

Module-5

Green Energy

Syllabus:

- Introduction
- Fuel cells: Classification of fuel cells – H₂
- Operating principles
- Zero energy Concepts
- Benefits of hydrogen energy
- Hydrogen production technologies (electrolysis method only), hydrogen energy storage
- Applications of hydrogen energy
- Problem associated with hydrogen energy.

Fuel Cell

Introduction

- A cell (or combination of cells) capable of generating an electric current by converting the chemical energy of a fuel directly into electrical energy.
- A fuel cell consists of two electrodes - an anode and a cathode - separated by an electrolyte. When fuel is supplied to the anode and oxygen is supplied to the cathode, a chemical reaction occurs that produces electricity, water, and heat. The process is clean and efficient, with little to no harmful emissions.
- Main uses of fuel cells are in power production, automobile vehicles and in special military use.
- Fuel cells have many advantages over traditional power generation technologies. They are highly efficient, with fuel-to-electricity conversion efficiencies ranging from 40% to 60%, compared to around 30% for conventional power generation. They also produce fewer greenhouse gas emissions and other pollutants, making them a cleaner alternative to fossil fuels.

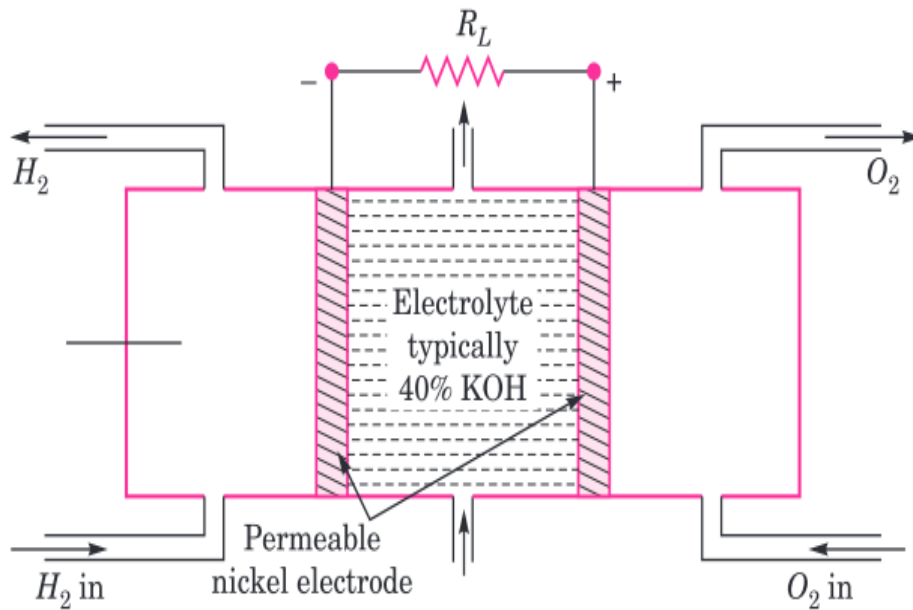


Fig. 10.1. A hydrox (H_2 , O_2 cell).

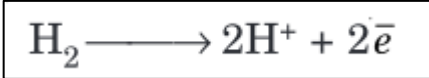
The main components of a fuel cell are:

- (i) a fuel electrode (anode),
 - (ii) an oxidant or air electrode (cathode), and
 - (iii) an electrolyte.
- In most fuel cells, hydrogen (pure or impure) is the active material at the negative electrode and oxygen (from the oxygen or air) is active at the positive electrode.
 - Since hydrogen and oxygen are gases, a fuel cell requires a solid electrical conductor to serve as a current collector and to provide a terminal at each electrode. The solid electrode material is generally porous.

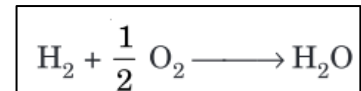
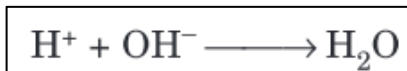
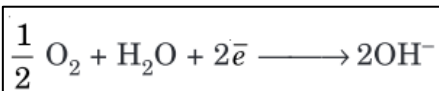
Operating Principle of Hydrogen Fuel Cell:

- The operating principle of a hydrogen fuel cell involves the electrochemical conversion of hydrogen and oxygen into electrical energy and water. This process occurs in a fuel cell stack consisting of multiple individual fuel cells.
- Each fuel cell contains an electrolyte (usually a polymer electrolyte membrane or PEM) that separates the anode and cathode. Hydrogen is fed into the anode, while oxygen from the air is fed into the cathode. A catalyst on each electrode facilitates the electrochemical reaction that converts hydrogen and oxygen into water and electrical energy.

- **At the anode:** Hydrogen molecules are separated into protons (H^+) and electrons (e^-), with the help of the catalyst. The protons pass through the electrolyte to the cathode, while the electrons travel through an external circuit to the cathode, generating electrical energy.



- **At the cathode:** the protons, electrons, and oxygen combine to form water, which is released as a by-product. The only emission from a hydrogen fuel cell is water, making it a clean and environmentally friendly energy source.



- Overall, the operating principle of a hydrogen fuel cell involves the conversion of the **chemical energy of hydrogen and oxygen into electrical energy**, with the **only by-product being water**. This process is efficient, clean, and promising for a wide range of applications.

Classification of fuel cell

1. Fuel cells may be classified according to the **temperature range** in which they operate:

- Low temperature- 25—100⁰c
- Medium temperature-100—500⁰C
- High temperature-500—1000⁰c
- Very high temperature-above—1000⁰C

2. According to the type of **electrolyte**: e.g., aqueous, non-aqueous, molten or solid.

3. According to the **physical state** of the fuel:

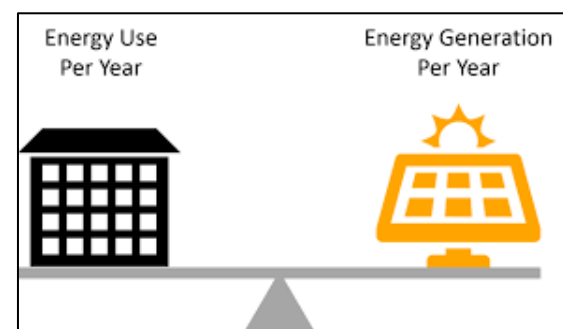
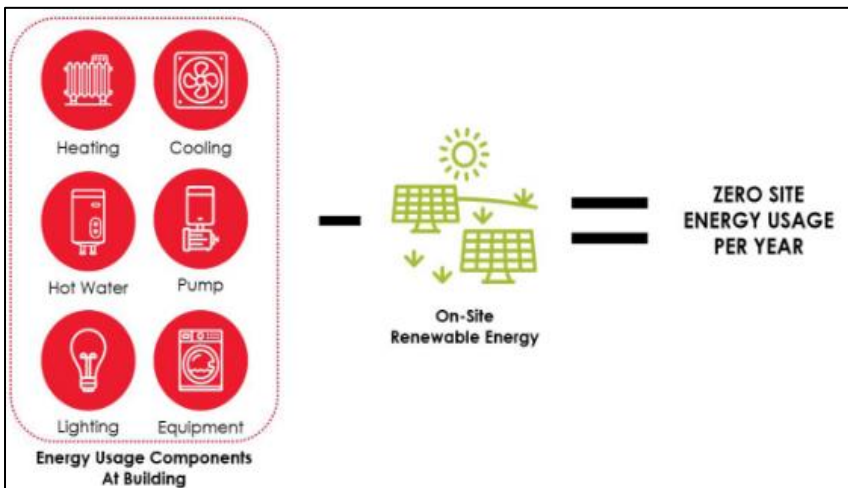
- Gas—hydrogen, lower hydrocarbons
- Liquid—alcohols, hydrazine, higher hydrocarbons
- Solid—metals etc.

4. According to **type of fuel** used

- **Hydrogen fuel cells:** These are the most common type of fuel cells and use hydrogen as fuel. Hydrogen fuel cells produce electricity by combining hydrogen and oxygen to form water, with no harmful emissions. These fuel cells are used in a range of applications, including transportation, stationary power generation, and portable electronics.

- **Methanol fuel cells:** Methanol fuel cells use methanol as fuel and produce electricity through a chemical reaction with oxygen. Methanol fuel cells are mainly used in portable devices, such as laptops and cell phones.
- **Direct Methanol Fuel Cells (DMFCs):** DMFCs are a type of methanol fuel cell that directly convert methanol into electricity without the need for a reformer. DMFCs have a lower energy density than hydrogen fuel cells, but they are simpler, more compact, and can be used in portable devices.
- **Natural gas fuel cells:** Natural gas fuel cells use natural gas as fuel and are mainly used in combined heat and power (CHP) applications. These fuel cells are highly efficient and produce both electricity and heat for buildings and other facilities.
- **Proton Exchange Membrane (PEM) fuel cells:** PEM fuel cells use hydrogen as fuel and a PEM electrolyte to generate electricity. PEM fuel cells are compact, lightweight, and have a fast startup time, making them ideal for transportation applications such as fuel cell vehicles.
- **Solid Oxide Fuel Cells (SOFCs):** SOFCs operate at high temperatures and use a solid oxide electrolyte. They can use a variety of fuels, including hydrogen, natural gas, and biofuels. SOFCs are used in stationary power generation and distributed energy applications.

Zero-energy concept



- The **zero-energy concept**, also known as net-zero energy or zero-net-energy, refers to a building or community that produces as much energy as it consumes on an annual basis. This is achieved through a combination of energy-efficient design, the use of renewable energy sources, and energy storage technologies.
- A zero-energy building typically has a highly insulated and airtight building envelope, efficient lighting and HVAC systems, and uses renewable energy sources such as solar, wind, or geothermal to generate electricity.

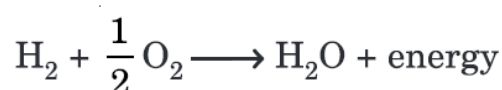
- In some cases, the building may also include energy storage technologies such as batteries or thermal storage to store excess energy for use when needed.
- The goal of zero-energy buildings is to reduce reliance on non-renewable energy sources and to minimize greenhouse gas emissions associated with energy consumption.
- Zero-energy buildings are becoming increasingly popular, particularly in commercial and institutional settings, as building owners and occupants become more aware of the environmental and economic benefits of sustainable buildings.
- The zero-energy concept can also be applied to communities, where a group of buildings or homes collectively produce as much energy as they consume. In this scenario, energy can be shared among buildings within the community, allowing for greater efficiency and flexibility in energy production and consumption.
- Overall, the zero-energy concept represents a shift towards more sustainable and efficient energy use, and has the potential to reduce reliance on fossil fuels, mitigate climate change, and improve energy security.

Introduction to Hydrogen Energy

- Hydrogen as an energy carrier can play an important role as an alternative to conventional fuels, provided its technical problems of production, storage and transportation can be resolved satisfactorily and the cost could be brought down to acceptable limits.
- One of the most attractive features of hydrogen as an energy carrier is that it can be produced from water which is abundantly available in nature.
- Hydrogen has the highest energy content per unit of mass of any chemical fuel and can be substituted for hydrocarbons in a broad range of applications, often with the increased combustion efficiency.

Its burning process is non-polluting and it can be used in the fuel cells to produce both electricity and useful heat.

- Use of hydrogen as an energy source involves five basic issues:
 - (1) Production (2) Storage and transportation (3) Safety and Management
 - (4) Utilization (5) Economy.
- The hydrogen can be used as a fuel directly, or it might be used as a raw material to produce methanol, ammonia, or hydrocarbons by using either carbon dioxide or nitrogen from the atmosphere.
- The combination of hydrogen with oxygen (e.g., from air) results in the liberation of energy, with water as the sole material product; thus,



- The reaction can be carried out and the energy made available in several different ways, so that hydrogen is a versatile fuel material.

Benefits of Hydrogen Energy

1. Use of hydrogen greatly reduces pollution:

When hydrogen is combined with oxygen in a fuel cell, energy in the form of electricity is produced. This electricity can be used to power vehicles, as a heat source, and for many other uses, only by-products are water and heat.

2. Hydrogen can be produced locally from numerous sources:

Hydrogen can be produced either centrally, and then distributed, or onsite where it will be used. Hydrogen gas can be produced from methane, gasoline, biomass, coal, or water.

3. A sustainable production system if hydrogen is produced from electrolysis of water:

Electrolysis is the method of separating water into hydrogen and oxygen. Renewable energy can be used to power electrolyzers to produce hydrogen from water. Using renewable energy provides a sustainable system that is independent of petroleum products and is non-polluting. After the hydrogen is produced in an electrolyser, it can be used in a fuel cell to produce electricity. The by-products of the fuel cell process are water and heat.

4. Efficiency:

Hydrogen fuel cells can be up to twice as efficient as internal combustion engines, making them a highly efficient energy source. Additionally, using hydrogen in combined heat and power (CHP) applications can further increase efficiency by generating both electricity and heat.

5. Versatility:

Hydrogen can be used in a variety of applications, from powering vehicles and homes to providing backup power for critical infrastructure. It can also be used to store and transport energy generated from renewable sources, helping to integrate intermittent renewable energy sources into the grid.

6. Scalability:

Hydrogen has the potential to scale up to meet global energy demands, with a wide range of potential applications in transportation, industry, and power generation.

7. Durability:

Hydrogen fuel cells have a longer lifespan than traditional batteries and can operate for thousands of hours without degradation.

Hydrogen Production Technologies

These processes can be divided into three major research areas:

1. Thermochemical production technologies

2. Electrolytic production technologies

3. Photolytic production technologies

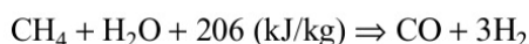
1. Thermochemical Production Technologies

Hydrogen bound in organic matter and in water makes up 70% of the earth's surface. Breaking up these bonds in water allows us produce hydrogen, and then, to use it as a fuel. There are numerous processes that can be used to break these bonds.

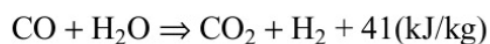
i. Steam Reforming

Steam reforming uses thermal energy to separate hydrogen from the carbon components in methane and methanol and involves the reaction of these fuels with steam on catalytic surfaces. The first step of the reaction decomposes the fuel into hydrogen and carbon monoxide. Then, a 'shift reaction' changes the carbon monoxide and water to carbon dioxide and hydrogen. These reactions occur at temperatures of 200⁰C or greater. 90% of hydrogen production worldwide is by Steam reforming.

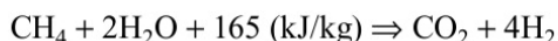
The endothermic reforming reaction is:



It is usually followed by the exothermic shift reaction:



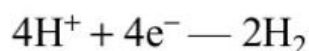
The overall reaction is:



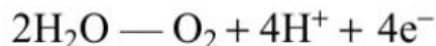
ii. Partial Oxidation or Ceramic Membrane Reactor

In the partial oxidation process, natural gas (or other liquid or gaseous hydrocarbons) and oxygen are injected into a high-pressure reactor. The oxygen to carbon ratio is optimally set for maximizing the yield of CO and H₂ and avoiding the formation of soot. In a PEM electrolyzer, the mobile ion is a proton in an electrolyte that is a proton-conducting polymer membrane. In this case, the reactions at the electrodes are as follows:

Cathode reaction



anode reaction



iii. Water Electrolysis

Until the 1950s, water electrolyzers were in widespread use for hydrogen (or oxygen) production. Currently, electrolysis provides only a small percentage of the world's hydrogen, most of which is supplied to applications requiring small volumes of high purity hydrogen (or oxygen, such as for breathing atmospheres for submarines).

iv. Steam Electrolysis

Steam electrolysis is a variation of the conventional electrolysis process. Some of the energy needed to split the water is added as heat instead of electricity, making the process more efficient than conventional electrolysis. At 2,500⁰C, water decomposes into hydrogen and oxygen. This heat could

be provided by a solar energy concentrating device to supply the heat. The problem here is to prevent the hydrogen and oxygen from recombining at the high temperatures used in the process.

v. Photoelectrolysis

Multi-junction cell technology developed by the PV industry is being used for photoelectro-chemical (PEC) light harvesting systems that generate sufficient voltage to split water and are stable in a water or electrolyte environment.

vi. Thermochemical water splitting

Thermochemical water splitting uses chemicals such as bromine or iodine assisted by heat. This causes the water molecule to split. It takes several steps—usually three—to accomplish this entire process.

vii. Biological and Photobiological process:

Certain photosynthetic microbes produce hydrogen in their metabolic activities using light energy. By employing catalysts and engineered systems, hydrogen production efficiency could reach 24%. Photobiological technology holds great promise but because oxygen is produced long with the hydrogen, the technology must overcome the limitation of oxygen sensitivity of the hydrogen-evolving enzyme systems.

Electrolysis or the Electrolytic Production of Hydrogen

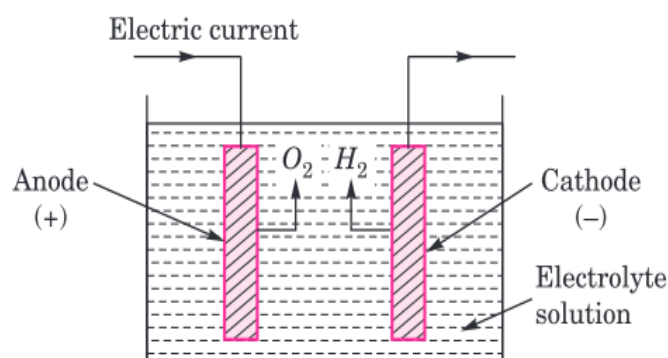


Fig. 11.1. Simple electrolytic cell.

- The process of splitting water into hydrogen and oxygen by means of a direct electric current is known as electrolysis; this is the simplest method of hydrogen production.
- In principle, an electrolysis cell consists of two electrodes, commonly flat metal or carbon plates, immersed in an aqueous conducting solution called the electrolyte.
- A source of direct current voltage is connected to the electrodes so that an electric current flows through the electrolyte from the positive electrode (or anode) to the negative electrode (or cathode).
- As a result, the water in the electrolyte solution is decomposed into hydrogen gas (H_2) which is released at the cathode, and oxygen gas (O_2); released at the anode.
- Although only the water is split, an electrolyte (e.g., KOH solution) is required because water itself is a very poor conductor of electricity.

- Ideally, a voltage of 1.23 volts should be sufficient for the electrolysis of water at normal temperature and pressure.
- For various reasons, especially the slowness of the electrode processes that lead to the liberation of hydrogen and oxygen gases, higher voltages are required to decompose water.
- The decomposition voltage increases with the current density (i.e., the current per unit (area of electrode)).
- Since the rate of hydrogen production is proportional to the current strength, a high operating current density is necessary for economic reasons.
- Hence, in practices the decomposition voltage (per cell) is usually around 2 volts. Theoretically, 2.8 kW-hr of electrical energy should produce one cu.m. of hydrogen gas.
- Because of the higher than ideal decomposition voltage, however the actual electrical energy requirement is generally from 3.9 to 4.6 kW-hr per cu.m.). This means that the efficiency of electrolysis (i.e., the proportion of the energy supplied that is used in electrolysis) is roughly 60 to 70%.

Hydrogen Energy Storage

1. Compressed Gas and Liquid Hydrogen Storage Tanks

- Hydrogen has a very high energy content by weight, but it has a very low energy content by volume. This makes hydrogen a challenge to store.
- Liquefied hydrogen is denser than gaseous hydrogen, and thus, it contains more energy in a given volume.
- Similar sized liquid hydrogen tanks can store more hydrogen than compressed gas tanks, but it takes energy to liquefy hydrogen.
- However, the tank insulation required to prevent hydrogen loss adds to the weight, volume, and costs of liquid hydrogen tanks.

2 Materials-based Storage

- Hydrogen can be stored in materials by following different processes. It can be stored on the surfaces of solids (by adsorption process) or within solids (by absorption process).
- In **adsorption process**, hydrogen attaches to the surface of a material either as hydrogen molecules (H_2) or hydrogen atoms (H). This is also referred to as surface adsorption storage.
- In **absorption process**, hydrogen molecules dissociate into hydrogen atoms that are incorporated into the solid lattice framework. This is also known as intermetallic hydride storage. This method may make it possible to store larger quantities of hydrogen in smaller volumes at low pressure and at temperatures close to room temperature.
- Finally, hydrogen can be strongly bound within molecular structures, as chemical compounds containing hydrogen atoms in the form of compressed gas or cryogenic liquid.

3 Methods of Hydrogen Energy Storage

Based on the above mentioned processes, methods of hydrogen energy storage may be classified as follows:

1. Compression

- The hydrogen can be compressed into containers or underground reservoirs. This is a relatively simple technology, but the energy density and efficiency (65%—70%) are low.
- Further, problems have occurred with the mechanical compression. However, this is, at present, the most common form of hydrogen storage for the transport industry, with the hydrogen compressed to approximately 700 bar (the higher the storage pressure, the higher the energy density).
- However, the energy required for the compression is a major drawback.

2. Liquefied Hydrogen

- The hydrogen can be liquefied by pressurising and cooling. Although the energy density is improved, it is still four times less than conventional petrol. Further, keeping the hydrogen liquefied is very energy intensive, as it must be kept below 20.27K

3. Metal Hydrides

- Certain materials absorb molecular hydrogen such as nanostructured carbons and clathrate hydrate. By absorbing the hydrogen in these materials, it can be easily transported and stored.
- Once required, the hydrogen is removed from the parent material. The energy density is similar to that obtained for liquefied hydrogen.
- The extra material required to store the hydrogen is a major problem with this technique, as it creates extra costs and mass.
- This is still a relatively new technology, and therefore, with extra development, it could be a viable option, especially if the mass of material is reduced.
- Carbon-based absorption can achieve higher energy densities but it has higher costs and even lesser demonstrations. Both the metal-hydride and carbon-based absorption use thermal energy.
- This thermal heat could be got from the waste heat of other processes with HESS, such as the electrolyser or fuel cell, to improve overall efficiency.

Use of Hydrogen Energy

- Hydrogen is being used to power commercial buses both by internal combustion engines burning a combination of hydrogen and other fuels and solely by hydrogen used in fuel cells.
- Hydrogen is used in many commercial applications from welding metal to dying fabrics for making electronics, plastics, and fertilizers.
- When a renewable economically viable production process of hydrogen can be achieved, the advantages will be spread out to many industries.

- Some of the proving grounds for various production methods can be locally developed to provide hydrogen for these industries. Hydrogen can be used as a mobile source of power for transportation by being compressed and stored in small tanks for applications similar to gasoline or propane.
- The following are the two superior ways of using hydrogen energy:
- ✓ **Internal combustion engine (ICE):** It is expected that the ICE will act as a transition technology while fuel cells are improving, because the modifications required to convert an ICE to operate on hydrogen are not very significant.
- ✓ **Fuel cell (FC):** It is expected to be the generator of choice for future hydrogen-powered energy applications owing to its virtually emission-free, efficient, and reliable characteristics. A fuel cell converts stored chemical energy, in this case hydrogen, directly into electrical energy.

Applications of Hydrogen Energy

1. At Home Sector

Fuel cells are ideal for residential zones. They are virtually silent with no moving parts and provide reliable power 24/7. In addition, a fuel cell, which is large enough to power an entire home, is about the size of a traditional AC unit. Fuel cells already power thousands of homes in Japan and are beginning to power similarly in the United States.

2 At Work Sector

Fuel cells can be produced in stacks large enough to power the large office buildings, but only occupy the area of couple of parking spaces. Again, fuel cells are a great fit in this situation, as they are noiseless, environmentally friendly, and efficient. Distributed power from fuel cells does not rely on transmission lines, and thus eliminates the need for backup power generators.

3 At Transport and Industrial Sectors

Fuel cells are just as mobile as human beings. Fuel cells can power cars, buses, airplanes, cell phones, laptops, and more. With nearly 10 times the lifespan of batteries on a single charge, fuel cells can keep powered no matter where the road takes the transport vehicles.

Advantages of Hydrogen Energy

1. Uncoupling of primary energy sources and utilization.
2. Hydrogen is a gas; thus, it is easier to store than to store electricity.
3. Hydrogen can be obtained from any primary energy source, including renewable energy source.
4. Decentralized production is possible. Hydrogen is viewed as capable of providing services where electricity is not available, in particular as a fuel for vehicles and energy storage in remote areas.
5. Very efficient when used in fuel cells.
6. Very good experience of hydrogen as a chemical reactant (ammonia, methanol, and oil refining)
7. Very good safety records (for a specific range of applications).

Disadvantages of Hydrogen Energy

1. Poor overall energy efficiency when produced from electricity made with fossil fuels.
2. Very low density and poor specific volume energy density.
3. Need for high pressures and very low temperatures if stored in the liquid phase.
4. Specific safety problems and poor public acceptance (Hindenburg syndrome and Apollo Challenger space shuttle).
5. No existing infrastructures for transport, distribution, and storage.
6. Rather high cost (till today).

Problems Associated With Hydrogen Energy

The serious problems that are affecting the development of hydrogen for household and transport applications are as follows:

1. **Hydrogen storage:** The concerns surrounding the storage of hydrogen are a major issue. It must be stored at extremely low temperatures and high pressure. A container capable of withstanding these specifications is larger than a standard gas tank. Hydrogen storage could be viewed as a problem by consumers.
2. **High reactivity of hydrogen:** Hydrogen is extremely reactive. It is combustible and flammable. The Hindenburg disaster, where a hydrogen-filled blimp exploded and many people died, has caused a fear of hydrogen
3. **Cost and methods of hydrogen fuel production:** Current production of hydrogen takes a lot of energy. If one has to burn fossil fuels to make hydrogen, what has really gained? New, clean energy technology or hydrogen production methods will need to be developed for hydrogen vehicles to make sense.
4. **Consumer demand:** Another problem for hydrogen fuel is consumer demand and the cost to change all gasoline filling stations and vehicle production lines into hydrogen. The major transport companies will not start to produce hydrogen vehicles until there is consumer demand. Why would a person pay for an expensive hydrogen vehicle?
5. **Cost of changing the infrastructure:** To accommodate hydrogen equipment and appliances.