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Original Research Article

Hydrogen the energy of the future: From production to applications

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ABSTRACT
Using hydrogen and/or chemicals containing hydrogen to produce energy with great energy efficiency, overwhelmingly positive environmental and social effects, and competitive economic rewards is known as hydrogen energy. The globe is now experimenting with the introduction of hydrogen energy in all areas, including feedstock production, energy generation, storage, and distribution, industry, transportation, and power, heat, and cooling for homes and buildings. The transition from the current fossil fuel-based economy to a circular economy—a renewable circular sustainable fuel utilisation cycle that will characterise the highly efficient engineering and the energy technological choices of the 21st century—is being fueled by two key factors: energy efficiency and sustainability. In this paper, the energy of hydrogen is discussed. The production methods and applications are also discussed.

1. Introduction

The world is on track to achieve international climate commitments and continues to address the challenges of climate change. In such a situation, the importance of hydrogen is increasing day by day, because it is a source of conventional fuel that can meet the need of clean energy [1]. Hydrogen is being considered the energy of the future, with the potential to replace fossil fuels. With its use, the emission of carbon dioxide can be reduced, which is also possible to control the threat of climate change. While fossil fuels have been responsible in getting our society to the point it is at today, there are four big problems that fossil fuels create: air pollution, environmental pollution, global warming and economic dependence. These consequences were leading the world toward what is broadly known as the hydrogen economy [2].

The use of hydrogen energy will not be limited to the transport sector, but it will also be used in industries like chemical, steel, iron, fertilizer etc. Also, with its use, the increase in the demand for energy in the future can also be met. At present, most of India's electricity generation is produced from coal. Therefore, the introduction of hydrogen energy will replace fossil fuels, thereby controlling pollution levels and oil-price rise in the future [3]. Thus hydrogen energy is being focused to achieve the energy potential of the most abundant element on Earth in the form of hydrogen and to revolutionize the transportation sector [4].

Hydrogen - a colorless, odorless gas is being seen as the energy of the future free from environmental pollution [5]. Its new uses have been found in vehicles and power generation sector. The biggest advantage with hydrogen is that the element has the highest energy per unit mass among known fuels and it releases water as a by-product after burning. Hence it is not only full of energy efficiency but also environment friendly [6].

In India, the Ministry of New and Renewable Energy has been supporting a massive Research, Development and Demonstration (RD&D) program for the last two decades on various aspects of Hydrogen Energy. As a result, a National Hydrogen Policy was formulated in the year 2005, which aims to provide new dimensions of development related to the production, storage, transportation, security, distribution and applications of hydrogen energy. While the existing technologies for the use of hydrogen are yet to be optimally utilized and commercialized, efforts have been initiated in this regard [7].

2. Production of hydrogen

Hydrogen is found only in the mixed state on Earth and therefore it is produced by the process of decomposition of its compounds. It is a method that requires energy. In the world, 96% of hydrogen is being produced using hydrocarbons. About four percent of hydrogen is produced through the electrolysis of water. Oil refining plants and fertilizer plants are the two major sectors that are producers and consumers of hydrogen in India. It is produced as a by-product in the chloro-alkali industry.

Hydrogen can be extracted from water, biomass, fossil fuels, or a combination of the three. Currently, natural gas is the main fuel used to produce hydrogen, making up roughly 75 percent of the 70 million tonnes of dedicated hydrogen produced annually worldwide (Figure 1). This makes up around 6% of the world's natural gas consumption. Due to coal's dominance in China, gas comes in second, and a negligible amount is produced through the usage of oil and electricity [8]. A variety of technical and economic considerations, with gas prices and capital expenditures being

the two most significant, affect the cost of producing hydrogen from natural gas.

Between 45% and 75% of manufacturing expenses are accounted for by fuel expenditures, which are the major cost factor. Some of the lowest expenses for hydrogen generation can be found in the Middle East, Russia, and North America due to low gas prices. Gas importers like Japan, Korea, China, and India must deal with rising gas import prices, which increases the cost of producing hydrogen as a result.

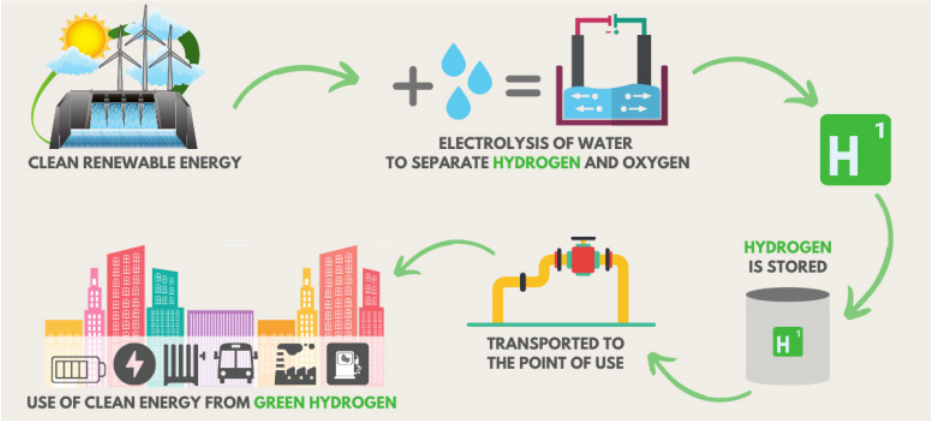

Figure 1. Production of green hydrogen

There are three different ways to produce hydrogen, the first of which is thermal; the other two are electrolysis and photolysis [9]. Some thermal methods require energy resources, while others use heat in combination with closed chemical reactions to produce hydrogen from reactants such as water. This method is called the thermal chemical method. But this technique is adopted at an early stage of development. Heat methane recycling, coal gasification and biomass gasification are also other methods of hydrogen production [10]. The advantage of coal and bio-fuels is that both are available as local resources and bio-fuels are also renewable resources. When water is broken down into hydrogen and oxygen using the electrolysis process, there is also a decrease in the production of greenhouse gases [11, 12] if the energy source is clean.

3. Storage of hydrogen

Storage of hydrogen for transportation is the most challenging of all technologies in view of the large commercialization of related technologies. The most common method of storing it in the gaseous state is by placing it in a cylinder at high pressure. However, it is the lightest element that requires high pressure. It is kept in a cryogenic system in a liquid state, but it requires more energy. It can also be kept in solid state in the form of metallic hydride, liquid organic hydride, carbon microstructure and chemically. Government of India is assisting in R&D projects in this area.

4. Types of hydrogen energy

Gray Hydrogen: It is derived from fossil fuels. Its by-product is carbon dioxide.

Blue Hydrogen: This is also obtained from fossil fuels. But the by-products released from it are absorbed and stored carbon monoxide and carbon dioxide. Thus it is environmentally superior to gray hydrogen.

Green Hydrogen: By separating water into hydrogen and oxygen, green hydrogen can be produced. Renewable electrical energy from sources like sun and wind is employed in its production. Both water and water vapour are its byproducts. It is a clean source of fuel.

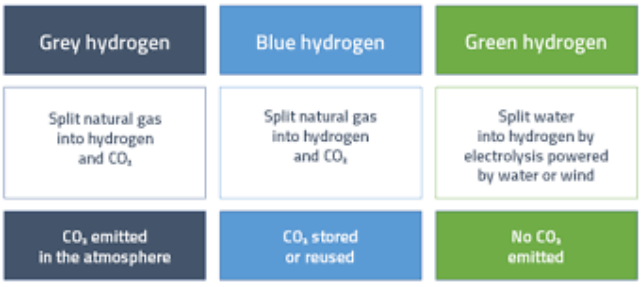

Figure 2. Types of hydrogen energy

5. Hydrogen economy and hydrogen energy

Hydrogen economy refers to a system of economy in which most of the energy needs will be met by hydrogen. The term 'hydrogen economy' was first used by John Bockris in 1970. He had told that the hydrogen economy can replace the existing hydrocarbon economy, which can create a clean and pollution free environment.

Carbon-free fuel hydrogen is regarded as a significant source of clean energy. It is the sole energy source that emits only water vapour and doesn't leave behind any hazardous waste. It can be created using clean energy sources like solar and wind power. Hydrogen energy can also be created by electrolysis and natural gas reforming. Figure 3 depicts the potential for hydrogen production globally.

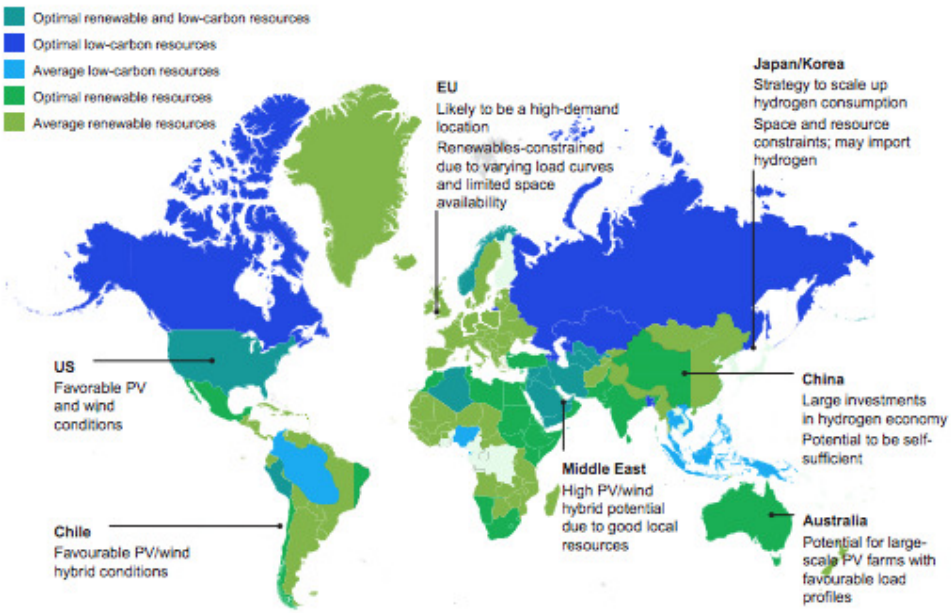

Figure 3. Hydrogen production potential across world-wide

6. Hydrogen economy in India

In the initial efforts of hydrogen energy, in the year 2006, the Ministry of New and Renewable Energy constituted a high-level committee to prepare the hydrogen energy roadmap. After this, in 2016, Dr.K. The Kasturirangan committee had recommended the adoption of this clean energy by preparing a report on hydrogen and fuel cells. Focusing on this source of energy, the Government of India has announced a 'National Hydrogen Energy Mission' in the budget 2021-22 to prepare a hydrogen roadmap in the country [13]. This mission focuses on producing hydrogen energy from renewable energy sources. By reaching this aim, India will get closer to its targets of decarbonization by 2050 and 175 GW of renewable energy capacity by 2022. The mission will outline precise long-term concepts as well as short-term (4 year) initiatives (10 years and above). India is to be transformed into a centre for the worldwide production of fuel cell and hydrogen technology along the entire value chain [14].

Presently, pilot projects of Hydrogen CNG (H-CNG) are under progress in India. Hydrogen CNG is produced by mixing hydrogen with compressed natural gas (CNG), which is being used as a transportation fuel and in industrial units related to oil refining. It is known that Delhi became the first Indian city to employ H-CNG buses in October 2020. The scheme will be rolled out in other major cities of India in the coming months as well. Companies like Indian Oil Corporation and NTPC Limited are working towards H-CNG. It will be produced with carbon capture technology resulting in production of blue hydrogen.

Efforts are on to transport hydrogen by building CNG pipeline infrastructure so as to reduce its transportation cost. In addition, its synergy with natural gas allows hydrogen to be combined with a variety of energy options without having to wait for large infrastructure to be developed.

7. Advantages and disadvantages of green hydrogen

Hydrogen is a basic element of the earth which is abundantly available as well as a renewable source of energy. In its generation and combustion processes, green hydrogen does not release any harmful gases and is simple to store. As a result, it is a sustainable resource. It is readily transformable into electrical energy and synthetic gas, both of which have home, commercial, and industrial uses. Up to 20 percent of natural gas can be blended with it. As a strong and effective source of energy, it can be utilised as rocket fuel. Crew men on space stations can also receive water using green hydrogen. Because it can provide more energy per pound of fuel than diesel or gas, it is a considerably more effective fuel source. Additionally, it can be applied to air, sea, and heavy freight.

Green hydrogen is currently produced using electrolysis using renewable energy sources, which can raise the cost of production. Compared to other fuels, it requires more energy to produce. Hydrogen separation from water is a technologically sophisticated and expensive procedure. Due to the gas's high volatility and flammability, stringent safety precautions must be taken to avoid leaks and explosions.

8. Green hydrogen policy in India

The government has announced a policy to make green hydrogen and green ammonia. This is the first step under the National Hydrogen Mission. India aims to become a green hydrogen hub as part of this mission, according to the government. By 2030, the government wants to produce 5 million tonnes of green hydrogen. On August 15 of last year, Prime Minister Narendra Modi unveiled the National Hydrogen Mission.

The government is considering hydrogen and ammonia as the major fuels of the future. It will replace fossil fuels (petrol, diesel, coal) in future. According to the new regulation, businesses that produce green hydrogen can purchase renewable energy from the power exchange. Additionally, businesses can build their own renewable energy facilities.

In green hydrogen policy in India, permission will be given within 15 days from the date of submission of Hydrogen Production Application. Inter-state transmission duty exemption will be available for 25 years if it is launched before

30 June 2025. A company with a hydrogen mission can keep renewable energy for up to 30 days. A website will be created for the hydrogen mission, in which all the work related to it will be done at one place. The company that makes Green Hydrogen and Green Ammonia will be given storage space near the port for export and shipping. India wants to become self-reliant in future fuel. Making green hydrogen and green ammonia is being discussed since it is thought that this will be a key source of fuel in the future. India aspires to achieve self-sufficiency in fuels like green hydrogen and green ammonia under this plan.

India does not wish to rely on other nations for these fuels, similar to how it does with petroleum. On August 15, 2021, Prime Minister Narendra Modi made the first step official by announcing the National Hydrogen Mission. Numerous businesses, including Reliance, Tata, and Adani, have begun making preparations for the Hydrogen Mission since it was announced.

9. Applications of hydrogen

Apart from being used as a chemical substance in industries, hydrogen can also be used as a fuel in vehicles. Additionally, it can be used to produce power using fuel cells and internal combustion engines [15]. In the area of hydrogen, R&D projects for use of internal combustion engines, hydrogen containing CNG and diesel and development of hydrogen fueled vehicles are being carried out in the country.

Hydrogen fueled motorcycles and three wheeler scooters have been manufactured and demonstrated. Catalytic combustion cooker using hydrogen fuel has also been developed. In India, Banaras Hindu University has improved commercial-profit motorcycles and three-wheelers to run on hydrogen fuel. In order to equip automobiles with hydrogenated CNG, an HCNG station has been established in Dwarka, New Delhi, for which the Ministry has also provided some financial support. Up to 20% hydrogenated CNG gas is supplied from this station for demonstration and test vehicles. A development-cum-demonstration project is also being implemented to use Hydrogenated CNG (HCNG) as fuel for certain types of vehicles – buses, cars and three wheelers. Banaras Hindu University and Indian Institute of Technology-IIT, Delhi are also developing generator sets powered by hydrogen fuel.

Fuel cells, an electrochemical device that directly transforms the chemical energy of hydrogen into electricity without combustion, are another application for hydrogen energy. It is a clean and efficient system of power generation. It can be used in place of batteries and diesel generators in UPS systems i.e. systems with uninterrupted power supply. Considering the suitability of fuel cells in vehicles and power generation, many organizations around the world are conducting research and development in this area. There are also experiments about using these fuel cells by moving them from one place to another.

The current emphasis is on lowering the price of fuel cells and lengthening their shelf life. The Ministry of New and Renewable Energy's Fuel Cell Program in India aims to aid in the research and development of various kinds of fuel cells.

10. Conclusions

At present, it is very important to promote green fuels to prevent the rapidly increasing global warming and the emission of greenhouse gases, so as to ensure a clean environment for the future generations. Efforts are being made to build a hydrogen energy based economy as energy of the future. India is moving rapidly in the direction of changing energy sources as a result of its extensive efforts. For this, National Hydrogen Energy Mission has been announced recently by Government of India, which manifests the commitment to convert India's hydrocarbon economy into a hydrogen economy.

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