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Future Fuels: Harnessing Hydrogen from Biomass for a Sustainable Tomorrow

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Abstract*: Green Hydrogen has a lot of promise in India because the country has a self-sufficient and developed renewable energy sector, particularly in solar energy. With its uses in fuel cell-based vehicles for transportation, steel, cement, refining, chemical, and fertilizer industries, as well as net zero emission targets for India, it may prove to be the fuel of the future for energy security. More than $76 billion in government money has been allocated to at least 43 countries that have established or are establishing roadmaps or policies for a hydrogen economy. With the government's announcement of a green hydrogen strategy in February 2022, as well as the investment in the technology by a number of private industrial firms like Reliance and Adani and public sector undertakings like IOC, GAIL, and NTPC, India has also seized the lead. The industry is beset by obstacles such as high production costs, little current R&D, lack of market demand, transportation and storage needs, water availability, reliance on renewable energy tariffs for cost, and safety concerns. In order to attain widespread implementation and economies of scale, India must concentrate on generating demand through purchase mandates, establishing a stable regulatory framework with appropriate policies for market creation, lowering reliance on imports for raw materials needed by the solar and electrolyzer industries, and allocating enough resources to technology research and development and the development of a green hydrogen supply chain.

Key Words: Fuel cells, electrolyzes, green hydrogen economy, green hydrogen India, and renewable energy sources in India.

INTRODUCTION

India is the fifth most polluted country or region in the world (IQAir, 2021). 73% of India's greenhouse gas emissions are attributable to the energy sector, with electricity generation accounting for 43% of these emissions (GWEC, 2021). Given that it is a growing nation, the demand for energy is expected to increase by 9.9% annually through 2025 (GWEC, 2021). India must immediately decarbonize its energy-intensive industries, including power, transportation, and industry. India has also started down the path towards renewable energy, having set a goal to install 500 GW of non-fossil fuel electricity by 2030 at the COP26 summit in Glasgow. Furthermore, it has pledged to attain net zero emissions by 2070, which refers to the equilibrium between produced and reduced emissions. (Subrahmanyam,2022). The renewable energy sector, which is primarily made up of solar and wind power, has advanced to the point where it can support itself on stabilized tariffs. When combined with other renewable energy technologies, hydrogen can be extremely helpful in reaching our country's energy objectives, especially in light of the transportation and industrial sectors' constantly rising energy demands. According to Priya (2021), hydrogen is a carbon-free, non-polluting energy source with the highest energy content by weight and the lowest energy content by volume.

Global attention is now primarily focused on green hydrogen as a renewable energy source and industrial feedstock. The hydrogen roadmaps of Australia, Japan, and the European Union (EU) have already been released (Biswas et al., 2020). With the overarching goal of increasing the production and use of green hydrogen and bringing India's efforts into line with international best practices in technology, policy, and regulation, the Indian government launched the National Green Hydrogen Mission on August 15, 2021 (Priya, 2021). On February 17, 2022 (MoP, 2022), the government furthered this momentum by announcing India's Green Hydrogen Policy.

In India, green hydrogen is still in its infancy as it enters the energy industry. It is still too expensive to have a sustainable business model, and the green hydrogen economy as a whole is still developing. Due to all of this, research on green hydrogen in India is necessary in order to understand the industry's current state, potential for expansion, and numerous obstacles. To the best of the author's knowledge, there is a dearth of thorough study on green hydrogen in India and just a small amount of literature available on the subject. It makes it necessary to research green hydrogen in India in order to understand the industry's current state and the different obstacles it may encounter. This paper fills a vacuum in the relevant literature.

The explanation of research methods is provided in Section 2. An summary of hydrogen's industrial uses, energy applications, and definition of "green hydrogen" is provided in Section 3. In Section 4, the global status of green hydrogen is provided. Section 5 provides a detailed explanation of the National Green Hydrogen Mission and Green Hydrogen Policy. The stakeholders and value chain in the green hydrogen economy are outlined in Section 6. Section 7 discusses how green hydrogen is affecting India's present industries and sectors. The effects of green hydrogen on current industries are discussed in Section 8. Section 9 outlines the obstacles and path forward. Section 10 provides limitations and the scope of future research, followed by the conclusion and policy implications in section 11.

Methods of Research

The research technique has been a systematic literature review. Key phrases for the search included "use of hydrogen in India," "green hydrogen in India," "challenges in green hydrogen in India," "hydrogen as a source of energy," and "status of green hydrogen in the world."

Articles on the utilization, policy, status, and technological aspects of green hydrogen in India were taken into consideration. Because there are so few research articles on the topic, the writers had to rely on what is known as "grey literature," which includes data from government websites, studies and reports from businesses, and stories from newspapers and magazines. 35 items in total were found and examined.

Hydrogen as a Potential Energy Source.

Compared to diesel or gasoline, hydrogen has an energy density that is about three times higher (Agarwal et al., 2022). Fuel cells utilize hydrogen to produce both heat and electricity, which is why hydrogen is becoming a vital component of transportation technology. Other significant uses of hydrogen include the manufacturing of fertilizer and the refining of petroleum (Satyapal, 2017).

Synthesis of Hydrogen

The most popular method for creating hydrogen is steam methane reforming, which produces hydrogen by the reaction of steam with a hydrocarbon fuel at a high temperature.

Another popular method for separating water into oxygen and hydrogen is the electrolysis process. Hydrogen gas can also be produced by biological processes. Furthermore, sunlight is used via processes including solar thermochemical, photo-electrochemical, photovoltaic-driven electrolysis, and photo-biological to create hydrogen (Satyapal, 2017).Based on the method or source of production, hydrogen has been color coded as a global.

Table 1: Utilizing several methods and color labeling to generate Hydrogen

Color Code	Technology Used/Process
Green	Using renewable energy sources, electrolysis (the process of splitting water with electricity)
Blue	Natural gas reforming via the thermochemical process using CCUS
Grey	Natural gas is reformatted thermochemically without the need for carbon capture, utilization, and storage (CCUS).
Brown	Thermochemical Process with Lignite, or brown coal
Pink	Nuclear energy-based electrolysis

3.2 Generation of Green Hydrogen

Hydrogen created from renewable electricity is known as green hydrogen. Hydrogen electrolyzes, which take in power from renewable sources like sun and wind, are the apparatus where this splitting occurs. The value chain for green hydrogen is shown in Figure 1. The main characteristic of green hydrogen is that it doesn't release any harmful gasses when it is produced or burned. It can currently be blended with natural gas at a ratio of 20% and use the same gas pipeline transmission infrastructure. Any additional rise in this proportion or to ensure compatibility, transmitting it separately would necessitate alterations to the current gas networks. Physically, hydrogen can be kept as a gas in tanks with extremely high pressure (350–700 bar) or as a liquid at cryogenic temperatures. Additionally, solids can store hydrogen by adsorption on their surfaces or absorption within them (energy.gov, 2021).

Green Hydrogen Applications

Green hydrogen has multiple applications, including as an industrial feedstock and a fuel source for electricity and transportation. The different uses for green hydrogen are explained in more detail below.

3.3.1. Steel

Green hydrogen can be utilized as the reducing agent in direct reduced iron (DRI), which will enable almost emission-free steel manufacturing. Steel manufacture requires DRI as reductant.

3.3.2. Refinery Production

A refinery's ability to operate depends on hydrogen since it is necessary for the de-sulfurization of crude oil, which produces gasoline, diesel, and other chemicals. Currently, natural gas is used as the feedstock and steam methane reformation (SMR) is used in refineries to make it. Because of this process' significant co_2 production per tonnes of hydrogen produced, refineries want to go green in order to lower that amount.

3.3.3. Fertilizers and Chemicals

In order to produce synthetic nitrogen fertilizers like urea, ammonium sulphate, ammonium sulphate nitrate, and ammonium chloride, ammonia is one of the main ingredients. Traditionally, atmospheric nitrogen and hydrogen—which is currently made from fossil fuels—are combined to create ammonia. Additionally, this procedure uses a lot of co_2. Production of ammonia without emissions will result from the use of green hydrogen. Hydrogen may be transported as ammonia and then transformed back to hydrogen at the destination, making ammonia an easy substance to transport.

3.3.4. Cement

Globally, the cement sector is one of the biggest sources of carbon dioxide emissions. That uses a lot of energy and needs a temperature of 1500 degrees Celsius. In the cement industry, green hydrogen can be used in place of natural gas at such high temperatures.

3.3.5. Energy Source for Vehicles

Hydrogen can be used to power fuel cells. The most popular kind of fuel cell, the polymer electrolyte membrane (PEM) fuel cell, employs a thin surface known as a membrane to separate hydrogen and oxygen. Through an electro-chemical process, the hydrogen molecules in the fuel cell are further divided into protons and electrons. These electrons fuel the battery and further accelerate the car through an external connection. Water released from the exhaust is the only byproduct of the system. Compressed hydrogen is kept in a tank, just like gasoline or diesel. Long-distance trucking is a good fit for hydrogen cell refueling because it is far faster than charging battery cells and can resemble current diesel vehicles (Ralston, 2022).

3.3.6. Fuel for Power

In order to lessen reliance on natural gas, new gas turbines based on green hydrogen are also being developed. Currently, hydrogen power projects use grey hydrogen. Furthermore, there are certain specialized uses, such as the short-term energy source of replenishable hydrogen fuel cells in place of diesel generators.

Worldwide Situation of Green Hydrogen

The global targets to keep temperature increases to 1.5 degrees Celsius can be achieved in large part thanks to hydrogen. Numerous international initiatives towards the hydrogen economy have been taken as it was realized how important the same is. Global investments until 2050 are projected to be US$10.2t, government support for the switch to hydrogen is projected to be US$70b, and yearly sales by that time are projected to be US$2.5t (Moda, 2022). The world currently produces 75 million tonnes of hydrogen annually, however 98% of that comes from fossil fuels (The Green Hydrogen Catapult, 2021). Today, governments and business worldwide believe that green hydrogen—with its wide range of industrial applications—is essential to achieving a net carbon zero economy. Despite the fact that numerous nations have started initiatives aimed at developing, using, and expanding green hydrogen, the technology and its various industrial uses are still in their infancy and will only be implemented through pilot projects. Very little large-scale and widespread commercialization has been done (Ghosh and Chhabra, 2021). Approximately thirty nations worldwide have developed plans. for the development of green hydrogen and have set aside $76 billion (Gupta, 2021).In an effort to lower the price of green hydrogen, global leaders in the UN High Level Champions for Climate Action have helped the world make a the Green Hydrogen Catapult coalition. Additionally, it has pledged using secured funding. In order to develop and put into service 45 GW of electrolyzers by 2027. In addition to committing to producing 5 GW of low-carbon hydrogen by 2030, Britain has developed a Ten Point Plan for a Green Industrial Revolution ("The Ten Point Plan for a Green Industrial Revolution," 2021). With over 33 million tonnes of hydrogen produced annually, China leads the world in this regard. Collins, 2022). By 2025, Sinopec, the state-owned energy firm in China, plans to establish facilities that will generate 500,000 tons of green hydrogen annually using renewable energy sources (Reuters, 2021). In January 2022, Zhangjiakou, China saw the start of operations for one of the largest hydrogen electrolyzers in the world, with a 20 megawatt capacity, intended to manufacture green hydrogen for fuel cell vehicles during the Winter Olympics (Frangoul, 2022). In 2020, China implemented a new fuel cell vehicle subsidy program with the goal of expanding the FCEV industry's production capabilities and concentrating on the use of fuel cells in medium- and heavy-duty commercial vehicles (IEA, 2021). China plans to significantly increase the number of hydrogen-fueled vehicles from the present 7,500 to 50,000 by 2025 (Collins, 2022).

Approximately 10 million metric tons of hydrogen are produced annually in the United States; this amounts to 1% of the country's energy consumption. Of this, over 95% of the hydrogen produced is grey hydrogen. The majority of hydrogen generated in the United States is utilized for fertilizer manufacturing, metal treatment, and petroleum refining. Still, several new uses and applications for green hydrogen are on the horizon. There are currently about 40 hydrogen vehicle refueling stations operational. Furthermore, fuel cells with a combined capacity of roughly 250 MW are operational at about 110 industrial locations. In the USA, green hydrogen is now expected to cost $5 per kilogram on average. The US government has also introduced "Hydrogen Shot," a "1-1-1" target that attempts to bring the price of clean hydrogen down to $1 per kilogram in ten years, in recognition of the significance of green hydrogen. "THE PRESENT AND FUTURE OF HYDROGEN IN THE US ENERGY SECTOR," (2020). Table 2 below shows the Green Hydrogen Strategies of various countries.

Table: 2 strategies of various countries for using green hydrogen

Country	Year Hydrogen Strategy/ Roadmap Issued	Key Points of Emphasis
Japan	2017	seeks to bring costs into line with liquefied natural gas and other rival fuels. By 2030, the goal is to have electrolyzer costs of $475/kW, 70% efficiency, and $3.30/kg production expenses.
South Korea	January 2019	Focus on Electric Vehicles Using Fuel Cells
Australia	November 2019	The goal of "H2 under 2" is to produce green hydrogen at a cost less than AU$2/kg.
Netherlands	April 2020	In 2050, an entirely sustainable energy source Biogas and hydrogen account for 30% to 50% of the total energy consumed.
Norway	June 2020	Increase the amount of hydrogen used as an energy carrier in the maritime industry Government support for cutting-edge subsea hydrogen storage technology derived from offshore wind farms
Germany	June 2020	Capacity increase of electrolyzers to 5 GW by 2030 Production of 14 TWh of green hydrogen by 2030
European Union	July 2020	Targets for electrolyzer capacity are 6 GW by 2024 and 40 GW by 2030. Targets for renewable hydrogen production are 1 million tons by 2024 and 10 million tons by 2030.

France	September 2020	A total of €7.2 billion in investments by 2030, including €1.5 billion for the building of electrolysis units. A goal of 6.5 GW for hydrogen production capacity by 2030.
Spain	October 2020	4 GW of electrolyzer capacity installed by 2030 . Production of green hydrogen is expected to reach between 300 and 600 MW by 2024.
Chile	November 2020	By the 2030s, wants to be the world's most affordable producer of green hydrogen and a top exporter. A goal of 25 GW by 2030 and a cost per kilogram of hydrogen produced of less than $1.50
Canada	December 2020	By 2050, aim to supply up to 30% of Canada's final energy needs with green hydrogen. Aim for CA$1.50–3.50/kg for delivered hydrogen.

India's Current Situation with Green Hydrogen

India is the world's third-largest producer and consumer of gray hydrogen. It is mostly used as an industrial feedstock to make fertilizers with an ammonia basis. In India, grey hydrogen is mostly used. The Nangal Facility, which opened in 1962, was one of the first significant alkaline electrolyser plants in the world to create hydrogen from electricity (Hall, 2019). In India, green hydrogen technology is still in its infancy. Its manufacturing, storage, power generating, and transportation uses are the main focus of all agencies' pilot projects and research and development activities; commercialization and widespread implementation in India are still far off.

However, it is predicted that the cost of green hydrogen would drop to less than $1 per kilogram in the future, making India one of the lowest-cost producers of green hydrogen worldwide, given the country's extremely high potential for renewable energy and the correspondingly low cost of renewable energy. The goal of current Indian research is to enhance the water-splitting reaction's efficiency in the process of electrolysis. More than 100 research groups are focused on fuel cell technology, making it another important field of study. Additionally, there are several Indian and international businesses engaged in the production, storage, or distribution of hydrogen in India (Priya, 2021; ET, 2022).

India has a great deal of potential for using green hydrogen, which it plans to use three to ten times more by the year 2050. The National Hydrogen Mission was established on August 15, 2021, with the goal of positioning India as a major hub for the production and export of green hydrogen worldwide. India intends to produce five million tons of renewable hydrogen annually by 2030. In addition, distinct manufacturing zones and a 25-year interstate power transmission fee waiver are planned. Give manufacturers of green hydrogen and ammonia priority access to power grids in addition to offering incentives for production (Varadhan, 2022).

On February17,2022, the Indian government unveiled the Green Hydrogen and Ammonia Policy in an effort to provide more clarity and foster an atmosphere that is favorable and supportive of investments in the industry. The policy waives interstate transmission fees and provides unrestricted access to purchase electricity within 15 days of application. Manufacturers of green hydrogen and ammonia will have the option to establish their own renewable energy capacity or work with any other developer to install renewable energy through the power exchange. Renewable energy may be deposited by manufacturers with distribution firms for a 30-day period, after which they may withdraw it as needed. Distributing license holders are able to find and provide renewable energy to green hydrogen producers. ammonia in their states at a discounted cost. An additional component of the Renewable Purchase Obligation will be Green Hydrogen. For the purpose of exporting green ammonia, plans call for the construction of bunkers close to ports. Priority should be given to connecting renewable energy facilities to the grid in order to minimize procedural delays. This program is the Indian government's first real effort toward developing a green hydrogen economy, and it primarily helps those states where importing renewable energy from other states is necessary (Kumar, 2022)

India's recent advancements in green hydrogen

As of right now, the only hydrogen-powered transportation in India is a bus pilot project that will operate in New Delhi in 2020 on hythane, a mixture of 18% hydrogen and CNG (Kelly and Zhou, 2022). With an installed capacity of 10 kg per day, Oil India Limited has started operating the first green hydrogen pilot plant in India in Assam. Furthermore, Hazira, Jorhat, and Bikaner are home to commercial production facilities with a combined capacity of 200 tonne per annum (TPA) of green hydrogen. In 2024, two diesel-electric hybrid commuter cars with hydrogen power will be put into service. The fuel cell module will be developed by Ballard Power Systems, a fuel cell technology company. The project's investments should pay for themselves in less than two years. Additionally, it will remove almost a metric ton of particulate matter year and cut carbon dioxide emissions by over 11 metric tons annually (Sridhar, 2022).

Additionally, Indian Oil has established a goal to convert at least 10% of the hydrogen it uses in refineries to green hydrogen. Additionally, Indian Oil Corporation has declared its intention to construct a green hydrogen plant at its Mathura refinery in Uttar Pradesh, with a capacity of about 160,000 barrels per day. Additionally, IOC plans to build a standalone green hydrogen production facility in Kochi that will use electricity from the airport's solar power system. (Master Equity, 2021). With a 10 MW capacity, GAIL India also intends to construct the biggest green hydrogen plant in India. In a same vein, NTPC intends to build a 5 MW plant at Rann of Kutch in order to manufacture green hydrogen. Additionally, NTPC is operating a test project in its Vindhyanchal division. In Leh, Ladakh, NTPC also intends to build its first green hydrogen fueling station, with the primary goal of operating hydrogen buses (Equitymaster, 2021).

Through partnerships and private investments, India is becoming a major hub for the manufacture of hydrogen electrolysers, with plans to reach 8GW capacity by 2025. Together with Ohmium of Nevada and John Cockerill of Belgium, Greenko is constructing a 2GW facility.
In order to produce green hydrogen, renewable Greenko ZeroC and Korean steelmaker POSCO have struck a contract. Sarkar (2022).

By 2035, Reliance Industries Ltd (RIL) wants to be a net carbon-zero company. It seeks to substitute hydrogen and clean electricity for transportation fuels. Over the following three years, it plans to invest Rs 750 billion on renewable energy. In order to develop and produce hydrogen electrolysers, RIL has teamed with the Danish business Stiesdal A/S and plans to construct a 2.5 gigawatt (GW) electrolyser manufacturing unit. Within ten years, the business hopes to create hydrogen for "under US$1/kg." (Master Equity, 2021).In Hazira, Gujarat, L&T has also put into service a 45 kg/day green hydrogen plant (Kurup, 2022). H2E Power Systems, a clean technology start-up, is building an electrolyser facility in Pune (Cardoz, 2022).

A plan to manufacture three million tons of hydrogen by 2030 has also been revealed by Adani Group, requiring 16GW of electrolyser capacity (Baruah, 2022; Prasad, 2021; Sarkar, 2022)

One of the few green hydrogen-based advanced Fuel Cell Electric Vehicles (FCEVs) made by Toyota, the Mirai, was introduced in March 2022 as a part of a pilot project between Toyota Kirloskar Motor (TKM) and the International Center for Automotive Technology (ICAT).With a five-minute refueling period, the vehicle's hydrogen fuel cell battery pack can cover a distance of up to 650 miles on a single charge. If effective, the cost of transport might be as low as Rs 2 per kilometer on Indian highways and in certain climates.(Business Today Desk, 2022) .

Difficulties

India has the potential to become a global leader in the production, use, and export of green hydrogen if the correct laws, financial incentives, and private sector investments are put in place. However, India's use of green hydrogen is still in its infancy. It is changing in terms of technology and commerce, and the industry as a whole is facing several difficulties. A few of these difficulties have been covered in the paragraphs that follow.

CONCLUSION AND POLICY REPERCUSSIONS

India's reliance on fossil fuels may be lessened in the future by using green hydrogen as fuel, helping the country reach its net zero emission goal. Given its enormous potential for renewable energy and its stable, self-sufficient solar and wind energy sectors, India has a special opportunity to lead the world in exports in the near future. Due to its current lack of affordability and status as a niche technology. India must concentrate on building demand in order to achieve widespread deployment and economies of scale. This can be done by first imposing a government mandate or obligation on all industries. Additionally, the industry needs a solid regulatory framework with the appropriate policies to create new markets, reduce reliance on imports for raw materials needed by the solar and electrolyzer industries, and give adequate attention to technology research and development as well as the establishment of a green hydrogen supply chain. With the release of the green hydrogen policy in February 2022, the Indian government made a significant advancement in the migration to an energy transition based on green hydrogen. The main incentives that have been offered will aid in increasing demand for green hydrogen and installed capacity for renewable energy, including the waiver of Inter State Transmission Charges (ISTS), which permits developers to erect bunkers in port areas to investigate export activities, and banking facilities. India also requires robust supply push and demand side strategies in order to advance to the position of technological leaders in hydrogen. Additionally, it must guarantee that sufficient funding—both public and private—is accessible along the whole green hydrogen chain. Policies and incentives are also needed to promote solar and electrolyzer manufacturing in India and reduce imports. With investments from all major industrial groups and government support, the green hydrogen sector is a rising star in India. In the years to come, it will expand rapidly and contribute to the nation's twin objectives of decarbonization and energy security, as well as its ambition to become an energy exporter by 2030.

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