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Future of Hydrogen Fuel – A Potential Contribution in India

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ABSTRACT

Negative environmental consequences of fossil fuels and concerns about petroleum supplies have spurred the search for renewable transportation alternative fuels. In India, Domestic demand for crude oil and import bill for the same moved up by 13 times in last 20 years. In 2020, India's dependency on oil imports is projected to go beyond 90% from 80% at current level. It is high time to shift for alternate fuels like Hydrogen. The use of hydrogen as an alternative fuel can significantly minimize the dependency of importing crude oil in India also increasing fuel prices will come down and it is a win-win situation for all stakeholders. Hydrogen is an attractive alternative fuel because it is produced from renewable resources, thereby providing the potential to reduce particulate emissions in compression–ignition engines. This paper explains hydrogen as a fuel along with its properties and production techniques. It is the need of hour that hydrogen friendly policies should be framed and hydrogen production is encouraged.

Keywords: Hydrogen Fuel, Production Technique, Dependency

I. INTRODUCTION

With increasing gap between the energy requirement of the industrialized world and inability to replenish such needs from the limited sources of energy like fossil fuels, ever increasing levels of greenhouse pollution from the combustion of fossil fuels in turn aggravate the perils of global warming and energy crisis . Motor vehicles account for a significant portion of urban air pollution in much of the developing world. According to Goldenberg , motor vehicles account for more than 70% of global carbon monoxide (CO) emissions and 19% of global carbon dioxide (CO2) emissions. CO2 emissions from a gallon of gasoline are about 8 kg. There are 700 million light duty vehicles, automobiles, light trucks, SUVs and minivans, on roadways around the world. These numbers are projected to increase to 1.3 billion by 2030, and to over 2 billion vehicles by 2050, with most of the increase coming in developing countries. This growth will affect the stability of ecosystems and global climate as well as global oil reserves with growing concerns for environmental pollution, energy security, and future oil supplies, the global community is seeking on-petroleum-based alternative fuels, along with more advance energy technologies, to increase energy use efficiency. Hydrogen fuel plays a very significant role in generating power. There are number of alternative fuels like (liquefied petroleum gas (LPG), biogas, compressed natural gas (CNG), biodiesel, ethanol, propane) available as a substitute for hydrocarbon based fuel, thus reducing exhaust emission. Out of this hydrogen is a long-term renewable and less pollution fuel. In addition, hydrogen having characteristics & better performance drives more interest in hydrogen fuel.

Table 1 : Energy Demand and Supply GAP

Fuel	Demand	Imports	Dependence
Oil	144.58	94	73%
Coal	190.00	54	12%
Natural Gas	42.70	81	45%

II. METHODS AND MATERIAL

A. What Is Hydrogen

Hydrogen is an element, which is denoted by 'H' having atomic number 1 and atomic mass 1.00794. The simplest and lightest fuel is hydrogen gas. It contains one proton & one electron. It also contains low-level carbon monoxide & carbon dioxide. It occurs naturally as a gas. Hydrogen is a colorless, odorless, tasteless flammable gas. It is found in water, organic compounds, biomass & hydrocarbons such as petrol, natural gas, methanol, and propane. Formula for hydrogen is $H_{2.}$ Its specific gravity is 0.07.Auto ignition temperature is 400˚c. Flammable range – upper explosive limit=74% & lower explosive limit=4%.Lower heating value of hydrogen is 51900but/lb(British thermal units per pound mass).Hydrogen mainly bounded to oxygen in the form of water (H_2O).The burning velocity is so high that very rapid combustion can be achieved. The limit of flammability of hydrogen varies from an equivalence ratio (φ) of 0.1 to 7.1 hence the Engine can be operated with a wide range of air/fuel ratio. The minimum energy required for ignition of hydrogen–air mixture is 0.02 mJ only. This enables hydrogen engine to run well on lean mixtures and ensures prompt ignition. The density of hydrogen is 0.0838 kg/m3, which is lighter than air that it can disperse into the atmosphere easily. Hydrogen has the highest energy to weight ratio of all fuels. The hydrogen can be used to create energy through combustion (combustion occurs within internal combustion engine).The energy density of hydrogen is very low under ambient conditions which prevent greater transportation & storage hurdles than for liquid fuel. Hydrogen produces only water after combustion. It is a non-toxic, non-odorant gaseous matter and also can be burn completely .When hydrogen is burned, hydrogen combustion does not produce toxic products such as hydrocarbons, carbon monoxide, and oxide of sulfur, organic acids or carbon dioxides shown in equation below.

$$2H_2+O_2=2H_2O$$

B. Suitability of Hydrogen as an Automotive Fuel

Hydrogen energy is an important part of developed nation's clean energy plan. Hydrogen is one of the best solutions which fulfill requirements - lightness, highest energy density, clean and inexhaustible. Hydrogen is high in energy contents as it contains 120.7 kilojoules/gram. This is the highest energy content per unit mass among known fuels. However, its energy content per unit volume is rather low, so it is difficult to store them. Thus, number of challenges comes to us in the storage of hydrogen for civilian applications. When burnt, hydrogen produces water as by-products & is therefore not only an efficient energy carrier & environment friendly. Hydrogen can be used for power generation & also for transport application. It is possible to use hydrogen in internal combustion engines, directly or mixed with diesel and compressed natural gas (CNG). Hydrogen can also be used directly as a fuel in fuel cells to produce electricity. Hydrogen is used as a fuel in furnaces, turbines and jet engine with more efficiency than fossil fuels (coal, petroleum & natural gas) .It also used in bikes, ships, submarines, train, airplanes and rocket as well. Combustion of hydrogen and oxygen produces a pure steam. This steam can be used for many industrial purposes. It can be used in various industries like pharmaceutical, fertilizer & food industries. Hydrogen is often mentioned as a potential solution for several challenges that global energy system is facing.

C. Properties of Hydrogen

✓ **Wide range of flammability**

Compared to nearly all other fuels, hydrogen has a wide flammability range (4-75% versus 1.4-7.6% volume in air for gasoline). This first leads to obvious concerns over the safe handling of hydrogen. But, it also implies that a wide range of fuel-air mixtures, including a lean mix of fuel to air.

✓ **Small Quenching Distance**

Hydrogen has a small quenching distance (0.6 mm for hydrogen versus 2.0 mm for gasoline), which refers to the distance from the internal cylinder wall where the combustion flame extinguishes. This implies that it is more difficult to quench a hydrogen flame than the flame of most other fuels, which can increase back fire since the flame from a hydrogen-air mixture more readily passes a nearly closed intake valve, than a hydrocarbon-air flame.

✓ **Minimum Ignition Source Energy**

The minimum ignition source energy is the minimum energy required to ignite a fuel-air mix by an ignition source such as a spark discharge. For a hydrogen and air mix it is about an order of magnitude lower than that of a petrol-air mix 0.02 mJ as compared to 0.24 mJ for petrol - and is approximately constant over the range of flammability. The low minimum ignition energy of the hydrogen-air mix means that a much lower energy spark is required for spark ignition.

✓ **High diffusivity**

Hydrogen has very high diffusivity. This ability to disperse into air is considerably greater than gasoline and is advantageous for two main reasons. Firstly, it facilitates the formation of uniform mixture of fuel and air. Secondly, if a hydrogen leak develops, the hydrogen disperses rapidly. Thus, unsafe conditions can either be avoided or minimized.

Table 2. Comparison of Physical And Chemical Properties of Selected Fuels

Property/Information	Hydrogen	CNG	Propane	Methanol	Ethanol
	H2		C3	CH3OH	C2H5OH
	(gas)	(gas)	(liquid)	(liquid)	(liquid)
Molecular Weight	2.02	16.04	44.1	32.04	46.07
Chemical Composition					
Carbon (w/w %)	0	75	82	37.5	52.2
Hydrogen (w/w %)	100	25	18	12.6	13.1
Oxygen (w/w %)	0	-	-	49.9	34.7
Freezing Pt. Temp. (˚F)	-435	-296	-305.8	-143.5	-173.2
Specific Gravity	0.07	0.424	0.508	0.796	0.794
Density (60˚F)	-	1.07	4.22	6.63	6.61
Boiling point Temp (˚F)	-423	-263.2	-44	149	172
Flammability Range (V/v %)	69.9	9.7	7.3	28.7	14.7
air/fuel ratio(w/w)	34.8	17.2	15.7	6.45	9
Flame Speed(ft/s)	10.63-14.4	1.48	1.48	1.41	-
Flame Temp, (˚F)	3722	1.48	1.48	1.41	-
Types of Shipping	Pressurized	Pressurized	pressurized	tank cars,	tank cars,
Containers	cylinders &tank cars	cylinders	cylinders, tank trucks, tank cars,	tank trucks	tank trucks
Other Information	H2gas release is very buoyant and invisible	CNG gas release is buoyant and invisible, natural gas has characteristic odor	Liquid floats & Boils on water; heavier-than-air visible vapor cloud	liquid floats & mixes with water; near neutral vapor buoyancy	liquid floats & mixes with water; near neutral vapor buoyancy

D. Hydrogen Production

Hydrogen can be produced using following resources and technology:

(a) Electrolysis (water splitting) process
(b) Coal refining (coal gasification)
(c) Naphtha from crude oil
(d) Biogas Gasification
(e) Hydrogen from biomass
(f) Natural gas refining

Hydrogen Production from Natural Gas

In 2006, the United States was estimated to have a production capacity of 11 million tons of hydrogen. The most common source is natural gas, which is usually over 85% methane (CH4) which is excellent source of hydrogen. This technology is fully commercial and reprents the most cost effective hydrogen production technology today. The hydrogen production cost is dominated by most of the natural gas prices. This hydrogen is produced with the help of 'steam methane reforming' and 'partial oxidation'

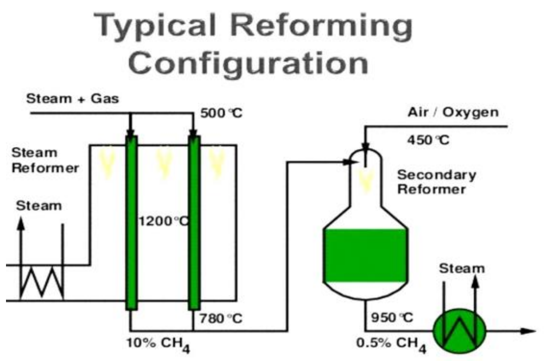


Figure 1. Typical Reforming Configuration.

✓ Steam Methane Reforming

About 95% of domestic hydrogen is produced through steam methane reforming. Steam methane reforming (CH4) is one of the most popular methods because methane has 4 hydrogen atoms for each carbon atom. Most hydrogen produced today in the United States is made via steam-methane reforming, a mature production process in which high-temperature steam (700°C–1,000°C) is used to produce hydrogen from a methane source, such as natural gas. This process consists of heating the gas in the presence of steam and a nickel catalyst. The resulting exothermic reaction breaks up the methane molecules and forms carbon monoxide CO and hydrogen H2. In steam-methane reforming, methane reacts with steam under 3–25 bar pressure (1 bar = 14.5 psi) in the presence of a nickel catalyst to produce hydrogen, carbon monoxide, and a relatively small amount of carbon dioxide. Steam reforming is endothermic i.e. heat must be supplied to the process for the reaction to proceed.

In a second stage, additional hydrogen is generated through the lower-temperature, exothermic, "water gas shift reaction", performed at about 360 °C. The carbon monoxide gas can then is passed with steam over iron oxide or other oxides and undergo a water-gas shift reaction. The carbon monoxide and steam are reacted using a nickel catalyst to produce carbon dioxide and more hydrogen.

In a final process step called "pressure-swing adsorption," carbon dioxide and other impurities are removed from the gas stream, leaving essentially pure hydrogen. The oxygen (O) atom is stripped from the additional water (steam) to oxidize CO to CO2. 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. Steam reforming can also be used to produce hydrogen from other fuels, such as ethanol, propane, or even gasoline.

Steam-methane reforming reaction

$$CH_4 + H_2O\ (+\ \text{heat}) \rightarrow CO + 3H_2$$

Water-gas shift reaction

$$CO + H_2O \rightarrow CO_2 + H_2\ (+\ \text{small amount of heat})$$

✓ Partial Oxidation

In partial oxidation, the methane and other hydrocarbons in natural gas react with a limited amount of oxygen (typically from air) that is not enough to completely oxidize the hydrocarbons to carbon dioxide and water. With less than the stoichiometric amount of oxygen available, the reaction products contain primarily hydrogen and carbon monoxide (and nitrogen, if the reaction is carried out with air rather than pure oxygen), and a relatively small amount of carbon dioxide and other compounds. Subsequently, in a water-gas shift reaction, the carbon monoxide reacts with water to form carbon dioxide and more hydrogen. The energy added to the process is achieved by the combustion of fuels, which also causes a negative impact to the environment.

Partial oxidation is an exothermic process—it gives off heat. The process is, typically, much faster than steam reforming and requires a smaller reactor vessel. As can be seen in chemical reactions of partial oxidation, this process initially produces less hydrogen per unit of the input fuel than is obtained by steam reforming of the same fuel.

Partial oxidation of methane reaction
$CH_4 + \frac{1}{2}O_2 \rightarrow CO + 2H_2$ (+ heat)

Water-gas shift reaction
$CO + H_2O \rightarrow CO_2 + H_2$ (+ small amount of heat)

E. World Hydrogen Production

The production data based on data from United States Department of Energy and consumption data are from the Ministry of Internal Trade and Industry of Japan. The statistics of hydrogen production and consumption are given in the following sections. Because most of the hydrogen is consumed on site there are not many data available and the data may not be accurate enough. Hydrogen production from various origins as shown in the following table. This data is taken from the website of U.S. Department of energy.

Table 3. Recent Worldwide Production Number For Hydrogen

Origin	Amount at normal temp. & pressure per year	Percentage
Natural Gas	240 billion m^3	48%
Oil	150 billion m^3	30%
Coal	90 billion m^3	18%
Electrolysis	20 billion m^3	4%
Total	500 billion m^3	100%

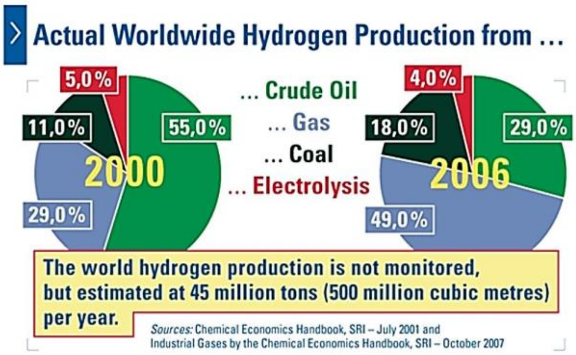


Figure 2. Actual Worldwide Hydrogen Production

F. International Senario

International Partnership on Hydrogen Economy set up in Washington D.C. in November 2003.India is one of the 16 founder member countries of IPHE (international partnership for hydrogen and fuel cells).China, India and Brazil are the three developing countries along with 13 advanced countries like USA, Japan, and European Union, UK Iceland etc. Fourth steering committee meeting of IPHE (International partnership for hydrogen and fuel cells) held in Kyoto in September 2005 in which India presented its achievements in hydrogen energy.

Table 4. Hydrogen Programmes In Major Countries

Japan	Set up hydrogen fueling stations plans to spend \$20 billion by 2020.
Germany	Largest number of demonstration of hydrogen based applications; Hydrogen fueling stations.
Iceland	Plans to be world's first hydrogen economy
USA	Annual spending around \$ 30M Hydrogen Freedom Fuel Initiative announced in January, 2003 with budget of US \$ 2.2 billion. IPHE set up in November 2003.

III. RESULTS AND DISCUSSION

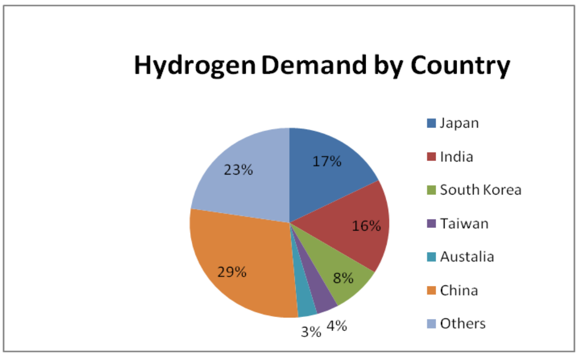
A. Demand of Hydrogen In India

Between 1998 & 2008, Indian hydrogen demand increased nearly to 19 billion cubic meters. This remarkable growth rate of growth is due to rapid increase in Indian refining capacity and the trend toward refinery modernization. Indian manufacturing continues to grow rapidly; hydrogen demand will increase at a healthy 6.1 % annual pace through 2013 to 25.8 billion cubic meters valued at$ 2.7 billion.

Table 5. India Hydrogen Demand By Market

Year	1998	2003	2008	2013	2018
Hydrogen Demand	4.2 billionm^3	12.0 billion m^3	19.2 billion m^3	25.8 billion m^3	36.0 billion m^3

Pie Chart : Hydrogen Demand by Country



B. Achievement and Importance of Hydrogen In India

Hydrogen, which is used in fuel cell, can reduce the petrol and diesel consumption by replacing petroleum based vehicles by Hydrogen based fuel vehicles. Two and three wheelers transportation hydrogen fuel provides energy security in India. Hydrogen energy which is a carbon free fuel provides a lot of security for global environmental problems. Larger areas in the country do not have a safe to electricity, thus electricity can be provided by using hydrogen energy with the help of renewable resources like solar, wind, hydro, and ocean.

India's achievement: India successfully provides hydrogen from organic wastes, which is demonstrated at pilot plant scale. Hydrogen is used in motorcycles and three wheelers; owner generating units, catalytic combustor, and air conditioning are successfully demonstrated and utilized. India developed efficient production in laboratory conditions.

C. Hydrohen Benefits

Hydrogen provides more energy than any conventional fuel. It can be refined from any substance that contains hydrogen. Hydrogen is one of the cleanest burning fuels available among all alternative fuels. It also provides health, environment and energy security. The combustion of hydrogen provides very low emissions than combustion of fuel because high pollution levels, Smog. NOx emission still occurs when the hydrogen is combusted with air.

D. Challenges

Growing gap between energy demand and supply requires production of hydrogen as an alternative fuel. As it's a new and innovative technology, there are multi-dimensional problems & number of challenges should be face by India to compete with other countries.

- Formation of high pressure vessel cylinder & tanks which is able to store good energy of hydrogen i.e. 500-700 bar.
- In larger cities where demand of hydrogen is high thus there is a requirement of long hydrogen gas pipeline with proper safety precautions.
- To reduce the cost of petroleum based IC engine by replacing it with hydrogen fuel (can be used to mix with diesel& petrol).
- Improving production of hydrogen by different methods to reduce the cost of hydrogen.
- To increase the operating life of fuel cell and made them more efficient.
- Reduce the cost of fuel cells, which is used in vehicles as compare to existing vehicles, which are used for transportation purpose.
- The quantity of hydrogen stored in vehicle should be high enough to give 150 to 500 km run per charge.
- Compact storage for which hydrogen can be easily refuels and transport.

IV. CONCLUSION

Hydrogen sale are being used promoted in the transportation sector worldwide. This is high time that India should engage in hydrogen production activity. Many research programmers recently focus on the development of Concept such as renewable resources, sustainable development, ecofriendly process etc. in the transportation sector. India has a capacity to expand hydrogen production sector by addressing concerns of all shareholders. This can significantly reduce the government money spend in importing crude oil. By empowering India's to use and produce their own limitless energy which provides a sustainable energy security for all.

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