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# Hydrogen Fuel Cell: Alternative to conventional fuels

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***Abstract:***
*The hazardous effects of pollutants from conventional fuel vehicles have caused the scientific world to move towards environmentally friendly energy sources. Though we have various renewable energy sources, the perfect one to use as an energy source for vehicles is hydrogen. Like electricity, hydrogen is an energy carrier that has the ability to deliver incredible amounts of energy. Onboard hydrogen storage in vehicles is an important factor that should be considered when designing fuel cell vehicles. In this study, a recent development in hydrogen fuel cell engines is reviewed to scrutinize the feasibility of using hydrogen as a major fuel in transportation systems. A fuel cell is an electrochemical device that can produce electricity by allowing chemical gases and oxidants as reactants. With anodes and electrolytes, the fuel cell splits the cation and the anion in the reactant to produce electricity. Fuel cells use reactants, which are not harmful to the environment and produce water as a product of the chemical reaction. As hydrogen is one of the most efficient energy carriers, the fuel cell can produce direct current (DC) power to run the electric car. By integrating a hydrogen fuel cell with batteries and the control system with strategies, one can produce a sustainable hybrid car.*
***Key word:*** *Renewable energy source; hybrid car; specific heat ratio;stoichiometric mixture;, gasification*

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## I. Introduction

Energy is a factor determining a country's economy, infrastructure, transportation, and standard of life. The problem faced globally is the disparity between the consumption and the availability of energy. All nations are presently depending upon fossil fuel for the energy production, and these fossil fuels are not sustainable sources. To supply the energy demands of the more rapidly increasing global population, it is essential to upgrade to an alternative, sustainable energy source that does not negatively affect the environment. In recent decades, the United States has been putting emphasis on the environmental impact of the transportation sector and reducing petroleum dependence. Depletion on non-renewable conventional fuels is one of the main issues of the modern energy scenario, which makes the state of the energy industry unsustainable, and it also causes environmental problems such as the greenhouse effect. Today, the proportion of fossil fuel use is still high, and it is projected that it will account for approximately 75% of energy production in 2050. Overall, the current energy scenario has many downsides. However, there exist many sustainable energy sources, and if their use increases, the scenario will be much more optimistic for future generations. It is predicted by environmentalists that the worst-case scenario of global warming and its effect will not be reached because of different initiatives. Over the last two decades, vehicles have become more fuel efficient, and hybrid electric vehicles are becoming more common. One of the fastest growing alternative energies in vehicles is electricity. As with conventional energy sources such as petroleum and coal, electricity is not a primary energy source. A fully charged battery is an energy carrier. Battery electric vehicles (BEVs) are highly efficient at converting energy from the grid into tractive force, and they can recover energy during drives by utilizing regenerative braking. One major drawback of BEVs is that they usually have a limited range due to the size and the cost of batteries necessary for vehicle power and energy requirements. The "refuelling" of the battery systems can also take several hours, rather than a few minutes with a conventional vehicle (CV). To use advantages of both electric and conventional vehicles and to bridge the gap between CVs and BEVs, an alternative is considered. Hydrogen is a chemical energy carrier that has the capability to produce electricity up to 39.39 kWh/kg, which surpasses the energy density of most batteries. A fuel cell (FC) has a direct analogy to an internal combustion engine (ICE). An ICE converts chemical energy stored in the fuel supplied to the engine to produce rotational mechanical energy. The rotational energy produced is then either used to propel a vehicle or focused through a generator and converted into electrical energy. An FC acts much in the same way as an ICE in that chemical energy is directly converted into electrical energy in the FC, but in an environmentally friendly process. Unlike a battery that drains while it used to power electrical components, internal combustion engines and fuel cells act as continually operational power sources as long as fuel is being provided to them. Hence, it is projected that the hydrogen fuel cell can overcome the disadvantages of BEVs, making hydrogen the transportation fuel of the future.

## II. Hydrogen as a fuel in internal combustion engines

In the following sub-sections several aspects that are related to the use of hydrogen as a fuel in internal combustion engine will be discussed further the discussion includes properties of combustive hydrogen, engine components, emission production, power output, cost, people acceptability of hydrogen fuelling station and lifecycle of hydrogen. engines and fuel cells act as continually operational power sources as long as fuel is being provided to them. Hence, it is projected that the hydrogen fuel cell can overcome the disadvantages of BEVs, making hydrogen the transportation fuel of the future.

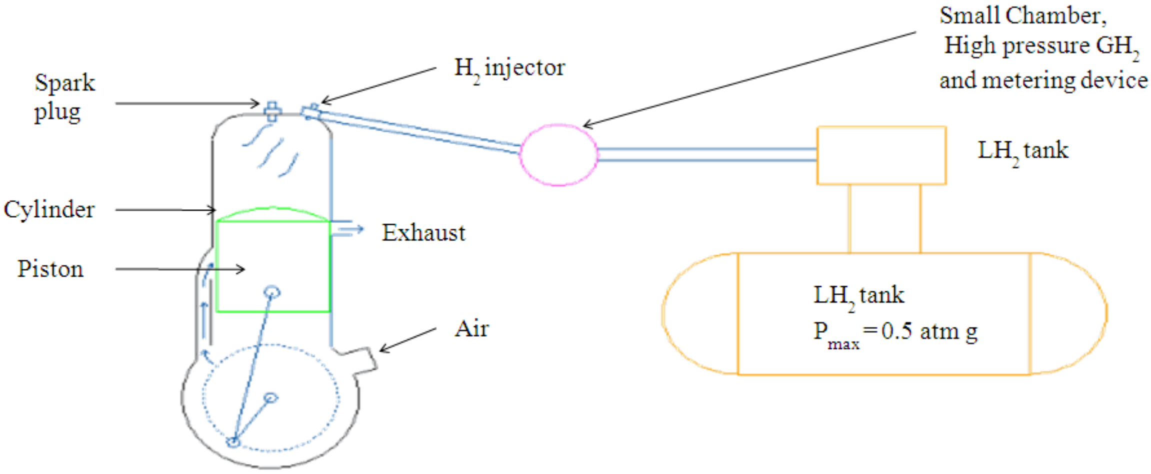


**Figure no 1**: Liquid hydrogen storage and gaseous hydrogen injection

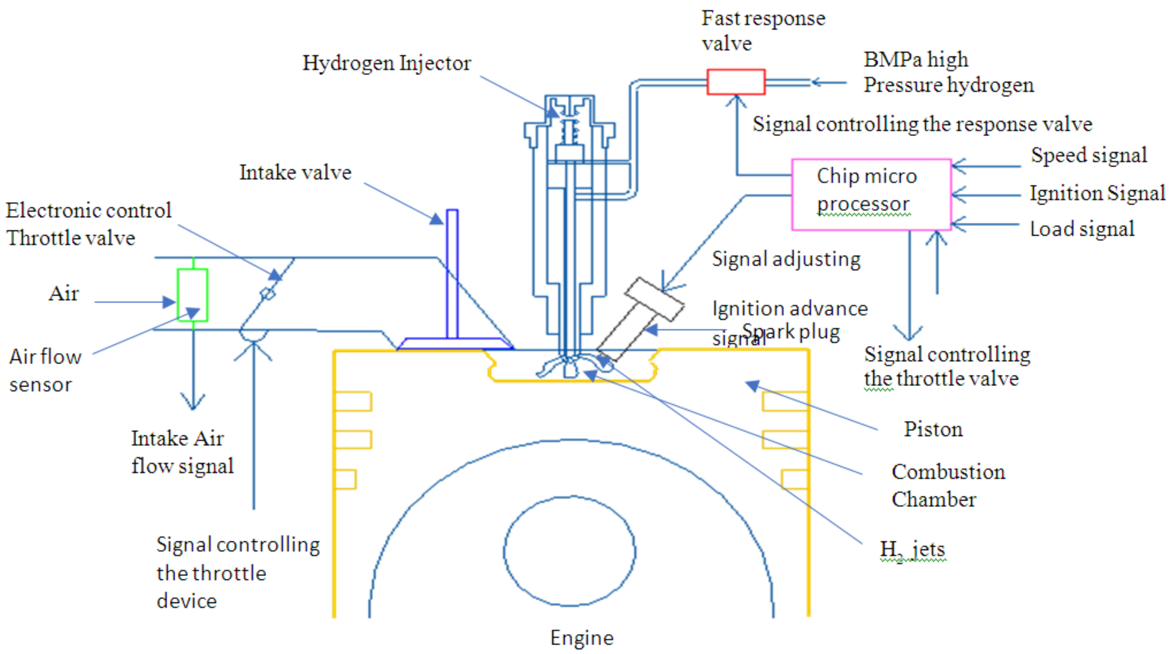


**Figure no 2:** Hydrogen induction in spark ignition engine

## II. Hydrogen as a fuel in internal combustion engines

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**(a)Engine concept:**
Hydrogen can be used in SI engine by three methods:
(i) By manifold induction:
Cold hydrogen is introduced through a valve-controlled passage into the manifold.
(ii) By direct introduction of hydrogen into the cylinder
Hydrogen is stored in the liquid form, in a cryogenic cylinder. A pump sends this liquid through a small heat exchanger where it is converted into cold hydrogen gas. The metering of hydrogen is also done in this unit. The cold hydrogen helps to prevent pre-ignition and also reduces NO formation.
xformation.
The arrangement of liquid hydrogen storage and details of hydrogen induction into the SI engine cylinder can be seen in figure number 1 and 2, respectively
(iii) By supplementing gasoline
Hydrogen can also be used as an add-on fuel to gasoline in SI engine. In this system, hydrogen is inducted along with gasoline, compressed and ignited by a spark

**(b) Combustive Properties of Hydrogen:**
Some properties of hydrogen are listed in Table 1 in comparison with iso-octane and methane, which are representing as the natural gas and gasoline, respectively. Table 2 shows the mixture properties of hydrogen–air when operated at lean and stoichiometric mixture in comparison with iso-octane–air and methane–air at stoichiometric mixture.

**Table no 1**: Hydrogen properties compared with methane and iso-octane properties. Data given at 300 K and 1 atm, taken from [2]

| Property | Hydrogen | Methane | Iso-octane |
|---|---|---|---|
| Molecular weight (g/mol) | 2.016 | 16.043 | 114.236 |
| Density (kg/m3) | 0.08 | 0.65 | 692 |
| Mass diffusivity in air (cm2/s) | 0.61 | 0.16 | -0.07 |
| Minimum ignition energy (ml) | 0.02 | 0.28 | 0.28 |
| Minimum quenching distance (mm) | 0.64 | 2.03 | 3.5 |
| Flammability limits in air (vol%) | 4.75 | 5-15 | 1.1-6 |
| Flammability limits (λ) | 10-0.14 | 2-0.6 | 1.51-0.26 |
| Flammability limits (ψ) | 0.1-7.1 | 0.5-1.67 | 0.66-3.85 |
| Lower heating value (MJ/kg) | 120 | 50 | 44.3 |
| Auto-ignition temperature in air (K) | 858 | 723 | 550 |
| Flame velocity (ms -1) | 1.85 | 0.38 | 0.37-0.43 |
| Higher heating value (MJ/kg) | 142 | 55.5 | 47.8 |
| Stoichiometric air-to-fuel ratio (kg/kg) | 34.2 | 17.1 | 15 |
| Stoichiometric air-to-fuel ratio (kmol/kmol) | 2.387 | 9.547 | 59.666 |

**Table no. 2 :** Mixture properties of hydrogen-air, methane-air, and iso-octane-air. Data given at 300 K and 1 atm (with the exception of the laminar burning velocity, given at 360 K and 1 atm) [2]

| Property | $H_2$-air<br>λ=1<br>ψ=1 | $H_2$-air<br>λ=4<br>ψ=0.25 | CH4-air<br>λ=1<br>ψ=1 | C8H18-air<br>λ=1<br>ψ=1 |
|---|---|---|---|---|
| Volume fraction fuel (%) | 29.5 | 9.5 | 9.5 | 1.65 |
| Mixture density (kg/m³) | 0.85 | 1.068 | 1.123 | 1.229 |

| | | | | |
|---|---|---|---|---|
| Kinematic viscosity (mnr/s) | 21.6 | 17.4 | 16 | 15.2 |
| Auto-ignition temperature (K) | 858 | >858 | 813 | 690 |
| Adiabatic flame temperature (K) | 2390 | 1061 | 2226 | 2276 |
| Thermal conductivity (102 W/mK) | 4.97 | 3.17 | 2.42 | 2.36 |
| Thermal diffusivity (mm2/s) | 42.1 | 26.8 | 20.1 | 18.3 |
| Ratio of specific heats | 1.401 | 1.4 | 1.354 | 1.389 |
| Speed of sound (m/s) | 408.6 | 364.3 | 353.9 | 334 |
| Air-to-fuel ratio (kg/kg) | 34.2 | 136.6 | 17.1 | 15.1 |
| Mole ratio before/after combustion | 0.86 | 0.95 | 1.01 | 1.07 |
| Laminar burning velocity ~360 K (cm/s) | 290 | 12 | 48 | 45 |
| Gravimetric energy content (kJ/kg) | 3758 | 959 | 3028 | 3013 |
| Volumetric energy content (kJ/m³) | 3189 | 1024 | 3041 | 3704 |

**Thermal Efficiency:**
The theoretical thermodynamic efficiency of an Otto cycle engine is based on the compression ratio of the engine as shown in Eq.

$$\eta_{th} = 1 - \left(\frac{1}{r^c}\right)^{\gamma-1}$$

The higher compression ratio $r^c$ and/or the specific heat ratio indicated by thermodynamic efficiency of the engine. Hydrogen (specific heat ratio = 1.4) has much simpler molecular structure than gasoline and therefore its specific–heat ratio is higher than that of gasoline (specific heat ratio = 1.1). As a result, theoretically, hydrogen engine can have higher thermal efficiency compared to gasoline engine. The high RON and low-flammability limit of hydrogen provides the necessary elements to attain high thermal efficiencies in an internal combustion engine. In DI-H2ICE, hydrogen injection at later stage of compression stroke can achieve the thermal efficiency higher than38.9% and the brake mean effective pressure 0.95 MPa.
cthespeci heat ratio
g,

**Emission Production:**
Because of the reasons that hydrogen can be produced form any kind of energy source and it is combusted without emitting carbon dioxide or soot, it is considered as an ideal alternative fuel to conventional hydrocarbon fuels. The only potential emissions are the nitrogen oxides as pollutants from hydrogen combustion, hence it becomes crucial to minimize the (NOx)emissions from the combustion of hydrogen.
Equations show the exhaust gas emission from hydrogen which is water and NOx.

$$2H_2 + O_2 = 2H_2O$$
$$H_2 + O_2 + N_2 = H_2O + N_2 + NO_x$$

The amount of $NO_x$ formed depends on;
**i.** The air/fuel ratio.
**ii.** The engine compression ratio.
**iii** The engine speed.
**iv.**The ignition timing.
**v**.Thermal dilution is utilized or not

**Power Output:**
Volumetric efficiency, fuel energy density and pre-ignition primarily determine the $H_2$ICEpeak power output. The volumetric efficiency has been proved to be the limiting factor for determining the peak power output for most of the practical applications. The displacement of intake air by the large volume of hydrogen in

the intake mixture is the reason for PFI-$H_2$ICEsto inherently fusser from volumetric efficiency. For example, about 30% of hydrogen is possessed by mixture of hydrogen and air by volume, whereas a 2% gasoline is possessed by stoichiometric mixture of fully vaporized gasoline and air by volume. The higher energy content of hydrogen partially offsets the corresponding power density loss. The stoichiometric heat of combustion per standard kg of air is 3.37 MJ and 2.83 MJ for hydrogen and gasoline, respectively. It follow that approximately 83% is the maximum power density of a pre-mixed or PFI-$H_2$CE relative to the power density of the gasoline operated identical engine. For applications where peak power output is limited by pre-ignition, $H_2$ICE power densities, relative to gasoline operation, can significantly be below 83%. For direct injection systems, which mix the fuel with the air after the intake valve closes (and thus the combustion chamber has 100% air), the maximum output of the engine can be approximately 15% higher than that for gasoline engines. Therefore, depending on how the fuel is metered, the maximum output for a hydrogen engine can be either 15% higher or 15% less than that of gasoline if a stoichiometric air/fuel ratio is u crucial to minimize the (NOx)emissions from the combustion of hydrogen. Eqs show the exhaust gas emission from hydrogen which is water and NOx used. However, at a stoichiometric air/fuel ratio, the combustion temperature is very high and as a result it will form a large amount of nitrogen oxides (NOx) which is a criteria pollutant. Since one of the reasons for using hydrogen is low exhaust emissions, therefore hydrogen engines are not normally designed to run at a stoichiometric air/fuel ratio. At this air/fuel ratio, the formation of NOx is reduced to near zero. Unfortunately, this also reduces the power output. To make up the power loss, hydrogen engines are usually larger than gasoline engines, and/or are equipped with turbochargers or supercharger.

**Table no 3 :** Cost and Emission:

| Fuel cost | 2010 (GJ) | 2030 Optimistic (GJ) | 2030 Pessimistic (GJ) | 2030 Average (G/J) | Miles (GJ) | Typical units |
|---|---|---|---|---|---|---|
| Gasoline | 12.7 | 19 | 38 | 28.5 | 253 | 40 mpg |
| Hydrogen | 42 | 14 | 56 | 35 | 506 | 72 miles/kg |
| Electric | 36 | 27 | 45 | 36 | 1013 | 3.6 miles kW/h |

**Table no 4 :** Summary of production cost, fuel cost and emissions

| | Production average cost in 2030 (RM) | Fuel costs (G/J) | Greenhouse gas emissions (kg/100 km) | Air pollution emission (kg/100 km) |
|---|---|---|---|---|
| Gasoline | 2,465 | 28.5 | 21.4 | 0.0600 |
| Hydrogen | 10,530 | 35 | 15.2 | 0.0342 |
| Electric or Battery | 7,865 | 36 | 12.0 | 0.0448 |
| Hybrid | 5,665 | 39 | 13.3 | 0.0370 |

## III. HYDROGEN PRODUCTION:

Following are some processes to produce hydrogen:

**1. Natural Gas to Hydrogen (Steam Reforming):**

Steam reforming is a hydrogen production process from natural gas. This method is currently the cheapest source of industrial hydrogen. The process consists of heating the gas to between 700–1100 °C in the presence of steam and a nickel catalyst. The resulting endothermic reaction breaks up the methane molecules and forms carbon monoxide CO and hydrogen $H_2$. The carbon monoxide gas can then be passed with steam over iron oxide or other oxides and undergo a water gas shift reaction to obtain further quantities of $H_2$. The downside to this process is that its major by products are CO, $CO_2$ and other greenhouse gases. Depending on the quality of the feedstock (natural gas, rich gases, naphtha, etc.), one ton of hydrogen produced will also produce 9 to 12 tons of $CO_2$, a greenhouse gas that may be captured.

For this process high temperature (700–1100 °C) steam ($H_2O$) reacts with methane ($CH_4$) in an endothermic reaction to yield syngas.

$$CH_4 + H_2O \rightarrow CO + 3\ H_2$$

In a second stage, additional hydrogen is generated through the lower-temperature, exothermic, water gas shift reaction, performed at about 360 °C:

$$CO + H_2O \rightarrow CO_2 + H_2$$

Essentially, the oxygen (O) atom is stripped from the additional water (steam) to oxidize CO to $CO_2$. This oxidation also provides energy to maintain the reaction. Additional heat required to drive the process is generally supplied by burning some portion of the methane.

**2. Coal Gasification:**

For the production of hydrogen from coal, coal gasification is used. The process of coal gasification uses steam and a carefully controlled concentration of gases to break molecular bonds in coal and form a gaseous mix of hydrogen and carbon monoxide. This source of hydrogen is advantageous since its main product is coal-derived gas which can be used for fuel. The gas obtained from coal gasification can later be used to produce electricity more efficiently and allow a better capture of greenhouse gases than the traditional burning of coal.

**3. Electrolysis:**

Around 8 GW of electrolysis capacity is installed worldwide, accounting for around 4% of global hydrogen production.

Electrolysis consists of using electricity to split water into hydrogen and oxygen. Electrolysis of water is 70–80% efficient (a 20–30% conversion loss) while steam reforming of natural gas has a thermal efficiency between 70–85%.[28] The electrical efficiency of electrolysis is expected to reach 82–86% before 2030, while also maintaining durability as progress in this area continues at a pace.

Water electrolysis can operate between 50–80 °C, while steam methane reforming requires temperatures between 700–1100 °C. The difference between the two methods is the primary energy used; either electricity (for electrolysis) or natural gas (for steam methane reforming). Due to their use of water, a readily available resource, electrolysis and similar water-splitting methods have attracted the interest of the scientific community. With the objective of reducing the cost of hydrogen production, renewable sources of energy have been targeted to allow electrolysis.

There are three main types of cells, solid oxide electrolyser cells (SOECs), polymer electrolyte membrane cells (PEM) and alkaline electrolysis cells (AECs). Traditionally, alkaline electrolysers are cheaper in terms of investment (they generally use nickel catalysts), but less efficient; PEM electrolysers, conversely, are more expensive (they generally use expensive platinum group metal catalysts) but are more efficient and can operate at higher current densities, and can therefore be possibly cheaper if the hydrogen production is large enough.

SOECs operate at high temperatures, typically around 800 °C. At these high temperatures a significant amount of the energy required can be provided as thermal energy (heat), and as such is termed High temperature electrolysis. The heat energy can be provided from a number of different sources, including waste industrial heat, nuclear power stations or concentrated solar thermal plants. This has the potential to reduce the overall cost of the hydrogen produced by reducing the amount of electrical energy required for electrolysis. PEM electrolysis cells typically operate below 100 °C. These cells have the advantage of being comparatively simple and can be designed to accept widely varying voltage inputs which makes them ideal for use with renewable sources of energy such as solar PV. AECs optimally operate at high concentrations electrolyte (KOH or potassium carbonate) and at high temperatures, often near 200 °C.

**4. Biomass gasification:**

Biomass can be a fuel source, derived from plant and animal wastes. From biomass, the natural gas (methane) can be obtained. Actually, methane can be obtained naturally as the waste; organic matter decays. Landfills are the places, where methane can be collected. The methane gas is used for heating and producing electricity. Biomass gasification is one of the most mature technologies to produce syn-gas. This technology is however very expensive due to high energy requirements and inherent energy losses in biomass gasification. Biomass gasification means incomplete combustion of biomass that produces combustible gases consisting of carbon monoxide (CO), hydrogen ($H_2$) and methane ($CH_4$). The mixture of combustible gases is also known as producer gas. Producer gas can be used to run both combustion engines either compression or spark ignition. The production of producer gas is called gasification. Gasification is partial combustion of biomass and is reacted in gasifier at 1000 degree Celsius. The gasification process occurs in a gasifier involving four processes; (a) drying the fuel (b) pyrolysis (c) combustion (d) reduction. Sometimes, the processes are overlapping but the processes can still be classified, happening at different zones and temperatures, based on the different chemical and thermal reactions.

**5. Photobiological water splitting:**

Biological hydrogen can be produced in an algae bioreactor. In the late 1990s it was discovered that if the algae are deprived of sulphur it will switch from the production of oxygen, i.e. normal photosynthesis, to the production of hydrogen. It seems that the production is now economically feasible by surpassing the 7–10 percent energy efficiency (the conversion of sunlight into hydrogen) barrier with a hydrogen production rate of 10–12 ml per litre culture per hour.

**6. Photocatalytic water splitting:**
The conversion of solar energy to hydrogen by means of water splitting process is one of the most interesting ways to achieve clean and renewable energy systems. However, if this process is assisted by photocatalysts suspended directly in water instead of using photovoltaic and an electrolytic system the reaction is in just one step, it can be made more efficient.

## IV. CONCLUSION

1. Hydrogen in internal combustion engines has many advantages in terms of combustive properties but it needs detailed consideration of engine design to avoid abnormal combustion which is the major problem in hydrogen engine. This, as a result can improve engine efficiency, power output and reduce NOx emissions

2. In fuel cell vehicles, the hydrogen purity can affect the performance of the fuel cell vehicles. This impurity comes from the poisoning of the sulphur during production process. From the environmental aspects, the emission of fuel cell is low as compared to conventional vehicles but as penalty, fuel cell vehicles need additional space and weight to install the battery and storage tank, thus increases it production cost.

3. The acceptability of hydrogen technology by people is through the knowledge and also the awareness of the hydrogen benefits towards environment and human life. Recent study shows that people still do not have the information of hydrogen. Media role in introducing hydrogen technology to citizens is crucial in order to get support of people in development of hydrogen technology

4. The best method to produce hydrogen is the one which has simplest process, easily to get the main sources, low cost and environmentally safe.

5. The study in the production methods, vehicle performance, plant performance, infrastructure availability, emissions and air pollution is needed, before the hydrogen fuel and vehicles can be commercialized and compete with other type of fuels.

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