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GREEN HYDROGEN OPPORTUNITIES FOR INDIA

DR. ARVIND KUMAR [1] | PRABHASH KUMAR [2]

[1] RESEARCH SCHOLAR, DEPARTMENT OF ENVIRONMENTAL SCIENCE, MAGADH UNIVERSITY, BODH GAYA

[2] RESEARCH SCHOLAR, DEPARTMENT OF ENVIRONMENTAL SCIENCE, MAGADH UNIVERSITY, BODH GAYA

ABSTRACT:

With increasing numbers of vehicles on roads, India is facing the issue of large vehicular emissions. The burning of crude oil is the major issue behind these emissions. India doesn't have enough resources to fulfill all the energy demands of vehicles and hence, imports crude oil from oil-rich countries. To tackle the issues associated with oil imports and vehicular emissions, there is a need to search for carbon-free alternate fuel that is available locally in sufficient quantity to meet India's energy demands. The green economy is a new concept evolving and gaining attention worldwide, the concept focuses on sustainable and environmentally friendly solutions. Hydrogen is such a carbon-free fuel that can help to achieve the targets of the green economy and the best means to store energy for a long time. Hydrogen is a high energy content fuel and has about zero greenhouse gas emissions when used in fuel cells. Hydrogen is not directly available in free form, but it can be produced using electrolyzers and various other techniques. India's continuously growing renewable power generation capacity gives the advantage to produce hydrogen from green sources like solar, and wind at the time of lower demand. The present review work focuses on the opportunities for India in green hydrogen production as the adaption of green hydrogen offers many benefits to India including energy security, and decarburizing the transport sector.

India is one among the largest energy consumers worldwide. Fuels contribute majorly to meet these energy demands leading to various environmental problems. Hence, this article discusses the different processes of water electrolysis as an alternate approach to produce highly pure hydrogen in an eco-friendly manner without any carbon emissions. Current status related to manufacturing, storage and transportation of hydrogen have also been discussed. Challenges faced regarding green hydrogen in India, such as cost, conveyance, storage, policies and public acceptance have been highlighted along with some of the action plans for hydrogen production in India with their estimated cost and completion time.

KEYWORDS:

INTRODUCTION

Hydrogen has been in use for many decades in sectors like refining and chemical industries. However, its use as an energy source has started receiving increased interest only in recent years. As this interest and end-use grow, the demand for hydrogen will also grow with an expected compound annual growth rate of 5.48% from 2019 to 2025. To ensure that this demand for hydrogen is met sustainably and with minimal impact on the environment, the production of hydrogen should have minimal or no carbon emissions. Such hydrogen, referred to as Green Hydrogen, can be produced from renewable, nuclear or fossil fuels with carbon capture, utilization and storage (CCUS). Emissions from green hydrogen production can range from 43 gCO2e/kg of hydrogen produced using electrolysis to 9.3 kgCO2e/kg of hydrogen produced using steam reforming process without carbon capture. To provide a context, one kg of hydrogen has an energy equivalent of one gallon of gasoline which produces 9.1 kgCO2 during combustion. The major end use of transport using fuel cells have an efficiency of more than 50% (60% for conversion of hydrogen into electricity and 90% for conversion of electricity into kinetic power) as against the 25% efficiency of internal combustion engines. That is, for similar miles, emissions from hydrogen is half that of gasoline considering production to tailpipe. Commercialization and deployment of green hydrogen on a large-scale faces significant challenges. This work, therefore, highlights the current challenges for the commercialization of green hydrogen across the four phases: production, storage, transport and distribution, and end-use. The challenges highlighted here are based on the high-level review of more than 200 completed or on-going hydrogen projects across the globe.

Hydrogen is the most abundant element on earth which is mostly present in the gaseous state. Around 90% of all atoms are hydrogen atoms. Due to lack of natural deposits on earth, hydrogen can be derived from the different chemical compounds using different processes. The hydrogen requirement is increasing day by day and may increase at a rate of between 3 and 10 times by 2050.

Hydrogen can be divided into different categories, namely, “grey hydrogen”, “brown hydrogen”, “blue hydrogen” and "green hydrogen". Grey Hydrogen is the hydrogen that is produced from steam methane reformation while brown Hydrogen is produced from gasification of coal or Ignite. Blue Hydrogen is produced from fossil fuels with carbon capture and storage and Green Hydrogen is produced from renewable electricity like solar electric it for water electrolysis.

In the world, 71% of the produced hydrogen approximates to 'grey' hydrogen while the rest is 'brown' hydrogen. Processes for the production of hydrogen e.g. Steam Methane Reformat ion, Gasification of coal and ignite have been used for the decade, but the main challenge with these processes is environmental pollution. While using these methods there is a high amount of carbon emission. To reduce this pollution, countries are opting research towards the area of blue and green hydrogen. The production process of blue hydrogen is aligned with carbon capture and storage units which are not yet extensively commercial. To overcome the mentioned obstacles, now the world is moving towards green hydrogen technology in which hydrogen is produced from water electrolysis using renewable resources. Green hydrogen production process leads to zero carbon emission and gives pure hydrogen, whereas grey or brown hydrogen contains impurities. With the increase in solar based and wind power energies, the framework costs will change and ought to be lower in the future. When there's excess renewable, costs will drop, turning out to be savvy for green hydrogen. Green hydrogen in this manner becomes both a type of vitality stockpiling and an adjusting device for renewable.

As of now, green hydrogen is associated with numerous business applications, for example, ammonia production, in refineries and as a raw material for chemicals. Nonetheless, the major application areas of green hydrogen are steel industry, aviation industry and long-distance freight transport industry where there is no undeniable choice to decarbonize. These industries are facing many problems to continue their work, for example, maintaining their social permits, and usage of low-carbon hydrogen is one approach which could prove helpful. One of the biggest reasons to choose hydrogen is that it burns clean, leaving only water vapour. Industries which require high temperatures like Steel Industries, foundries and Glass industries, this could be a turning point in supplanting petroleum derivatives.

In India energy demand can develop by 4.5% every year until 2020, and after 2020, the economy will develop at 7–8% yearly, in light of the current vitality utilization estimations. The development contrast between vitality request and gracefully relies upon imported oil for the expanded vitality utilization. The oil-based efficiency in India is a weight on account of the high utilization of vitality every day or year and the significant expense to import oil. In this manner, supplanting's for imported oil with sustainable power source from India could make sure about vitality flexibly, and with inexhaustible hydrogen, the significant impacts of the up and coming vitality emergencies can be limited. India is a more developing nation than the other Asian nations, and India's means towards an inexhaustible hydrogen economy have a fundamental job in the globalization and look for a universal move toward the sustainable hydrogen economy. India has far reaching vitality potential from sustainable power sources, for example, sun-oriented vitality, hydropower, wind vitality, and great biomass potential. Reports have suggested that India has started to use these assets for a hydrogen economy.

1. GREEN HYDROGEN PRODUCTION

Green hydrogen is commonly produced by electrolysis, steam reforming and fermentation. A brief description of the production method and the associated challenges are as follows.

A. ELECTROLYSIS: Electricity is used in this process to split water into hydrogen and oxygen. This process has an efficiency of around 60-80% by calorific value. The commercialization and large-scale deployment challenges of electrolysis are as follows.

i. Need for improved overall energy efficiency.
ii. Need for additional onsite compressors.
iii. Low lifetime of electrolysers (<5 years).

B. STEAM REFORMING: Steam reforming can be used to convert methane, liquids derived from biomass resources, and biogas to hydrogen. This process provides the advantage of being a mature technology and easy transportation of input fuels with conversion on-site or at refuelling stations. If methane or natural gas is used, then additional carbon capture mechanisms should be in place to limit the net emissions. The challenges associated with this method are as follows.

i. High complexity of the reforming process due to the relatively larger molecule sizes of biomass-derived liquids than fossil fuels.
ii. Low overall efficiency of the process (currently around 40%).
iii. The reformer should be able to adapt to different compositions and flow rates of biogas or bio fuels and local heat sources.

C. FERMENTATION: In this process, sugar-rich feedstock from biomass is fermented to produce hydrogen using microbes either through direct hydrogen fermentation or microbial electrolysis cells (MECs). The challenges associated with fermentation are as follows.

i. Low overall efficiency of the biogas reactor.
ii. Low rates and yields of hydrogen production from fermentation.
iii. Scaling-up of MEC systems while maintaining production rates and system efficiencies are not yet proven.

A series of alternative production methods to split water is also under development. For example, high-temperature water splitting, photo biological water splitting, photo electrochemical water splitting, low-temperature hydrogen production by replication of photosynthesis, and extraction of hydrogen by product from chemical industries.

2. STORAGE OF HYDROGEN

Hydrogen is stored typically by three methods: compression, cooling, or hybrid. Material based hydrogen storage is also being developed in the form of solids, liquids, or surface-based materials. Hydrogen can be stored on-site or bulk where in on-site storage is used for production plants and end-user applications, and bulk storage is used for large amounts of storage in geographical hydrogen storage (e.g. in salt caverns, abandoned mines etc.). However, there are some challenges with the storage of hydrogen as discussed below.

i. High energy requirement in compressed hydrogen storage, due to low specific gravity.
ii. Temperature and pressure requirements while storing hydrogen in solid form.
iii. Design aspects, legal issues, social concerns, and high cost.
iv. Low durability of materials (fiber, metals, polymers etc.) for storage and potential chemical reactions raise safety concerns.
v. Bulk storage at geographic features may contaminate the hydrogen creating the need for further purification before end-use.

3. TRANSPORT AND DISTRIBUTION OF HYDROGEN

Hydrogen can be either used onsite or transported and distributed to the end-user locations. The common methods of transport and distribution of hydrogen are pipelines, high-pressure tube trailers, and liquefied hydrogen tankers. Pipelines are currently the least expensive way and are already in use near large refineries and chemical plants. Liquefied hydrogen tankers transport the hydrogen that has been cooled to a temperature where it becomes a liquid. This increases the density of distributed hydrogen, making it more efficient for transportation than high-pressure tube trailers. However, if the delivery and consumption rates are not matched, the compressed hydrogen will evaporate causing significant losses and ineffective utilization. The challenges in transport and distribution of hydrogen are as follows.

i. Existing hydrogen transportation pipeline infrastructure is not sufficient to meet future demand.
ii. Existing natural gas pipelines cannot be directly used for hydrogen due to embrittlement. Though mixing of hydrogen with natural gas is considered an option, it significantly affects the life of the pipelines even at 5% concentration by volume.
iii. Lack of fine control of the flow of hydrogen at refuelling stations. The flow of hydrogen has a significant impact on evaporation and losses of the system.
iv. Fluctuations in temperature during fast transfers of compressed hydrogen have to be controlled optimally to minimize losses and prevent thermal instability.
v. The network of hydrogen refuelling stations has to be increased.
Alternate ways for transporting hydrogen, for example using liquid organic materials as hydrogen carriers, are being researched to enable a low-cost high energy density transfer of hydrogen.

4. END-USE OF HYDROGEN

Hydrogen can service multiple end-users with its major application in energy use for the supply of electricity or heating through combined heat and power units, power for remote or off-grid applications like telecom towers, automotive sector, etc. Hydrogen based Fuel Cell Electric Vehicles have higher efficiency than gasoline-based vehicles, long driving range, and no emissions, thus offering a potential solution for future sustainable transportation. The use of hydrogen fuel cells for portable applications in portable electronic devices like mobile phones and personal computers are being explored. There are various advantages of fuel cells over battery systems like a longer lifetime, zero end-use emission, higher efficiency, cleaner fuel (hydrogen), lower weight etc. However, when it comes to end-use there are several challenges which need to be addressed before the large-scale commercialization of hydrogen as discussed below.

i. Need for weight, volume, and cost minimization of compressed hydrogen gas tanks for vehicles and fuel cell stacks.
ii. Efficiency, degradation issues, durability, resiliency, size as well as power, and current densities of the fuel cell need improvement.
iii. Lack of systems monitoring the performance and state of health of the system.
iv. High complexity of the fuel cell system especially with thermal and water management, purification, and humidification.
v. Low run time of fuel cells for portable electronic devices has to be improved without increasing the size.

THE CHALLENGES FOR COMMERCIALIZATION THAT ARE RELEVANT ACROSS ALL PHASES ARE AS FOLLOWS.

i. High overall costs of the system including capital, operational, maintenance, and running costs.
ii. Supply chain development across all the pillars is still in its nascent phase.
iii. Integration with other energy vectors using information and communication infrastructure.
iv. Need for legal and administrative adherence, certification mechanisms, recommendations, and regulations for different components of the system.
v. Low user acceptance and social awareness.
vi. Developing after-sales service for hydrogen

technology.

In summary, green hydrogen has the potential to act as a lever to decarbonize the energy sector, especially the hard to reach areas of heating and heavy-duty transport. The advancement in digitalization offers various opportunities to harness Hydrogen as one of the prominent sources for energy and storage for energy needs. However, for maximizing the potential and commercialization, challenges spread across all four phases have to be addressed.

HYDROGEN PRODUCTION PROCESS

Green hydrogen can be produced using methods utilizing renewable resources, such as, through water splitting that produce pure hydrogen without harming environment. Water splitting can be achieved via electrolysis of water, which can be defined as the disintegration of water into oxygen and hydrogen by passing electric current through it .As the input energy source is electric current, therefore, this process is considered as expensive.

A water electrolysis cell consists of two plates of opposite polarity- anode and cathode which are connected through an external power supply and immersed in a conducting electrolyte. A direct current is applied to the cell to make the electrons move towards cathode from negative terminal of power source. Water electrolysis can be performed using two major processes, namely, alkaline water electrolysis, and PEM water electrolysis.

ALKALINE WATER ELECTROLYSIS

In alkaline water electrolysis, the electrolyte used is a strong base. The hydroxide ions are produced which move towards anode where they lose their electrons and return to the positive terminal of the DC power supply, The process takes place at lower temperatures (30–80 °C) in presence of either of aqueous solution of KOH or NaOH as the electrolyte. To separate the cathode and anode, in the middle of the cell unit. It also serves to avoid the mixing of the product gases.

Efficient and economically suitable catalysts are required for a sustainable production of the hydrogen in the process. Among the various catalysts that were analysed for anodes and cathodes, thin films of LaNiO3 on Nickel were also tested resulting in the best electro catalyst activity with 6 mg cm–2 of oxide film loading. With the help of two- step hydro thermalized method, a N-rGO-MoS2-Ni$(OH)_2$ nanocomposite was prepared for improved electro catalytic activity. It has a shape of marigold. One of the major drawbacks of the utilization of this method is less productivity. Activated nickel electrode has been developed by CSIR-CECRI for alkaline electrolyser.

Another technology which is in development stages in the field of alkaline water electrolysis, focusses on anion exchange membranes (AEM) which are made up of polymer materia ls having anionic conductivity.

SOLID OXIDE ELECTROLYSIS

Solid oxide electrolysis (SOE) is a process in which electric current changes in to chemical energy to produce hydrogen which is highly pure. This process, unlike the other two process discussed, takes place at higher temperatures of 500–850 °C and high pressure. In this process, hydrogen gas and negatively charged oxygen ions are produced when the water at the cathode combines with the electrons. These oxygen ions travel through the diaphragm to form oxygen gas at the anode. Being highly efficient and super ionic conductive at 500–700 °C, ceramic proton conducting materials are used for this electrolysis process instead of the traditionally used O2− conductors. Some of the drawbacks associated with the process include reduced stability and degradation, stopping it from being used for large scale commercialisation.

THERMOCHEMICAL SPLITTING OF WATER

For thermo chemical splitting of water, high temperature and a catalyst is needed to produce hydrogen and oxygen. One or more of the various sources such as solar energy, nuclear energy, or fusion of solar and nuclear energy can be used to provide the required energy for the process. Most of the cycles such as iron oxide, cerium (IV) oxide-cerium (III) oxide, sulphur- iodine and others are under research. It has been found that the iodine- sulphur (I-S) cycle is one of the most effective thermo-chemical water splitting technologies for the high scale production of hydrogen. It is being worked upon by BARC, Trombay, Mumbai. This closed loop glass system has been functioned continuously for 20 hours at the rate of 30 Lph of hydrogen production. India is one of the five countries to accomplish this closed loop cycle in glass system. The other five countries, being, USA, Japan, China and South Korea. This system was efficaciously demonstrated by Bhabha Atomic Research Centre in quartz/glass material in Lab. Further, it is planned to establish it in metallic construction.

REVERSIBLE FUEL CELLS

This technology is a combination of the functions of both, an electrolyser and a fuel cell into one device that can save capital cost. Therefore, this process is being extensively researched. However, this system can affect the operating cost as they cannot function at maximum efficiency in both modes.

CONCLUSION

Due to zero-carbon emission, hydrogen can be known as a future fuel. Various different processes for hydrogen production such as steam methane reforming method, coal gasification, biomass gasification, and photo electrochemical reforming leads to carbon emission leading to environmental issues. In order to overcome this problem, now the research is being focussed on means of green hydrogen production, i.e., via renewable resources. There are several factors which plays critical role for the acceptance of green hydrogen in India, the major being the cost related to the requirement of more electricity to produce hydrogen as compared to the conventional methods and equipment cost. Most of the parts of electrolyser are manufactured in India except the electrochemical stacks. Therefore, in order to reduce the equipment cost, it would be beneficial to work on the production of electrochemical stacks, indigenously, keeping in view the essential requirements. As discussed in the article, water electrolysis is a major technology for green hydrogen production that uses solar/wind powered electricity for water splitting. To meet and fulfil the demand of electricity needed for water electrolysers, different sources and technologies can be focussed for reduction of the cost, and to enhance the efficiency of electricity production via renewable resources. Despite of the fact that green hydrogen is produced with zero carbon emission, cost of its production through water electrolysis and its storage complications limits extensive utilization of hydrogen in India. Comprehensive research work and steps are needed to be taken to control the cost of green hydrogen production. The major area that needs to be focussed, after production, is the storage as hydrogen has a very lower density which makes its transportation and common use, far from feasible.

Briefly, major government actions and R&D is required to change from fossil fuel-based economy to the renewable hydrogen economy in order to produce green hydrogen to meet the growing energy demands as well as for the proper implementation of these technologies.

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