[2] http://www.fuelcellstore.com/information/benefits_of_fuel_cells.html
http://www.ecologicalhomes.com.au/hybrid_energy_cars.htm

The Negatives

Fuel Cells require fuel in the form of hydrogen, either as pressurized gas or liquid. Hydrogen doesn't occur naturally on the earth; it is always part of the molecular structure of some more complex material. In order to create hydrogen fuel, current methods involve the use of fossil fuels to separate hydrogen from any one of a number of other molecules, making hydrogen a "dirty" fuel because of the pollution involved in this separation process.

### *Solar Power*

Solar energy can be obtained through two methods – Photovoltaic (PV) and Concentrated Solar Power (CSP). PV uses silicon-based solar cells mounted on panels to absorb energy from sunlight. The energy transfers a small electrical current which then is picked up by metal grids surrounding the cell. CSP uses mirrors to concentrate sunlight and transform it into high temperature heat which is then used to heat water – producing steam that drives a turbine and produces electricity. Solar panels have no moving parts, require almost no maintenance, have an average life of 20-30 years and make no noise.

The major drawbacks of solar power are:

- It relies on sunlight – which is not available 24 hours a day nor is it always available in enough strength during the day to provide sufficient power.
- The current technology is very expensive. One kilowatt hour of solar energy costs anywhere from $.2 to $1 compared to $.08 per kilowatt hour from conventional means.
- Efficiency – efficiency in solar panels refers to the panel's ability to convert sunlight to electricity. Most commercially available panels range from 12-20% efficiency.

## 4. A Completely Clean Process: Solar Powered Hydrogen Fuel Cells

The main output that we're after is electricity to drive a motor. A hydrogen fuel cell does that with simple chemical reactions that yield no harmful waste. Generating energy to create hydrogen is another matter. Hydrogen can be separated from water by a method known as electrolysis, which uses electricity to break the bonds between oxygen and hydrogen atoms, releasing them as gasses.

One might ask, if its electricity you're after, why not just use solar cells to power motors? The problem with solar power is that it's only readily available during daylight hours – not at night. The solar to hydrogen energy conversion process makes the solar energy "storable" in the form of hydrogen gas, to be used later in a hydrogen fuel cell.

Below, we examine two recent developments in solar technology that make the possibility of clean hydrogen fuel creation much closer to reality.

### *Method 1: The Solar Farm*

The first method is to create a solar farm, as illustrated in the following diagram:

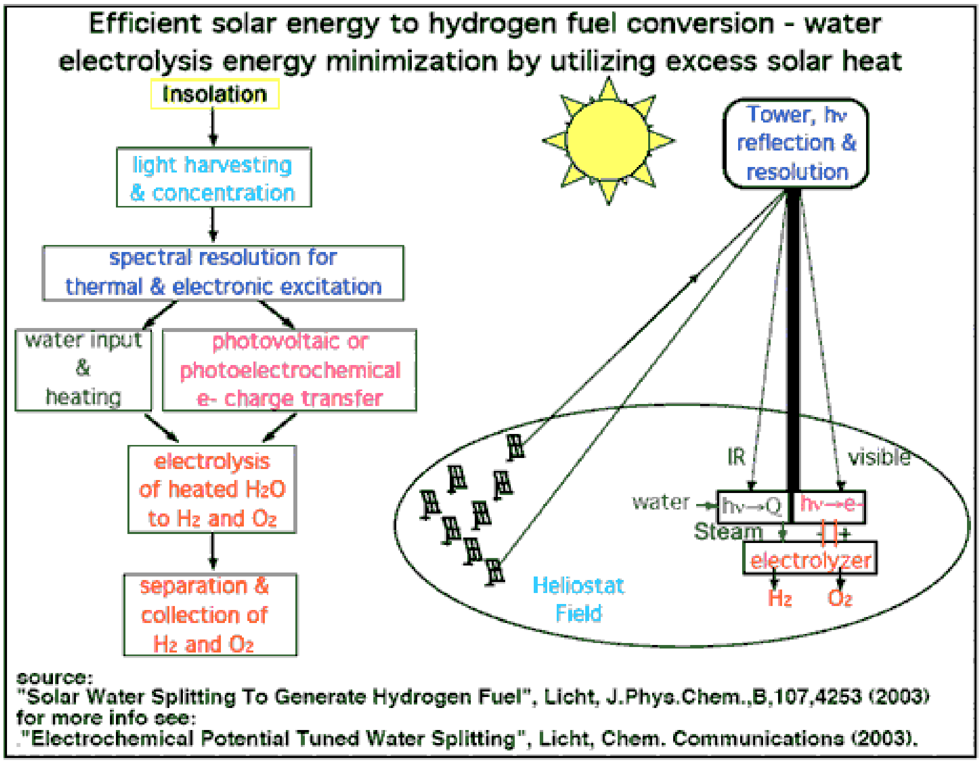



**Figure 2: Solar Farm Schematic**
*Source: http://www.energycooperation.org/solarh2.htm*

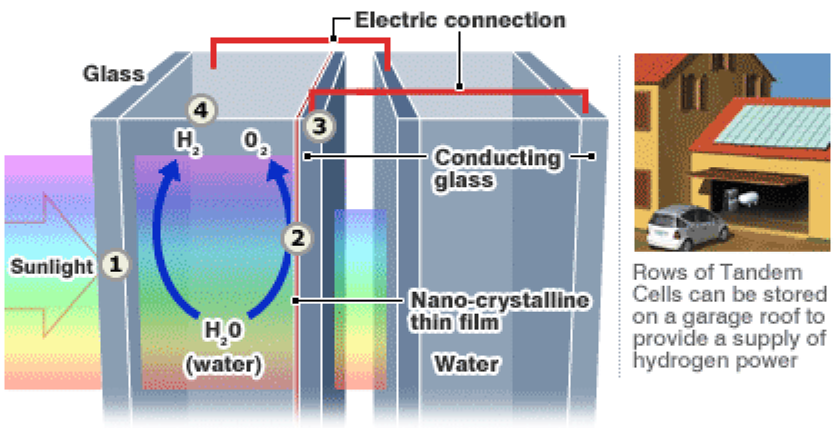
This method requires a large, permanent infrastructure in the form of a field of mirrors which reflect sunlight to a point on a collection tower. The tower uses photovoltaic or photo electrochemical means to convert the visible light into electric current. The infrared or heat energy reflected to the tower is also used to heat water into steam. Through the electrolysis of the heated water, hydrogen can be harvested with greater efficiency than through cooler methods.

The main issues with this method are the cost of the infrastructure and storage of the hydrogen. At present, there is little information on the exact cost to build and operate such a solar farm, although the Israeli government gave Solel (an Israeli solar power company) the go-ahead to build the plant in 2003.[3]

### *Method 2: Localized Solar Hydrogen Cell*

Perhaps a more exciting proposal is that of a localized solar hydrogen cell, one which can be attached to rooftops of hydrogen-powered homes, or homes that belong to hydrogen-powered car owners. This technology, called the Tandem Cell, developed by the UK's Hydrogen Solar, converts the sun's energy (including ultraviolet and infrared energy) into hydrogen by a simple disruptive technology. The following diagram, illustrates how the process works:

[3] http://www.energycooperation.org/solarh2.htm




**1** Ultraviolet sunlight passes through glass skin of cell
**2** Light is captured in glass coated with nano-crystalline film
**3** Nano-coating properties enable the glass to conduct electricity, which is used to separate the water into oxygen and hydrogen
**4** Hydrogen gas is stored for later use as a power source

**Figure 3: Localized Solar Hydrogen Cell**
*Source: http://news.bbc.co.uk/2/hi/science/nature/3536156.stm*

Currently, Tandem Cell technology operates slightly above 8% efficiency – not enough to be commercially viable. However, the 10% efficiency requirement is not out of reach, according to the company's leaders. Investors seem to agree – the company was awarded $400,000 from the University of Nevada Las Vegas, and announced April 11, 2005 that their latest stock offering was 78% oversubscribed[4].

Tandem Cell could be described as a disruptive technology – using simple elements (glass, water) along with some advanced technology (nano-crystalline thin film) to derive a solution to current energy needs that should be less costly in the long term.

### *Solar Technology Advances*

Cornell University and Lawrence Berkeley Labs combined efforts to find a more efficient solar technology – succeeding twice in the last 3 years. They first discovered a new combination of elements (indium gallium nitride) that is theoretically 72% efficient as a photovoltaic cell (current silicon-based cells are about 10-25% efficient)[5]. These cells would require stacking different layers to achieve greater efficiency, "tuning" each layer to a specific light energy level. To achieve the theoretical 72% efficiency, for example, 36 layers would have to be stacked.

Just under two years later, the same team discovered a single layer cell material: zinc manganese tellurium, which could achieve a theoretical efficiency greater than 50%.[6] Such discoveries are indeed the fodder for start up companies, as is shown by the fact that Cornell University just licensed a thin film solar technology to RoseStreet Labs in Phoenix, AZ.[7]

These increases in efficiency of solar cells could spell a big advancement in application of solar hydrogen cells, if coupled with existing technology. Such a breakthrough could shatter traditional thinking of the energy industry, and help us take a step further down the road to long-term sustainable energy manufacture and usage.

---

[4] http://www.hydrogensolar.com/new.html
[5] http://www.lbl.gov/msd/PIs/Walukiewicz/02/02_8_Full_Solar_Spectrum.html
http://www.lbl.gov/Science-Articles/Archive/MSD-perfect-solar-cell.html
[6] http://www.lbl.gov/Science-Articles/Archive/sb-MSD-multibandsolar-panels.html
[7] http://www.rosestreetlabs.com/RSL%20Solar%20Cell%20Press%20Release%20Final.pdf

## 5. Solar Power Hydrogen Fuel Cells: Invention to Innovation

We see two main components to moving the solar power hydrogen fuel cell from an invention to a widely adopted innovation.

The first component is the need to move the hydrogen fuel cell from a niche market product to widely used source of electricity. In order for that to occur, we believe the following changes must happen:

***1. The hydrogen fuel cell becomes the standard for alternative energy***

Although hydrogen fuel cells are more widely available today than ever before, a wide chasm still exists between the invention and widespread innovation of this technology. Products converting the invention to innovation for use by the mass population are still in emergent stages. In the automobile industry only a handful of models are available to consumers, but a de facto standard has yet to be established.

***2. Widespread Infrastructure is built to support the hydrogen fuel cell***

Alongside companies' and governments' move to roll out fuel cell vehicles, there exists an even more critical part of the fuel cell future: hydrogen infrastructure. While automakers such as Toyota and Daimler Chrysler deliver their latest model fuel cell vehicles, oil companies such as BP and Shell open up hydrogen stations in various countries from Munich to Singapore. According to technology research firm ABI, building early pilot hydrogen highways is the logical next step for the sector to make a faster transition into hydrogen fuel cell vehicles. … ABI forecasts show as many as 1 million vehicles could be fueled in the region [North America] by 2015 -- requiring 2,000 hydrogen fueling stations in the state of California alone.[8]

***3. Safe, convenient storage of hydrogen is developed.***

Hydrogen is usually stored under high pressure, is relatively heavy, and does not lend itself to convenient refueling. Storage in liquid form requires high energy to ensure safety. As the storage tanks are relatively large, liquid hydrogen is not suitable for use in automobiles. In transportation systems, converting non-hydrogen fuels, such as natural gas and ethanol, to hydrogen adds bulk and expense.[9]

The second component will need to move hydrogen production from fossil-fuel to solar-based. The following diagram illustrates an S-curve framework analysis to examine production of hydrogen in fuel cell technology:

[8] PEB based on material from ABI. "LATEST INCENTIVES SHOULD INCREASE INVESTMENT IN HYDROGEN INFRASTRUCTURE." 8 December 2003. Cited from: http://www.h2cars.biz/artman/publish/article_357.shtml

[9] "Cutting costs key to fuel-cell adoption." 10 December 2003. Cited from http://www.isa.org/InTechTemplate.cfm?Section=InTech&template=/ContentManagement/ContentDisplay.cfm&ContentID=29683

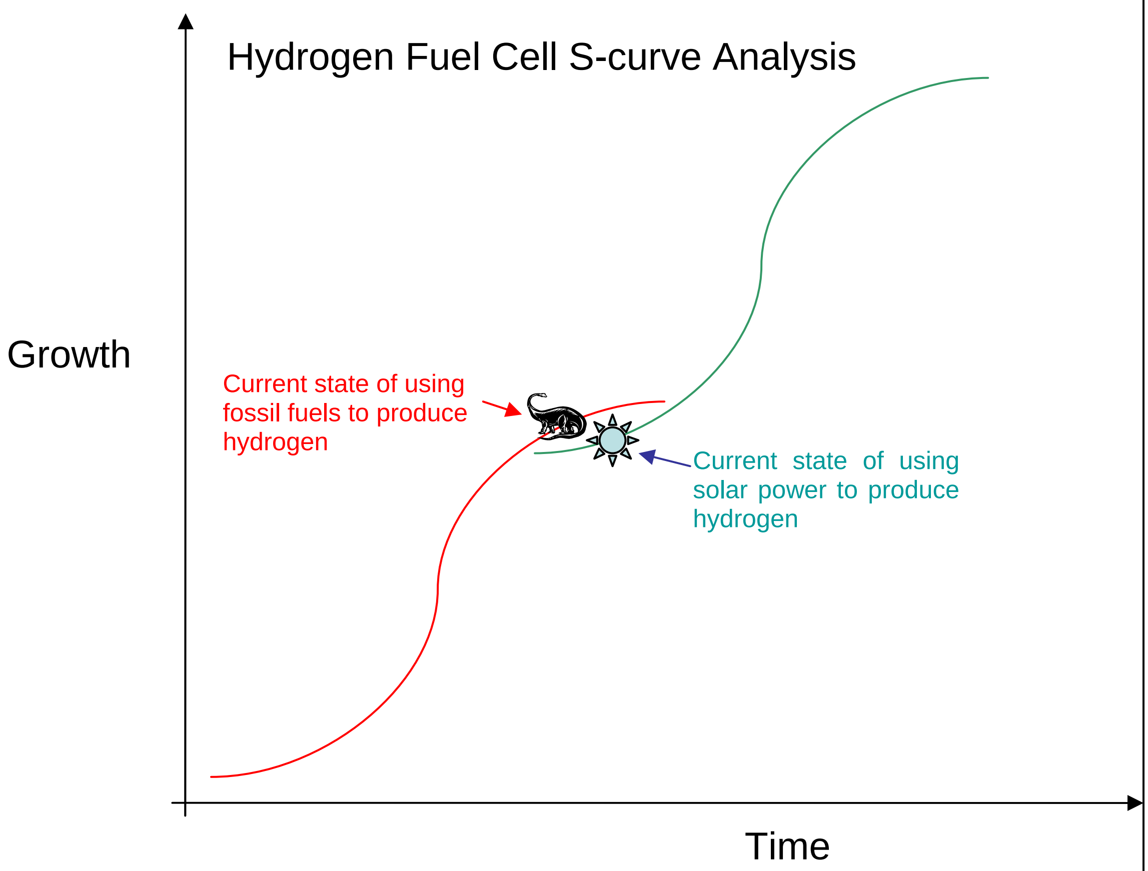



**Figure 4: Hydrogen Fuel Cells S-curve Analysis**

The current widespread use of fossil fuels to produce hydrogen in fuel cells is the maturing de-facto standard. However, the emerging evolution and advancement of solar technologies may become the next "jump" in technology to provide a fuel cell system that's clean from end-to-end. This could prove to be a disruptive technology pulling the entire innovation into a pre-paradigmatic state opening up the advancement of other competing hydrogen producing alternatives.

## 6. Closing

If innovative technologies addressing other larger concerns about hydrogen are not addressed including safety and complementary assets such as a hydrogen infrastructure, fuel cell technology could evolve away from a hydrogen system:

> "There is an energy revolution happening that is similar to what we saw with the PC revolution," says Jeremy Rifkin, president of the Foundation on Economic Trends and author of The Hydrogen Economy. "Moore's Law has set in with fuel cells," he says, referring to the falling cost and increased efficiency of fuel cell technology.
>
> The first wave of fuel cell adoption is likely to happen with miniature, methanol-based fuel cells for laptops, tablet computers, handhelds, and cell phones. Such fuel cells promise longer life and ultimately lower expenses, because methanol costs next to nothing."[10]

Regardless of which technology is adopted as the standard, the challenge of innovation to enable widespread adoption of fuel cells will persist.

[10] "Energy: Fuel Cells." 1 July 2003. Cited from http://www.pcmag.com/article2/0,1759,1130790,00.asp