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Review on Hydrogen as Fuel

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ABSTRACT: The Climate change is becoming a serious issue over the years. Rising CO2 levels have directly contributed to the global warming phenomenon, due to Green House effect as CO_2 and CO. And levels of these two gases are rising dramatically in the past 200 years. The main source of these two gases are combustion vehicles as fuel is burnt which produces these two gases. So, finding an alternative fuel to this is must as fuel levels are decreasing.

KEYWORDS: Renewable source, Biofuel, Hydrogen.

I. INTRODUCTION

Hydrogen fuel is a zero-carbon burnt with oxygen. In the early 2020's mostly, hydrogen is produced by steam methane reforming of fossil gas. Hydrogen is the fuel of the future. Hydrogen is an energy carrier that can be used in internal combustion engines or fuel cells producing virtually no greenhouse gas emissions when combusted with oxygen. The only significant emission is water vapour. An alternative fuel must be technically feasible, economically viable, easily convert to anther energy form when combusted, must be safe to use, and be harmless to the environment.

Hydrogen has a very high yield of energy, it has excellent air fuel ratio, it also has a high diffusivity when compared to the other fuels. This results in complete and predictable combustion. And if there is leak of the gas somewhere in the fuel system, then hydrogen will quickly disappear in the atmosphere.

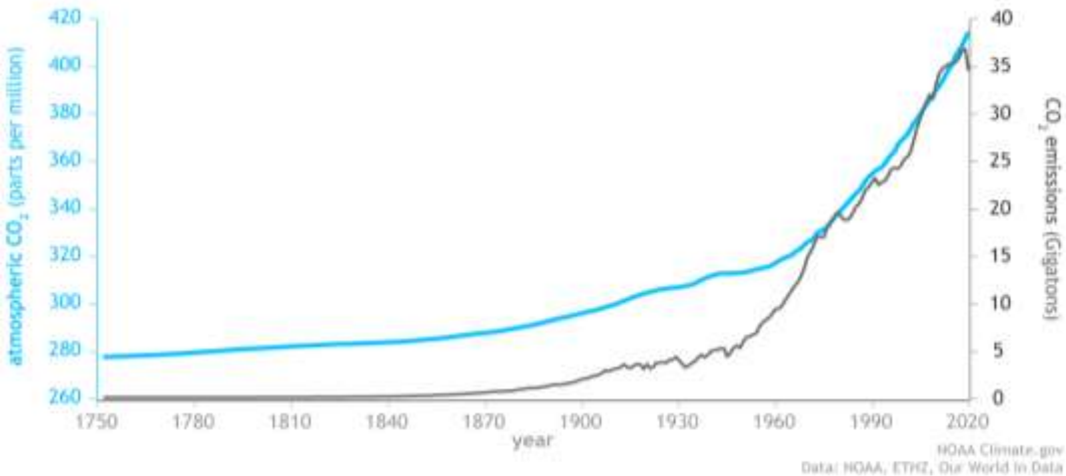

Fig:1 Concentration of CO_2

Source NOAA Climate.gov (https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide)

Advantages	Disadvantages
High energy yield (122 kJ/g).	Low density (large storage areas).
Most abundant element.	Not found free in nature.

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Wide flammability range.	Currently expensive.
High diffusivity.	Low ignition energy (similar to gasoline).
Water vapor is major oxidation product.	

Table:1 Advantagesand Disadvantages of Hydrogen as a Transportation Fuel.

Using hydrogen in the transportation sector can cut the emission by nearly 1/3 and can really help us head towards sustainable growth. Hydrogen is an energy carrier that can be produced and converted into energy through a variety of ways. Table 1 provides a brief explanation of the advantages and drawbacks of hydrogen as a transportation fuel. Electrolysis of water is deemed to be the cleanest route to the production of hydrogen. However, the advantages of this proposed hydrogen economy are dependent on the use of clean, renewable resources as the source of electricity.

II. PRODUCTION OF HYDROGEN

Production of hydrogen is from various diversified domestic resources and has a potential of nearly zero greenhouse gas emissions. More than half of the world lives in areas where pollution levels are high enough to damage public health and the surrounding environment. Emissions from diesel and gasoline vehicle such as nitrogen oxides, hydrocarbons, and particulate matter are a major source of this pollution. Hydrogen-powered fuel cell electric vehicles emit none of these harmful substances but only water (H_2O) and warm air.

1) **Natural Gas Reforming/Gasification:** Synthesis gas—a mixture of hydrogen, carbon monoxide, and a small amount of carbon dioxide—is created by reacting natural gas with high-temperature steam. The carbon monoxide is reacted with water to produce additional hydrogen. This method is the cheapest, most efficient, and most common.

A synthesis gas can also be created by reacting coal or biomass with high-temperature steam and oxygen in a pressurized gasifier. This converts the coal or biomass into gaseous components a process called **gasification**. The resulting synthesis gas contains hydrogen and carbon monoxide, which is reacted with steam to separate the hydrogen.

2) **Electrolysis:** An electric current splits water into hydrogen and oxygen. If the electricity is produced by renewable sources, such as solar or wind, the resulting hydrogen will be considered renewable as well, and has numerous emissions benefits. Power-to-hydrogen projects are taking off, using excess renewable electricity, when available, to make hydrogen through electrolysis.
3) **Renewable Liquid Reforming:** Renewable liquid fuels, such as ethanol, are reacted with high-temperature steam to produce hydrogen near the point of end use.
4) **Fermentation:** Biomass is converted into sugar-rich feedstocks that can be fermented to produce hydrogen.

Several hydrogen production methods that are in development:

1) **High-Temperature Water Splitting**: High temperatures generated by solar concentrators or nuclear reactors drive chemical reactions that split water to produce hydrogen.
2) **Photobiological Water Splitting:** Microbes, such as green algae, consume water in the presence of sunlight and produce hydrogen as a by-product.
3) **Photoelectrochemical Water Splitting:** Photoelectrochemical systems produce hydrogen from water using special semiconductors and energy from sunlight.

Method	Process Reaction
Steam reforming of methane gas	In presence of nickel catalyst & at 700 – 1100°C CH4(g) + H2O(g) →CO(g) + 3H2(g) Next reaction at lower temperature: CO(g) + H2O(g) → CO2(g) + H2(g)
Hydrogen from coal (Gasification)	At high temperature and pressure: Coal + H2O(g) + O2(g) →Syngas Syngas = H2 + CO + CO2 + CH4
Electrolysis of water	Electric current passed through water:

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	2H2O(l) →2H2(g) + O2(g)
Fermentation	$C_6H_{12}O_6 + 2\ H_2O \rightarrow 2\ CH_3CO_2H + 2\ CO_2 + 4\ H$

Table: 2 Methods to Produce Hydrogen.

III. STORAGE FORMS OF HYDROGEN.

Other than the production of hydrogen one of the major highlights, being its storage and transportation because of its low density

Storage Form	Advantages	Disadvantages
Compressed Gas	Reliable. Indefinite storage time. Easy to use.	Higher capital & operating costs. Heat can cause container rupture.
Liquid	High density at low pressure.	High cost. Low temperatures needed. Escape can cause fire or asphyxiation.
Metal Hydride	High volume efficiencies Easy recovery Very safe	Expensive materials Heavy storage tanks

Table: 3Storage Forms of Hydrogen.

The use of metal hydrides is the most promising storage material currently. The advantages are high volume efficiencies, easy recovery, and advanced safety.

Metal	Hydride	% Hydrogen by mass	Equilibrium Pressure (bar)	Equilibrium Temperature (K)
Pd	$PdH_{0.6}$	0.56	0.020	298
LaNi5	$LaNi_5H_6$	1.37	2	298
ZrV2	$ZrV_2H_{5.5}$	3.01	10^{-8}	323
FeTi	$FeTiH_2$	1.89	5	303
Mg2Ni	Mg_2NiH_4	3.59	1	555
TiV2	TiV_2H_4	2.60	10	313

Table: 4 Hydrogen Storage Properties of Metal Hydrides.

IV. COST OF PRODUCING HYDROGEN.

One of the biggest challenges of using hydrogen on a larger scale will be bringing down the cost/kg through renewable sources which can only be achieved when produced on a larger scale and by bringing innovation and cost cutting methods in the technology.

Demand for hydrogen, which has grown more than threefold since 1975, continues to rise – almost entirely supplied from fossil fuels, with 6% of global natural gas and 2% of global coal going to hydrogen production. Therefore, production of hydrogen is responsible for CO2 emissions of around 830 million tonnes of carbon dioxide per year. Various sectors like chemical, iron and steel, transportation etc, are expecting a massive spike in hydrogen requirements by 2030.

Considering the Net Zero Emissions by 2050 Scenario, total hydrogen demand from industry is expected to expand 44% by 2030 and the with low-carbon hydrogen becoming increasingly important and according to estimates, the net hydrogen demand is set to rise 10 fold to nearly 600 million metric tonnes by 2050.

Green hydrogen produced with renewable resources costs between about $3/kg and $6.55/kg, according to the July 2020 hydrogen strategy. Fossil-

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based hydrogen costs about $1.80/kg, and the commission estimated the cost of blue hydrogen which is based on natural gas is about $2.40/kg.

Green hydrogen is mainly extracted using electrolysis process. Installing new electrolysers and bringing down the cost of electrolysers is another major challenge for ramping up the production of green hydrogen. Access to low-cost renewable electricity will also be one of the most important factors in driving green hydrogen costs down to $1.50/kg.

The end goal of the industry is to bring down the cost of green hydrogen to around $1-2/kg which is about 50% of the current price to be viable for use.

Method	Source	Feed	Cost ($/kg)
SMR with CCS	Standard fossil fuels	Natural gas	2.27
SMR without CCS	Standard fossil fuels	Natural gas	2.08
CC with CCS	Standard fossil fuels	Coal	1.63
CG without CCS	Standard fossil fuels	Coal	1.34
ATR of methane with CCS	Standard fossil fuels	Natural gas	1.48
Methane pyrolysis	Internally generated steam	Natural gas	1.59–1.70
Biomass pyrolysis	Internally generated steam	Woody biomass	1.25–2.20
Biomass gasification	Internally generated steam	Woody biomass	1.77–2.05
Direct bio-photolysis	Solar	Water + algae	2.13
Indirect bio-photolysis	Solar	Water + algae	1.42
Dark fermentation	-	Organic biomass	2.57
Photo-fermentation	Solar	Organic biomass	2.83
Solar PV electrolysis	Solar	Water	5.78–23.27
Wind electrolysis	Wind	Water	5.89–6.03
Nuclear electrolysis	Nuclear	Water	4.15–7.00
Nuclear thermolysis	Nuclear	Water	2.17–2.63
Solar thermolysis	Solar	Water	7.98–8.40
Photo-electrolysis	Solar	Water	10.36

Table: 5Cost of Producing Hydrogen.

	$/gge (production costs only)	2011 Status	2015 Target	2020 Target	Ultimate Production Target
Distributed	Electrolysis from grid electricity	$4.20	$3.90	$2.30	$1-$2
	Bio-derived Liquids (based on ethanol reforming case)	$6.60	$5.90	$2.30	
Central	Electrolysis From renewable electricity	$4.10	$3.00	$2.00	
	Biomass Gasification	$2.20	$2.10	$2.00	
	Solar Thermochemical	NA	$14.80	$3.70	
	Photoelectrochemical	NA	$17.30	$5.70	
	Biological	NA	NA	$9.20	

Fig 2: Year wise cost of producing Hydrogen

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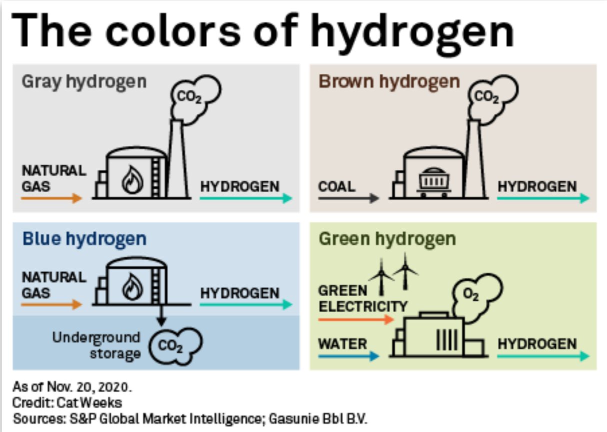

Fig 3: Colours of Hydrogen

V. TRANSPORTATION OF HYDROGEN.

Hydrogen is a widely used and stored industrial gas. Hydrogen transportation is specific issue in terms of safety. The issues are strongly related to chemical and physical properties of hydrogen its ability to embrittle materials its ease in escaping from containment, its wide flammability range, all represent barriers to use. At the same time, it's extremely low density is a guarantee that the gas will likely ascend instead of forming dense dangerous clouds as other gases do.

Different options are available for hydrogen transport and distribution: delivery of compressed gaseous and liquid hydrogen by trucks and of gaseous hydrogen by pipelines. Pipelines have been used to transport hydrogen for more than 50 years, and today, there are about 16,000 km of hydrogen pipelines around the world that supply hydrogen to refineries and chemical plants; dense networks exist for example between Belgium, France, Netherlands, in the Ruhr area in Germany or along the Gulf coast in the United States. The technical and economic competitiveness of each transport option depend on transport volumes and delivery distances.

Pipelines are the preferred option for large quantities and long distances. Liquid hydrogen trailers are for smaller volumes and long distances and compressed gaseous hydrogen trailers are suitable for small quantities over short distances.

Hydrogen is typically stored in steel ASME-certified vessels, or in composite vessels that currently are DOT certified, but not yet fully ASME certified, for stationary uses. The applicable codes are the ASME Boiler and Pressure Vessel Code, Section VIII, for stationary uses, and 49 Code of Federal Regulations for transportation uses. Additional applicable codes and standards include CGA G-5.4 (piping) and G-5.5 (hydrogen vent systems), CGA H-5 (storage) and NFPA 55.

DOT-certified hydrogen tube trailer and a DOT-certified cryogenic liquid transportation trailer. Typical 22-foot and 44-foot tube trailers are available, depending on the volume of hydrogen needed. The larger 44-foot trailers typically hold 85,000 to 112,000 standard cubic feet (SCF) of hydrogen at 2,400 to 2,800 psi of pressure. For applications where hydrogen demands are such that tube trailers become cumbersome, delivery of hydrogen as a cryogenic liquid becomes more attractive owing to its higher energy density. However, that requires somewhat higher amounts of energy than compression to even 3,600 or 5,000 psi for bulk gas delivery. These higher-pressure levels for ambient temperature compressed hydrogen distribution are being explored as an alternative to the currently used methods of lower pressure (2,400-2,800 psi) gas and cryogenic liquid delivery.

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Fig 4: Compressed Hydrogen Gas Tube Trailer – 30 Cylinders and 43,260 SCF (105 kg) capacity.

Fig 5: Cryogenic Liquid Hydrogen Trailer – 13,000 gallon (3,500 kg) capacity.

Fig 6: Next Generation Hydrogen Delivery System Undergoing Testing

Once delivered for stationary uses, hydrogen is typically stored in what is known as "ground storage" in ASME-certified pressure vessels, or in liquid hydrogen "Dewar" systems if the hydrogen was delivered as a cryogenic liquid These ASME pressure vessels and liquid hydrogen

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storage systems must be tested and re-certified every five years.

Fig 7: Cylinders for Hydrogen Storage

VI. FORMS OF HYDROGEN WHICH CAN BE USED AS A FUEL.

Hydrogen plays an important role in advanced energy conversion systems since it is considered as a sustainable source of renewable energy. In recent years, various industries have validated hydrogen to generate electricity through fuel cells and combustion technologies. Hydrogen can be used to reduce Greenhouse gas emissions in combustion engines and gas turbines.

Hydrogen gas is the most favourable fuel in recent years. In future it can be used to generate Electricity, portable fuel cell applications, fuel for numerous automobiles, hydrogen powered industries, liquid- propellant rockets, and for all our domestic energy requirements.

Liquid Hydrogen when burned together with liquid oxygen benefits in many ways. It can power an electric motor used in liquid-propellant rockets. Due to its low molecular weight and high energy output liquid hydrogen fuel is mostly recommended for secondary rocket stages after extra thrust is provided by solid rocket fuels required during lift off.

Hydrogen fuel cells are utilised in various applications in aerospace. The unmanned vehicles use a hybrid system with hydrogen fuel cells which were build up by electrical power from solar arrays, therefore allowing a continuous day and night flight. Hydrogen is also used in navigation thrusters in orbit as a low-density fuel.

Hydrogen offers multipurpose options for mobile power generation. In fact, few companies in the aerospace sector have developed some of the earliest hydrogen fuel cells to provide electricity for rockets and shuttles in space.

Hydrogen is used as a fuel in generation of power in various transportation sectors including buses, mini-trucks and trains. Several major cities have experimented with hydrogen powered Vehicles. Hydrogen powered vehicles help in reducing emissions caused in the transportation sector, these vehicles do not generate greenhouse gases while in operation. Hence, causing no harm to the environment unlike diesel and gasoline powered vehicles.

Numerous Companies containing large warehouses and distribution needs have shifted to hydrogen fuel cells to power clean trucks, forklifts, pallet jacks etc.

Hydrogen has already been experimented in various applications such as buses, passenger cars, buses, trucks, UAVs, planes, trains and marine applications.

VII. CONCLUSION

Hydrogen can be one of the alternatives that can replace fossil fuels as a primary source of energy. As we know hydrogen is the most abandoned element on our planet, but hydrogen does not exist freely, it requires various complex processes to produce hydrogen which can be used as fuel. The main reason behind the look for alternative fuel is to scale back $CO2$ emissions as a drag like heating is one among the main concerns of the whole world. As discussed earlier the main issues associated with the utilization of hydrogen are its storage and transportation facilities. Furthermore, the infrastructure cost for the hydrogen economy is high as transportation of hydrogen can be done only through a specialized method that requires the use of an underground pipe system and this technique are often economical when the demand growth is enough. Hence the conclusion that can be drawn from this paper is that hydrogen can be the fuel of the future but for the time being the economic impact of the use of hydrogen as a fuel is not acceptable, but a further modification in the infrastructure like building a proper pipeline system can help to reduce the transportation cost and clear the trail for hydrogen to exchange fossil fuels.

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