ISSN NO.2395-0692
IJAHMS International Journal of Arts, Humanities and Management Studies

GREEN HYDROGEN- A GLOBAL CHALLENGE

Professor Dr. Chittaranjan Sarkar,
FCA Professor of Commerce, NSOU, Kolkata

INTRODUCTION

The mission 'Green Hydrogen' has become the buzzword across the globe. The scientists, academicians all around the world have long been in search of ways and means to fight against global warming- mainly caused by combustion of fossil fuels. This combustion of fossil fuels leads to much of GHG emissions and its corollary increasing global warming making the world a threat to live sustainably for the entire flora and fauna of it. Green hydrogen is considered to be the future of global atmosphere as a perfect messiah to tackle the forces of global warming.Owing to meeting the ever-increasing global energy demandby indiscriminate use of fossil fuel, natural gas and forest products etc. and its consequence the emergence of tremendous environmental pollution, the global economy has been under sheer pressure and biodiversity is almost destroyed. It has marred the spirit of global socio-economic development where the production and use of green, hassle-free as well as environment-friendly hydrogen has become the essence of sustainable future to ensure clean energy. A high-performance green hydrogen production system is at the core of safe and secure energy regime across the globe whereby production of green hydrogen through water electrolysis system with renewable powers like solar energy, tidal energy, air energy can be a solution to overcome the problems of environmental pollution and global warming to a large extent since use of renewable sources of energy does not lead to carbon emission. The green hydrogen could play a magnificent role in tomorrow's energy mix to cater to the needs of providing fuel for cars, trains, ships etc. amid the vital needs of energy for industrial sectors.

TECHNOLOGY OF GREEN HYDROGEN PRODUCTION

Green HydrogenTechnology is regarded as a solution for the production of hydrogen on commercial basis to meet the growing demand of energy in an environment-friendly and carbon-free technique. The researchers and the social scientists have come forward to implement the technological developments to produce climate-neutral as well as carbonless hydrogen on an industrial scale with the noble mission to arrest environmental degradation.

Abundant, cheap and clean-burning without carbon emission, hydrogen has long been described as the vital fuel of the future. In recent years, all throughout the globe an emphasis has been given to produce 'green hydrogen (GH_2), i.e. hydrogen produced without using fossil fuels.In fact, the recent most emphasis is being given on to use renewable sources of energy like solar energy, air turbine energy, tidal turbine energy, energy from bio-degradable waste etc. to produce hydrogen and the same has been identified as the clean energy source that could help reach the world to net-zero emissions as to carbon and other polluting agents. The hydrogen so produced with the help of renewable energy with least of environmental pollution is so called as 'Green Hydrogen-(GH_2)'.

ISSN NO.2395-0692
IJAHMS International Journal of Arts, Humanities and Management Studies

Green hydrogen technology that has become much popular is the simple process to produce hydrogen through the process of electrolysis of water with the of electrolyser using renewable energy sources as may be available. Green hydrogen is remarkably recognised as hydrogen produced by splitting water molecule (H_2O) into Hydrogen (H_2) and Oxygen (O_2)with the help of renewable electrical energy through a common laboratory process known as electrolysis. This ideology to split water into H_2results in very low or zero carbon emissions inherently due to non-use of fossil fuel or other form of pollutant energy.Electrolysis is currently the most promising method of hydrogen production from water due to high efficiency of conversion and relatively low required energy input when compared to thermochemical and photocatalytic methods.

While consuming hydrogen, the combustion of it does not release carbon dioxide, rather when burns in oxygen it forms water- symbolically it may be expressed as: $H_2 + O_2 \rightarrow$ water; $2H_2 + O_2 \rightarrow 2H_2O$. The production as well as consumption of hydrogen both ways are seen conducive to mankind in terms of environment-friendliness.Thus, hydrogen could be a clean fuel (green fuel) for use in the future as a solution to replace fossil fuels (key to global warming) causing severe global warming and also that they are being extinct sharply.

PRODUCTION EFFICIENCY AND COST GAP OF GREEN HYDROGEN

At present, the overall efficiency is around 50-60% depending on the use of cell technology. On an average, as of now, it requires 9 litres of water and about 50 kWh of electricity to generate 1 kg of hydrogen, i.e. 14.128 litres of hydrogen.There are four main sources for the commercial production of hydrogen: natural gas, oil, coal, and electrolysis of water; which account for 48%, 30%, 18% and 4% of the world's hydrogen production respectively. There are three main types of electrolytic 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 since they generally use nickel catalysts, but this nickel catalyst is less-efficient in production.PEM electrolysersare more expensive as they generally use expensive platinum group metal catalysts, they are more efficient in production and can operate at higher current densities, and thus in this electrolyser hydrogen can be produced at cheaper rate under large scale production system.

However, there isbarrier for maximising low-carbon hydrogen production due to the cost gap with hydrogen generated from fossil fuels. Till date, producing hydrogen from fossil fuels is the cheapest option in most parts of the world. Depending on regional gas prices, the estimated cost of hydrogen production from natural gas ranges from USD 0.5 to USD 1.7 per kilogramme (kg). Using Carbon Capture, Usage and Storage Technology (CCUS)which is used to capture and make effective use of high concentration of CO_2 emitted from industrial activities with the mission to decarbonise and address the challenge of global climate change, the estimated cost of hydrogen production comes to around USD 1 to USD 2 per kg. On the contrary, cost of producing hydrogen using renewable electricity costs USD 3 to USD 8 per kg.

In the coming years, there is significant scope for cutting production costs through technology innovation and increased deployment. The potential is reflected in the IEA's Net Zero Emissions by 2050 Scenario (NZE Scenario) in which hydrogen from renewables likely to fall as low as USD 1.3 per kg by 2030 in regions with excellent renewable resources, comparable with the cost of hydrogen from natural gas with CCUS. In the longer term, hydrogen costs from renewable

electricity shallfall as low as USD 1 per kg by using solar panel (Solar Photovoltaic)in comparison withhydrogen produced from natural gas even without CCUS benefit.

Australia is the No. 1 country in the world with the largest number of green hydrogen plants.As of 2022, there were 96 such facilities in the country. Solar photovoltaic is the chief source of Australia's renewable power production, with some 8.1 to 15.7 terawatt hours generated from solar PV plants. Oil India Limited (OIL) isfirst Indian Company to install Green Hydrogen Plant in Jorhat, Assam with an installed capacity of 10 kg per day in 2022.

Table-1: Number of facilities (Green H2 Plant) installed in different global destinations as of 2022

Name of country	Number of facilities
Australia	96
Germany	50
Spain	50
Netherlands	48
United Kingdom	46
United States of America	37
Russia	36
Portugal	28
China	26
Chile	22
Bharat	1

Source: www.statista.com

GLOBAL INVESTMENT IN CLEAN & GREEN ENERGY AND FOSSIL FUEL

According to the IEA World Energy Investment 2023 report, globalinvestment in clean and green energy technologies has significantly outpacedthe spending on fossil fuels as its increasing cost and security concerns coupledwith global energy crisis towardsfuture sustainable global economy has become a major concern. Table-2 exhibits the global energy investment in clean energy and fossil fuel in billion USD whereby it is highlighted that over years from 2015 to 2023 there is increasing trend of investment in clean energy ranging from 1074 to 1740 billionUS Dollar showing an increase of 62.01% in 2023 over 2015 and corresponding decreasing trend of investment in fossil fuel ranging from 1319 to 1050 billion US Dollarshowing a decrease of 20.4% in 2023 over 2015. More than 90% of the increase in global energy investment comes from advanced economies including China to emphasise on production of clean and green hydrogen to tackle global warming.

Table-2: Global Energy Investment in clean energy and fossil fuel (Billion USD 2022)

Year	Clean Energy	Fossil Fuel
2015	1074	1319
2016	1132	1105

2017	1129	1114
2018	1137	1109
2019	1225	1066
2020	1259	839
2021	1408	914
2022	1617	1002
2023 (Estimated)	1740	1050

Source: International Energy Agent's World Energy Investment Report, 2023

NET-ZERO EMISSION OF CARBON

Over the last few years, global economies have taken strong determination to achieve a net-zero carbon emission status in the overall production of green hydrogen. A net-zero energy system gives focus on reducing carbon emission as much as possible first by the system itself using renewable sources of energy, and with any remaining emissions to be re-absorbed from the atmosphere, by other means like oceans, forest etc. Net zero emissions refers to achieving an overall balance between greenhouse gas produced and greenhouse gas taken out of the atmosphere. In fact, it is highly needed to keep or maintain carbon emissions as close as possible to real zero through Carbon Capture, Utilisation and Storage (CCUS) to removeCO_2 by phasing out all fossil fuels for ensuring green hydrogen production.

Table-3 presents the global picture of H_2 production in MT in the Sustainable Development Scenario (2019-70). Data analysis from Table-3 suggests that the share of clean hydrogen production as a percentage of total production has been projected from 11% in 2019 to 94% in 2070 because of giving more emphasis to combat with the fierce impact of global warming using fossil fuel without CCUS in hydrogen production.

Table-3: Global H_2Production in the Sustainable Development Scenario (2019-70) [Figures in MT]

Year	Fossil Fuel without CCUS [1]	Fossil Fuel with CCUS [2]	Low-Carbon Electricity [3]	Share of Clean and Green Hydrogen as %age of total [4=(2+3)/(1+2+3)x100
2019	64	8	-	11%
2030	55	18	14	37%
2040	35	49	56	75%
2050	39	113	117	86%
2060	42	185	190	90%
2070	31	213	291	94%

Source: www.iea.org/data

ISSN NO.2395-0692
IJAHMS International Journal of Arts, Humanities and Management Studies

DIFFERENT TYPES OF HYDROGEN PRODUCTION

Based on the nature or method of extraction of hydrogen from various sources, it is recognised as - Grey Hydrogen, Blue Hydrogen and Green Hydrogen.

a) Grey Hydrogen- It is produced with the help of coal or lignite gasification (black or brown), or via a process called steam methane reformation (SMR) of natural gas or methane (grey). This process has the drawback since it tends to be mostly carbon-intensive process.

b) Blue Hydrogen-Blue hydrogen is produced through natural gas or coal gasification combined with carbon capture storage (CCS) or carbon capture use (CCU) technologies to reduce carbon emissions. This process is to some extent effective to reduce global warming.

c) Green Hydrogen- It is produced using electrolysis technique of water with electric power generated by renewable sources of energy. This method of producing green hydrogen is highly effective to maintain carbon-free atmosphere as well as to restrict global warming significantly.

Of the three kinds of hydrogen production, green hydrogen production is considered safest, effective and user-friendly. Although, it is often criticised that production of green hydrogen is not cost-effective and is not always feasible to produce hydrogen solely depending on renewable energy sources keeping pace with the increasing demand of hydrogen. The basic technique of using electrolysis to split water molecule into hydrogen is less productive in terms of energy spent since renewable energy may not be available amply as and when needed- these are natural resources like solar power, tidal power and air power etc. which have various limitations (for solar power cloudy atmosphere, for tidal and air power -these are limited to coastal areas only etc.). Despite all, considering the overall positive features of green hydrogen as to its production and consumption both environment-friendly and less active to global warming, the improvement in production technology as regards the use of powerful electrolyzers has been emphasised all over the globe.

SOME OTHER TECHNOLOGY OF HYDROGEN PRODUCTION

Apart from water electrolysis technique where Alkaline and PEM electrolyzer technologies are widely used for the production of green hydrogen, some other techniques are used:

a) Methane Pyrolysis- In this technique, thermal decomposition and plasma decomposition of natural gas are used to produce hydrogen and carbon. The carbon so produced as joint product can be stored in a solid form and used for various processes. Hydrogen produced from the process is free from CO_2 emissions and is a clean source of energy. The demerit of this technology is to separate carbon from the manufacturing process and its safe storing.

b) Solar Hydrogen production-This technique uses light energy to split water into hydrogen and oxygen. Researches are being conducted to produce hydrogenthrough photocatalytic water splitting technology. This process is currently in the early stages of research and offers the potential for green hydrogen production with low environmental degradation.

c) Photoelectrochemical water splitting (PEC) – In the PEC process, hydrogen is generated from water. It uses sunlight and specialized semiconductors that are called photoelectrochemical

materials. These materials use light to directly dissociate water molecules. Hydrogen production with help of PEC will be a promising future path.

d) Photocatalytic water splitting – This is an artificial photosynthesis process with photocatalysis used for the dissociation of water into oxygen and hydrogen. The related research activities is emphasising on developing high-performance photocatalystwith high light absorption properties, high rate of charge transfer, and suitable surface reaction properties.

e) Biological hydrogen production- This technique of biological hydrogen production uses sunlight and specialized microorganisms, such as green algae and cyanobacteria. Microbes use a natural metabolic process to consume water and produce hydrogen as a byproduct. According to US DOE, this biological production of hydrogen is in the primary stage andin the long run future is expected to produce on an average 1,500 kilogram per day.

f) Biomass gasification-This technology uses a process involving heat, steam, and oxygen to convert biomass to hydrogen and other products, without using combustion. It converts organic or fossil-based carbonaceous materials at temperatures higher than 700°C. In this process growing biomass accumulation in the atmosphere become carbon free and its corollary net carbon emission becomes low. Biomass gasification technique is highly effective to control and check environmental pollution emanating from different biomass sources like forestry and agricultural crops and their residues, industrial residues, domestic animal, poultry firm and other firm residues, and municipal solid waste etc. Production of hydrogen from biomass in a carbon free manner in one way and in the other solving via gasification of the environmental problem of huge waste stocks on a daily basis help significantly in balancing environment problems.

HURDLES OF CONSUMING HYDROGEN

There are some hurdles to consumption of hydrogen as regards its storage, transportation etc. Hydrogen is highly volatile and lighter than air, making transportation and storage really troublesome. Hydrogen is highly flammable and explosive, escapes easily, and has a relatively low density. Transporting it in one of its higher-density forms is preferable but it requires compression, liquification, or conversion. Hydrogen also reacts with many metals, causing them to become brittle.It is 20 times more explosive than petrol.

Because of its low density, hydrogen must be highly compressed in order to store it efficiently and ship it to its destination. Several technologies are under consideration. Hydrogen becomes a liquid at a temperature of –252°C, but transporting liquid hydrogen over long distances is only 70% efficient; the efficiency is limited by the need for super-cold cryogenic tanks and constant active cooling to prevent rising pressure and the associated risk of explosion.

Thus, long-distance transportation networks for carrying hydrogen must be developed, preferably using ships. For shorter distances, large amounts can be sent through pipelines, while a combination of trains and trucks can deliver smaller amounts. Thus, it is considered to locate hydrogen production adjacent to the place of use as far as possible to avoid the risk of transportation.

ISSN NO.2395-0692
IJAHMS International Journal of Arts, Humanities and Management Studies

PRESENT SCENARIO OF HYDROGEN PRODUCTION MISSION

Mounting pressure of global energy crisis and the devastating impact of environmental pollution, the development of green, sustainable, and low-cost energy has become the most vital issue for the sustenance of mankind and the universe as a whole and for this purpose Hydrogen has always been considered an essential form of clean energy since in its production renewable sources of energy is to be used instead of using the traditional forms of energy like coal, fossil fuels etc. which are highly responsible to environmentaldegradation and global warming.

At present, hydrogen is seen to be primarily used in petrochemicals and fertiliser industries and is produced largely from natural gas, fossil fuels, causing emission of enormous amounts of carbon dioxide into the environment during the highly polluting and energy-intensive processes to aggravate the overall global warming. To overcome the impasse to restrict environmental degradation and to combat with the fierce impact of global warming, the need for new technology of hydrogen production through renewable sources of energy under the electrolysis of water in an electrolyser to split water molecule into hydrogen.

Depending on the nature of the method of its extraction, hydrogen is categorised into three categories, namely, grey, blue and green. There is a growing focus on increasing production of green and blue hydrogen due to its no carbon emission and use of carbon offset technology, respectively. Additionally, several leading organizations are exploring technologies which can convert bio and plastic waste into hydrogen, thereby providing a huge scope for investment in this technology which can combat India's twin problems of waste management and energy security.

Asia-Pacific Zone

Many countries in Asia-Pacific sub-continent, including Japan, China and South Korea, have already taken positive stance to produce green hydrogen to take care of environmental pollution and global warming. In 2017, Japan formulated the Basic Hydrogen Strategy which sets out the country's action plan till 2030, including the establishment of an international supply chain. It has also entered memorandums agreeing to cooperation on the exchange of information and personnel and developing technology with countries like New Zealand. Likewise, South Korea is operating hydrogen projects and hydrogen fuel cell production units under the auspices of its's Hydrogen Economy Development and Safe Management of Hydrogen Act, 2020.

China is also at the forefront with other global economies in the production of green hydrogen. China has been committed to promoting the transition from traditional energy to low-carbon clean energy. The annual growth and installed capacity of solar power and wind power in China have surpassed all other countries globally, and there is a rich experience in research and development as well as a solid industrial foundation in the field of new energy. President Xi Jinping has solemnly promised that China will achieve 'carbon neutrality' by 2060.The liquid solar fuel synthesis demonstration project based on the technology of Prof. Can Li's team has integrated a 10 MW solar power plant with the water electrolysis system.

European Zone

The European Union has issued its national hydrogen strategy in 2020, whereby it has recognized hydrogen as a key technology for achieving policy goals such as the European GreenDeal. Its strategy is heavily focused on emissions-free green hydrogen, with a target to install 40 gigawatts of

renewable hydrogen electrolyzer capacity by 2030. The European Clean Hydrogen Alliance was launched to support investment and large-scale deployment of clean hydrogen projects, as the EU aims to become the industrial leader in clean hydrogen. Within the bloc, different member states look set to become large-scale hydrogen importers, exporters or transit hubs to offer a sustainable carbon-free world for everyone.

United States

The US is the world's second-biggest producer and consumer of hydrogen after China, accounting for 13% of global demand.The United States's National Clean Hydrogen Strategy and Roadmap explores opportunities for clean hydrogen to contribute to national decarbonization goals across multiple sectors of the economy. It provides a snapshot of hydrogen production, transport, storage, and use in the United States towards a strategic framework for achieving large-scale production and use of clean and green hydrogen within 2050.

The U.S. Department of Energy Hydrogen Program, led by the Hydrogen and Fuel Cell Technologies Office (HFTO) within the Office of Energy Efficiency and Renewable Energy (EERE), conducts research and development in hydrogen production, delivery, infrastructure, storage, fuel cells, and multiple end uses across transportation, industrial, and stationary power applications. The program also includes activities in technology validation, manufacturing, analysis, systems development and integration, safety, codes and standards, education, and workforce development with special emphasis on green hydrogen production.

Indian Context

Like other Asian countries, India has taken a big lip to produce green hydrogen to fortify its energy strength to match with its demand for power by its vast population in a safe and secure manner.India has set its sight on becoming energy independent by 2047 and achieving Net Zero by 2070. increasing renewable energy use across. Green Hydrogen is considered a promising alternative for enabling this transition. Hydrogen can be utilized for long-duration storage of renewable energy, replacement of fossil fuels in industry, clean transportation, and potentially also for decentralized power generation, aviation, and marine transport. To achieve this target, India has set its National Green Hydrogen Mission duly approved by the Union Cabinet on 4 January 2022, with the following objectives:

a) To increase the use of renewable energy across all economic spheres through Energy Transition.
b) To make India self-sufficient in energy production and also the supplier of Green Hydrogen in the world
c) Creation of export opportunities for Green Hydrogen
d) To reduce its dependence on imported fossil fuels and feedstock
e) To invent the indigenous manufacturing capabilities in the areas of green energy
f) To boost up the investment and business opportunities for the related industry
g) To enhance the scope employment opportunities and economic development
h) To accelerate the supporting R&D projects for safe and secure consumption of green hydrogen including its storing, transportation etc.

ISSN NO.2395-0692
IJAHMS International Journal of Arts, Humanities and Management Studies

Union Budget 2023 of India has put forward a big emphasis to India's transition to clean energy by allocating of Rs 35,000 crore in priority capital investment towards energy transition and achieving India's goal of net zero carbon emission by 2070. An additionalsanctioning Rs 19,744 crore for the National Green Hydrogen Mission, India plans to increase its annual green hydrogen production to 5 million tonnes by 2030, reduce dependence on fossil fuel imports and cut greenhouse gas emissions by nearly 50 million tonnes. The mission outcomes are expected to abate nearly 50 MMT of annual greenhouse gas emissions, estimated cumulativereduction in fossil fuel imports over Rs. 1 lakh crore, job creation of over 6 lakh and providing an ambience of safe and secure energy transition with the help of green hydrogen. India occupies a huge edge in green hydrogen production owing to its favourable geographic conditions and the presence of abundant natural elements. The Government has given impetus in scaling up the gas pipeline infrastructure across the length and breadth of the country and has introduced reforms for the power grid, including the introduction of smart grids. Such steps are being taken to effectively integrate renewable energy into the present energy mix. With appropriate capacity addition to renewable power generation, storage and transmission, producing green hydrogen in India can become cost-effective which will not only guarantee energy security but also ensure self-sufficiency gradually.

MERITS OF GREEN HYDROGEN

1) Green hydrogen production with the help of renewable energy under the electrocatalytic hydrolysis technology is safe and green as it does not produce GHGs.

2) Green hydrogenis a high-density energy carrier with a mass-energy density higher than traditional fuels like gasoline and diesel.

3) Green hydrogen does not emanate from fossil fuels, including coal, oil etc. which are being extinct fastly and are not likely to be available in near future.

4) It offers carbon neutrality owing to its both of production as well as consumption process are free from carbon emission.

5) Producing green hydrogen through a zero-pollution, low-cost, and sustainable approach is the focus of future energy development across the globe.

DEMERITS OF GREEN HYDROGEN

1) It is possible to form hydrogen from electrolysis of water, but this uses a lot of electrical energy.

2) The initial cost of implanting renewable energy technique is substantially high.

3) It is also a highly flammable gas and can explode, making it potentially more dangerous than oil-based fuels.

4) The flame is almost colourless. Mixtures of hydrogen and oxygen – or hydrogen and air – can be explosive when the two gases are present in a particular ratio, so hydrogen must be handled very carefully.

5) As hydrogen is a gas, it must be cooled and compressed to make it into a liquid for storage. The storage tanks must be extremely strong to withstand the high pressures and also insulated to keep it

cold. It must be kept at around –250°C. This makes it much more difficult and expensive to store and transport than liquid fuels, such as petrol or diesel.

CONCLUSION

Green hydrogen technology has been able to spotlighta bright and optimistic blueprint for solving energy and environment relatedcrises like emission of GHGs, threat to lethal global warming. However, there are some challenges prevailing in the manufacture and utilisation of green hydrogen since its manufacture is solely dependent on renewable sources of energy. Academia and scientistshave to come forwardto propound theoretical and application-oriented technology for the large-scale production of green hydrogen from the aspects of hassle-free production, safety storage and transportation, optimum utilization of green hydrogen and the supporting infrastructure for constructing hydrogen refilling stations.Although the extensive implementation of green hydrogen technology faces considerable challenges, it is expected that with the joint efforts of researchers, enterprises, and governments, a highly efficient green hydrogen production mechanism and its efficient as well as hassle-free consumption will be evolved in the years to come. Green hydrogen will then be integrated into the lives of people as a conventional energy source and provide significant support for building a greener andsafe future habitat for all in a free and sustainable manner across the globe.

REFERENCES:

i. www.iea.org
ii. www.usenergy.com
iii. www.livemint.com
iv. www.statista.com
v. World Energy Investment Report, 2023
vi. Probeshika, Kolkata