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SMALLEST ELEMENT HYDROGEN OFFERING BIGGEST OPPORTUNITIES FOR ENERGY TRANSITION: THE GLOBAL TRENDS FOR GREEN ENERGY

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ABSTRACT: As world is moving towards green and sustainable energy, there are several alternative sources which needs to be explored further. One such source of energy is Hydrogen which requires special attention in order to utilize it up to its full potential. On the basis of its origin Hydrogen can be categorised as Grey Hydrogen, Blue Hydrogen and Green Hydrogen. This paper comprehends all the aspects of Green Hydrogen. The objective of this study is to understand the current scenario and potential of Green Hydrogen in India and how to use it up to its greatest extent. This paper also focuses on global demand and supply of hydrogen. A comparative understanding has been done between blue and green hydrogen to understand its scalability along with opportunity and challenges. This paper also narrates the key attributes of Green Hydrogen policy in India along with future scope on production through less explored resources.

KEYWORDS

Green Hydrogen, Blue Hydrogen, Geothermal Energy, Sustainability, Fuel Cell.

Introduction

Hydrogen plays a pivotal role in global energy transition by its production from various renewable sources that have zero carbon emissions (Capurso et al., 2022). This green energy fuel makes them a successful alternative to petroleum-based products especially in the automobile industry. Moreover, the turbines at the thermoelectric plants could be powered by hydrogen by replacing coal and could be used in the secondary energy production including wind, solar and hydroelectric plants (Welder et al., 2019).

When we talk about the potential of Hydrogen fuel, the utilization of hydrogen fuel offers measurable advantages over conventional modalities in the energy and transportation sectors.

- Hydrogel fuel cell replaces the needs of ordinary batteries which operates on metals (lithium/ cobalt) that possess huge environmental and biological concern.
- Electric vehicles driven through hydrogen fuels signify a dual advantage on minimizing carbon emission and adequate restoration on depleting fossil fuels.
- Hydrogen offers a large volumetric energy storage density, thereby frequent discharge of cells shall be greatly minimized.
- Quick recharge and sustainable discharge make hydrogen fluid dynamics more interesting in the mobility industry.

Despite the energy and environmental credentials, countries around the globe still face certain limitations in acquiring the proper action plan that channelizes the mass production and supply of hydrogen fuel, some of the crucial limitations were listed below.

1. Storage and transportation network on large-scale production is still in primitive stage and needs high-level execution to widen the distribution cycle.
2. Lack of infrastructure and technologies substantially inflates the cost of hydrogen production.
3. The absence of international regulations concerning production, storage, and supply across the territories is still not well established, this scenario has a negative impact on formulating the global trade market.
4. Hydrogen is known for its flammability nature, hence requiring an expensive infrastructure for the cause of safe production and efficacious supply.

Steady-state collaboration among policymakers, academicians, and industries becomes inevitable in framing the guidelines that advocate the hassle-free production and supply of hydrogen through reliable sources. Novel technologies are required to explore the maximum potential of the biomass waste that tends to curtail the need for diminishing fossil fuels. Vibrant low-cost infrastructures which ensure a high level of safety could even synergize the investors to replenish their thoughts on next-generation renewable energies like hydrogen. Interdisciplinary research approaches enable well-organized logistics and supply chain of hydrogen fuel concerning geological mapping, mass production, safe storage, and channelized supply (Figure 1). In conclusion preparedness of future technology in securing a clean environment will surely make hydrogen an icon of international trade.

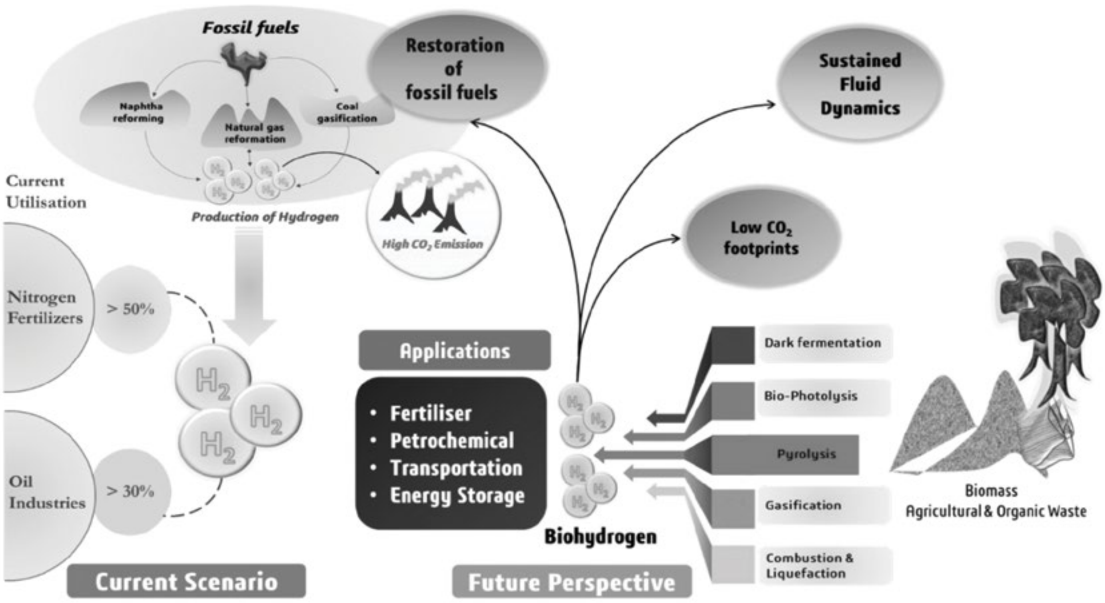

FIGURE 1: Current scenario and future perspective of hydrogen production

Depleting resources of fossil fuels gear the shift towards alternate sustained resources that adequately compensates for the energy demand in both developed and developing countries. The high conversion value and eco-friendly nature of hydrogen attract the researcher to explore diversified ways of synthesizing, storage, and utilization of hydrogen as a next-generation renewable fuel. By considering its potential there is a constant increase in annual demand (5-10%) for hydrogen and it may be expected to reach an exponential hike by the year 2050 (Agyekum et al., 2022).

On average, nearly 6 percent of natural gas along with 2% of coal consumption imparted for hydrogen production to accomplish the industrial requirement. Perhaps this process negatively impacts the environment by revoking 830 million tonnes of carbon dioxide annually (IEA, 2019).

Industrial demand for hydrogen attains newer hikes since the year 1975 and as per the estimate justified in the year 2018, it was hypothesized that a major quantum of hydrogen has been utilized by the industries for the production of fertilizers (ammonia based), petrochemicals, solvent, polymers, resins, etc. (Brandon and Kurban, 2017) Global industrial necessity for hydrogen has been significantly increased since 2013, it was estimated that about 324.8 billion cubic meters of hydrogen demand exist in the year 2020 (Wang et al., 2019).

By year 2020, emissions of carbon dioxide fell by 5.8%, or about 2 Gt CO2, the greatest record drop and nearly five times bigger than that of the drop following the international economic meltdown in 2009. Since the epidemic reduced demand for oil and coal faster than that of other forms of energy, Emissions of carbon dioxide decreased far beyond energy requirements in 2020, whereas renewables climbed. Causing a drop in 2020 (IEA, 2021), worldwide energy-related Emissions of CO2 continued at 31.5 Gt, contributing to CO2 hitting its maximum record average yearly atmospheric concentrations of 412.5 ppm in 2020 – over 50% greater than if the industrial revolution started (Figure 2). As coal consumption, petroleum, and gas recovers with the market, worldwide energy-related Emissions of CO2 are expected to rise and increase by 4.8 percent in 2021 (IEA, 2021).

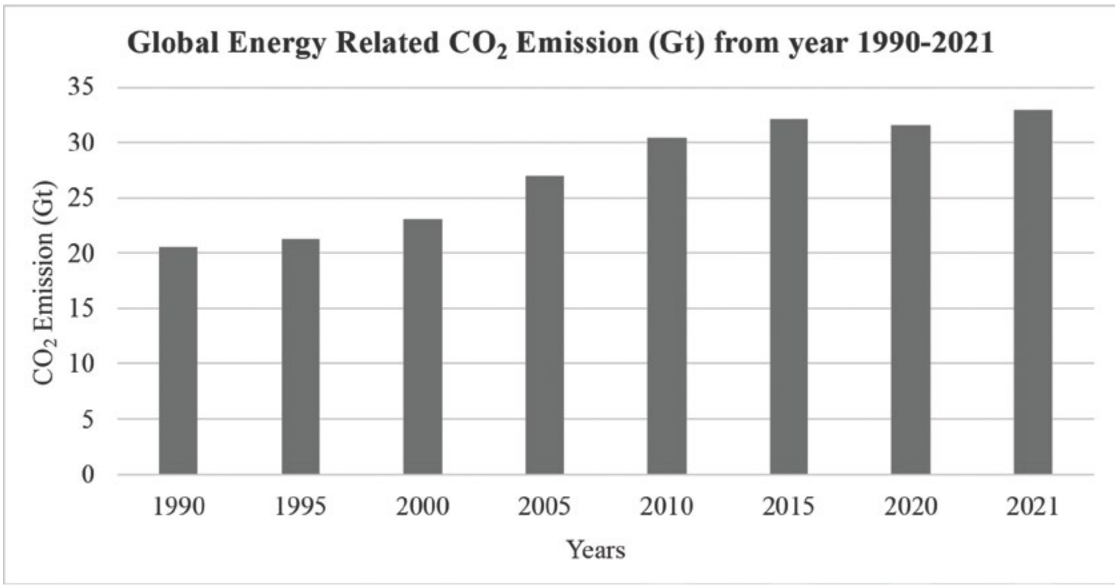

FIGURE 2: Global Energy Related CO2 Emission (Gt) from year 1990-2021 (IEA, 2021)

Nuclear power could speed the process that currently offers the majority of the globe's hydrogen. Using nuclear energy to aid natural gas vapor converting (methane). In order to generate Hydrogen and Carbon Monoxide by mixing methane with vapour the temperature of Stream Reformation of Methane (SRM) need to be set above 700oC (Nikolaidis and Poullikkas, 2017). By using Nuclear as production source for hydrogen one can cut down around 30% of the natural gas intake (El-Shafie et al., 2019). Beginning with electrolysis process the overall performance of the system increases by around 25% by using recent reactors to 36% with much more effective reactors, to 45 percent for high-temperature electrolyser of vapor, and to roughly 50% or over with continuous thermo - chemical synthesis. Table 1 represent the types of methods for hydrogen production using nuclear energy.

	Temp (°C)	Pressure (atm)	Efficiency (%)	Heat (MJ)	Water (kg)	Natural Gas (kg)
Alkaline Electrolysis	60	1	30	26	11.5	0
PEM Electrolysis	60	1	27	26	11.5	0
Solid Oxide Electrolysis	800	1.57	36	30	83	0
Steam Methane Reforming	870	4.1	79	0	10.3	2.9
Thermochemical	910	3.85	25	375	9	0

TABLE 1: Types of Hydrogen generator using Nuclear Energy (Pinksy et al., 2020)

Hydrogen Fuel Cell Vehicles (FCVs) are nearly identical to electric vehicles (EVs) in which power their wheels with an electric engine rather than a combustion engine. FCVs, on the other hand, create their own electricity rather than relying on cells which must be recharged. In a battery pack, hydrogen (H2) fuel from car's fuel system reacts with oxygen (O2) from atmosphere to make electricity, leaving only heat and water as residual materials. Fuel cell automobiles are propelled by pressurized hydrogen gas, which is fed into an inbuilt fuel cell "stacking" that converts the chemical energy of the fuel into electrical energy rather than burning it. The electric engines in the car are then powered by this electricity. There are no combustion pollutants, and the only residue generated is clean water. The fuel cell is constructed similarly to a power supply. Hydrogen reaches the anode and gets into touch with catalysts, which aids in the dissociation of hydrogen into electrons and protons.

The high calorific value of hydrogen (119.9 MJ/kg) than the methane (50.02 MJ/kg), propane (45.6 MJ/kg), gasoline (44.5 MJ/kg), diesel (42.5 MJ/kg), ethanol (27.0 MJ/kg), and methanol (18.5 MJ/kg) makes them a promising fuel by generating high amount of energy during combustion. The safety of hydrogen as fuel depends on several physical parameters such as Lower Detonability Limit (LDL) in Air, Upper Detonability Limit (UDL) in Air, Lower Flammable Limit (LFL) in Air, Upper Flammable Limit (UFL) in Air, Maximum Laminar Burning Velocity, Maximum Concentration, Stoichiometric Laminar Burning Velocity, Stoichiometric Concentration, Density, Ignition Limit in Air, Ignition Temperature, Minimum Ignition Energy in Air, Maximum Combustion Rate in Air, Detonation Limits in Air and Stoichiometric Rate in Air.

The explosion and fire hazards of several flammable substances can be determined by their detonation limits, LDL and UDL. The LDL for hydrogen ranges between 11 to 18% which is much higher than methane (6.3%), propane (3.1%), and gasoline (1.1%). Similarly, the UDL of hydrogen is much higher (39%) than the other gases respectively. Although, methane has a slightly higher LFL at 5.3%, hydrogen when compared to gasoline (1.4%) and propane (2.1%) has high LFL value. In contrast, the UFL of hydrogen is 75% which is 5, 8 and 10 times higher than methane, propane and gasoline. The relativity, diffusivity, and exothermicity information are required for designing, modelling and validation of turbulent combustion and kinetic mechanism of the engine. Laminar burning velocity parameter measures these information for hydrogen with a value of 3.46 m/s at its maximum and the peaking flame speed or stoichiometric laminar burning velocity if 2.37 m/s. This represents the efficient thermodynamic conditions of hydrogen upon ignition. The conversion of mass and energy of resources to produce hydrogen is denoted by its stoichiometric concentration. Hydrogen holds a high stoichiometric value of 29.5% than methane (9.5%), propane (4.1%), and gasoline (1.8%). Also, the maximum combustion rate of hydrogen in air is 3.46 m/s which is several fold increase in range compared to methane (0.43 m/s) and propane (0.47 m/s) (Farias et at., 2022).

Blue and Green Hydrogen

Steam methane reforming (SMR) process reforms natural gas to form hydrogen and carbon monoxide from methane and steam (Andrews et al., 2020). The production of hydrogen through SMR with CO2 capture and storage (CCS) is referred as “blue hydrogen”. Globally, till date, blue hydrogen is produced by Shell in Alberta, Canada and Air-products in Texas, USA (Howarth et al., 2021). Although blue hydrogen claims to have zero greenhouse gas emissions, there is no substantial evidences to prove the amount of hydrogen emitted during the production of blue hydrogen. Methane, being a powerful warming agent, is a strong greenhouse gas than CO2 that constitute approximately 25% of the total global warming share (Sun et al., 2021).

The assessment of methane based severity depends on the greenhouse gas emission metric. Global warming potential (GWP) metric analyses the future threats of global warming by greenhouse gases (Neubauer et al., 2021). Furthermore, the higher and lower calorific value of natural gas extracted with crude oil are directly related to the methane emission. In context with the blue hydrogen, further research and relevant data collection are highly required to frame the impact of global natural gas system.

On the other hand, green hydrogen uses renewable energy to generate hydrogen through electrolysis technology (Zhou et al., 2022). Although this process is slightly expensive than other established model, electrolysis based hydrogen generation uses green technology with total decarbonisation.

As recently predicted by Rystad Energy, an independent energy resource and business Intelligence Company at Oslo, Norway, the economic impacts after Russia’s invasion to Ukraine has spiked the grey and blue hydrogen production as the green version (PV magazine global, 2022).

Presently, Europe has set a target to produce 3 million tons of green hydrogen annually from 2030. India, on March 21, 2022, has started its first huge project on green hydrogen based energy storage at National Thermal Power Corporation Limited (NTPC)-Simhadri plant, Visakhapatnam, Andhra Pradesh. This facility aims to initiate green hydrogen production using advanced 240kW solid oxide electrolyser and storing them in a 50kW micro grid based standalone fuel cell. Multinational companies like Goldman Sachs, USA have predicted the hydrogen fuel market could reach up to $1 trillion by 2050 and have bought 3 stocks analysing the India's focus on green hydrogen production. The green hydrogen International (GHI) has recently announced setting up the world's largest green hydrogen hub at Texas, USA to be commenced on 2026 aiming for the benefit of sustainable energy fuel and green ammonia production. Table 2 represents the characteristics and advantages of blue hydrogen and green hydrogen.

	BLUE HYDROGEN	**GREEN HYDROGEN**
Source	Natural gas	Renewable energy
GHG emission	CO_2 capture and reused	Zero emission
Technology readiness level (TRL)	8-9	9
Technology	SMR with CCS	Water electrolysis
Scalability	Industrial	Commercial
Process	Well established technology	Sustainable technology
Strength	Economically competitive	Clean fuel with zero GHG emissions
Weakness	Usage of methane from natural gas	Remains in small sector; Limited specialized workforce
Opportunity	Fossil fuel industries will account an significant improvement Environmental, Social, and Corporate Governance (ESG) metrics	Real investment accounting 24% of world's energy by 2050
Challenges	Optimization of integrated systems to produce blue hydrogen	Production of green hydrogen with low energy losses

TABLE 2: Comparison of Blue and Green Hydrogen

Green Hydrogen Policy in India

The green hydrogen policy for any nation should be based on four major foundations. These four foundations are (1) Strategies for National Hydrogen: The strategy stage should be based on the research and development programs in order to have better understanding of the green hydrogen technology (IRENA, 2020); (2) Priorities for setting policy: As green hydrogen has broad range of applications, the priorities for its applications must be defined properly(IRENA, 2020); (3) Guarantees of Origin: As the molecules of green hydrogen are quite similar to the characteristics of grey hydrogen it is important that the origin of produced green hydrogen is renewable source (IRENA, 2020); (4) Governance system and enabling policies (IRENA, 2020): The production of green hydrogen should not only be beneficial with its application but should also contribute value to the economy and environment.

There is a growing global understanding that coordinated action is required to keep global warming below 2 degrees Celsius, and if achievable, to 1.5 degrees Celsius above pre-industrial conditions. Therefore to achieve energy transformation and mitigate emissions, several nations have pledged their Nationally Determined Contributions. The majority of major economies, including India, have pledged to net-zero goals. One of the most important criteria for reducing emissions, particularly in hard-to-reduce industries, is the switch to green hydrogen (Hydrogen Energy, 2022). The Indian government is considering a range of legislative initiatives to smooth the transition beyond fossil fuel-based sources to green hydrogen as a fuel transmitter and chemical raw material for various industries. Following are some key highlights of Green Hydrogen policy in India:

- Green hydrogen is characterized as hydrogen produced through the water electrolysis process utilising clean source of energy (Ministry of Power, 2022).
- A remission of transmission rates for inter-state will be provided to Green Hydrogen producers for a term of 25 years for work executed until June 30, 2025. Renewables sources used to make Green Hydrogen will be allowed to be banked for a duration of 30 days. The price gap between both the mean tariff of sustainable energy bought by supply authority during

prior year and the market clearing price (MCP) in the Day Ahead Market (DAM) during month wherein the green sources has indeed been saved up shall be determined by the State Commission as well as shall not exceed (Ministry of Power, 2022).

- Green hydrogen generation by a producer utilising green energy from one co-located sustainable energy plant, or acquired from a distant clean energy plant, either built by the same builder or a foreign entity, or obtained through a power exchange method. After 15 days of receiving a request that is comprehensive in all aspects, Green Hydrogen facilities will be given Freely Accessible for acquiring green resources. The prices for public access must be in compliance with the established rules (Ministry of Power, 2022).
- Under Power Regulations 2021, connection to the ISTS for renewable power generation built up with the intention of producing Green Hydrogen will be permitted on a priority basis (Ministry of Power, 2022).
- Green Hydrogen manufacturing land might be given in sustainable energy zones.
- Green sources used in the manufacturing of Green Hydrogen counts toward consumption institution's RPO compliance. The green energy consumption in excess of the producer's requirement will be counted to towards the DISCOM's Disciplined in the region where the property is situated.
- Green Hydrogen producers in respective states may purchase and distribute green energy from transmission licensees. In these kind of circumstances, the transmission licensee is just allowed to charge the price of acquisition, wheeling fees, and a tiny margin imposed by the state government (Ministry of Power, 2022).
- The Ministry of New and Renewable Energy (MNRE) will create a separate platform for all regulatory permits and licenses needed for Green Hydrogen manufacturing, transmission, storage, and sales. The involved authorities would be asked to do is provide permits and licenses as quickly as possible, ideally within thirty days of the filing date.
- To improve the competitive costs, MNRE might pool request from other industries and execute combined tenders for Green Hydrogen acquisition through any of authorized public entities.

Future scope on production through less explored resources

The manufacturing of nitrogen-based fertilizers grabs more than 50% of the total hydrogen production followed by oil industries (>30%). In the current scenario, fossil fuels remain the primary source of hydrogen synthesis, these resources were classified into three major categories which include 1. Naphtha reforming (30%) 2. Natural gas reformation (48%) and 3. Coal gasification (18%) (Agyekum et al., 2022). Limited resources and high carbon footprints are the major limiting factors of fossil fuels, hence exploration of the alternative source becomes the need of the hour.

India is a land of rich agricultural diversity intron uplift the scope of hydrogen production from biomass feedstock. Tons of agricultural/ organic waste generated from the crop field each year synergize the research on exploring the possibility of hydrogen production from this robust source. Conversion of biomass into bio-hydrogen is an ideal strategy to minimize greenhouse emissions (Adessi and De Philipps, 2012). Through dark fermentation technology and with the aid of viable anaerobic bacteria pyruvates derived from pre-treated biomass (waste) are successfully converted to format that yields hydrogen.

Bio-Photolysis is another unique mechanistic pathway of synthesizing hydrogen through microalgae (chlamydomonas reinhardtii) that are capable of releasing hydrogen-producing enzymes. Pyrolysis and gasification become a promising thermochemical model of generating hydrogen from biomass at a higher temperature. Avoidance of oxygen and water in these techniques greatly controls the emission of CO2 (Aydin et al., 2021).

Conclusion

With increasing demand of clean, green, sustainable and affordable energy sources hydrogen will play very important and competitive role. In this paper an aim is targeted to understand about the hydrogen its types of sources along with its marketing and policy strategies. In this paper it has been narrated that how the collaborative approach of policymakers, academicians, and industries becomes inevitable in framing the guidelines that advocate the hassle-free production and supply of hydrogen through reliable sources. This paper also talk about the techniques like Hydrogen Fuel Cell Vehicles (FCVs) which uses the waste heat from the combustion engine and convert it into hydrogen which can be used to power the vehicle. It also narrates about how the green hydrogen is better than the blue hydrogen. It talks that how the green hydrogen is more sustainable technology then blue hydrogen and how it can be generated by simple water electrolysis technique with zero emission. The four foundations of Indian Green Hydrogen Policy is describe which are (1) Strategies for National Hydrogen; (2) Priorities for setting policy; (3) Guarantees of Origin; (4) Governance system and enabling policies. With all this analysis future scope on green hydrogen production with less explored resources is concluded.

Nomenclature

SRM- Stream Reformation of Methane

FCV- Fuel Cell Vehicles

EV- Electric Vehicles

UFL- Upper Flammable Limit

LDL- Lower Detonability Limit

UDL-Upper Detonability Limit

LFL-Lower Flammable Limit

CCS- CO2 Capture and Storage

GWP- Global Warming Potential

NTPC- National Thermal Power Corporation Limited

MCP- Market Clearing Price

DISCOM- Distribution Company

MNRE- Ministry of New and Renewable Energy

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