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Hydrogen Energy: A Way Forward for India

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Hydrogen energy offers India a transformative opportunity to achieve energy security, reduce carbon emissions, and foster economic growth. As a clean and versatile energy carrier, hydrogen can decarbonize hard-to-abate sectors such as steel, cement, heavy transport, and power generation. India's abundant renewable energy resources, particularly solar and wind, make it well-suited to produce green hydrogen, positioning the country as a global leader in the hydrogen economy. Recent government initiatives, including the National Hydrogen Mission, highlight India's commitment to scaling up hydrogen production, creating demand, and building infrastructure.
However, challenges such as high production costs, technological gaps, and the need for efficient storage and transport must be addressed through targeted investments, policy support, and public-private partnerships. Developing hydrogen hubs, promoting R&D, and fostering international collaboration are essential steps. By capitalizing on its renewable potential and aligning efforts across stakeholders, India can chart a sustainable path forward, driving economic and environmental progress. The rapid acceleration and intensification of climate change due to pollution have reached critical levels, necessitating an urgent shift towards sustainable energy sources to preserve a cleaner environment. Green hydrogen, known for its complete absence of carbon emissions, emerges as one of the most environmentally friendly fuels, offering a ray of hope against climate change. This review centres on India's commitment to sustainability, specifically the National Green Hydrogen Mission 2023, and explores various government and private sector green hydrogen initiatives. The geography of India is such that various areas have the plenty of sources of renewable energy, it has got the potential, for instance strong wind speeds and solar energy. The study delves into India's innovative efforts in the green hydrogen energy sector, seeking to identify positive, well-balanced solutions for the future of cleaner hydrogen fuel, as green hydrogen generation and distribution can easily be facilitated by various parts of India. India can be major player of Hydrogen energy in the international market with the right roadmap and government favourable policies and regulations. Making the earth free from pollution the integration of world hydrogen committee is needed.

Keywords: Green Hydrogen, Sustainability, Green Technology, Pollution.

1. Introduction

Renewable-energy sources such as solar energy, wind power, hydrogen-powered cell and biomass, are characterized by their regenerative nature, making them inexhaustible over time. Their adoption not only reduces carbon emissions but also promotes sustainability and contributes to a nation's energy-security as well as economic growth. India, in its quest for energy independence and net-zero emissions by 2047 and 2070, respectively, is making

considerable strides in expanding its renewable energy capacity to accommodate the surging demand. The nation's energy consumption has doubled in the last two decades and is projected to rise by an additional 25% by 2030. India currently imports over 40% of its annual energy needs, amounting to approximately 90 billion US dollars, making it a proactive contributor to global efforts in reducing global warming and carbon emissions. Hence, India recognizes the imperative to transition towards innovative solutions that can utilize renewable energy sources and reduce dependence on fossil fuels, with this review focusing on green hydrogen as a promising energy resource in the Indian context.

Hydrogen as an Energy Source

Hydrogen stands as a compelling substitute for traditional fossil fuels due to its long-duration energy storage capabilities, suitability for various transportation and industrial applications, as well as its utility in aeronautics, power generation, and maritime transport.

Hydrogen can be classified into three types based on its extraction method:

1. Grey Hydrogen: Grey hydrogen is produced through carbon-intensive processes involving the steam reformation of fossil-fuels for example natural gas or coal gasification.

2. Blue Hydrogen: Generated from natural gas or coal gasification, coupled with carbon capture and storage technologies to reduce carbon emissions.

3. Green Hydrogen: Created via water electrolysis using electricity derived from renewable sources. The carbon trail of green-hydrogen hinges on the carbon neutrality of the electricity source, and its combustion yields only water, making it a clean and sustainable energy source with zero emissions.

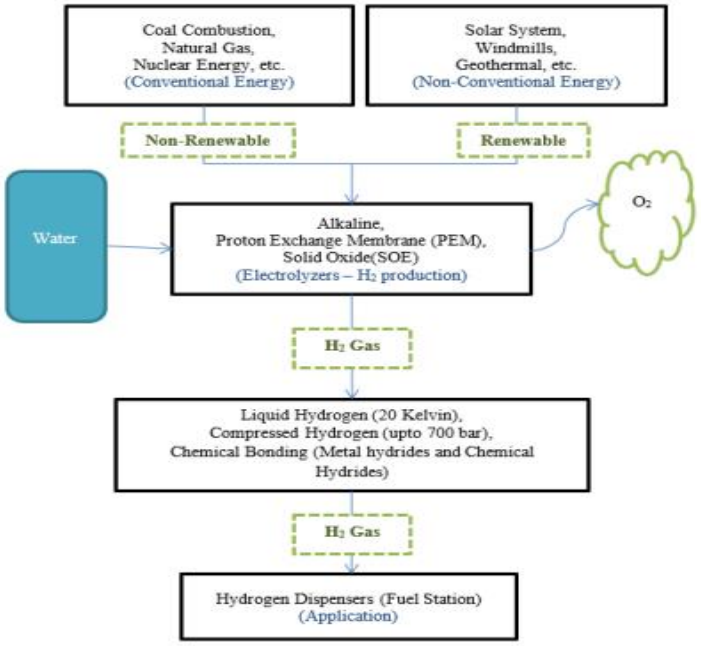


Fig 1: Hydrogen Energy Flow

Green Hydrogen:

A Sustainable Future: India's growing interest in green hydrogen aligns with its commitment to cleaner energy and carbon emissions reduction. Green hydrogen exhibits numerous potential applications, including use in industry, transportation, power generation, fuel cells for vehicles, and feedstock for industries like fertilizers and refineries. Its versatility positions it as a key player in meeting energy demands across diverse sectors, even in remote and isolated regions.

Current Scenario: An exploration of the current state of green hydrogen in India reveals four primary categories:

Policy Dynamism: The Government of India has acknowledged the potential of green-hydrogen and has initiated steps to fuel its development on a war-footing. The National Green Hydrogen Energy Mission, launched as part of the 2021-22 Union Budget and approved by the Union Cabinet in January 2022, aims to significantly de-carbonize the economy, reduce dependence on fossil fuel imports, and place India as a leader in green-hydrogen technology and markets. The mission aims to produce a minimum of 5 million metric tonnes of green hydrogen annually by 2030, with the potential to reach 10.0 million metric tonnes (MMT), bolstering export markets.

Objectives

The overarching objectives of the National Green Hydrogen Energy Mission include India's global leadership in green-hydrogen production, utilization, and export, aligning with the Aatmanirbhar Bharat mission. The mission seeks to spearhead economic decarbonization, reduce dependency on non-renewable sources, foster technology development for green hydrogen production, create job opportunities, become solution to almost every root cause of pollution and support research and development efforts.

Phases: The mission will be implemented in phases, with the initial phase (2022-2026) focusing on foundational measures, regulations, and green hydrogen adoption in sectors already consuming hydrogen. The second phase (2026-2030) will feature pilot projects in sectors like aeronautics and railways, enhanced research and development, and the incorporation of advanced green hydrogen technologies. The mission is expected to reduce annual greenhouse gas emissions by nearly 50 million metric tons by 2030.

Pilot Projects: Several pilot projects are underway to assess the viability of production of green-hydrogen involving collaboration between government agencies, research institutions, and private companies. Notable companies leading in green hydrogen production in India include IOCL, NTPC, RIL, GAIL, ANIL, and L&T, each contributing to India's green energy aspirations.

International Conference by Government of India: The Indian government organized the International Conference on green hydrogen (ICGH2023) from July 5 to July 7, 2023, in New Delhi. The conference, attended by delegates from India and abroad, aimed to explore new avenues in the green hydrogen ecosystem, review global decarbonization goals, and discuss emerging technologies and developments to unlock green hydrogen's potential.

Challenges

Despite its environmental benefits, green hydrogen faces challenges, including high manufacturing costs, production, storage and the need for a steady and cost-effective supply. India's transition to inexpensive green hydrogen depends on local electrolyzer production, technologically advanced electrolyzers, and low-cost renewable energy plants.

2. Literature Review

Numerous studies have investigated and states that our current economy which is mostly based on fossil fuel cannot seek sustainability in the mid-to-long term. "Hydrogen Nexus" which helps in developing a hydrogen economy where hydrogen is the central part in place of Carbon becomes principal chemical currency for our energy related needs. Some intrinsically "CHEMICAL" challenges of hydrogen production, storage and utilization have been reviewed. The Carbon Economy means the global economy evolves around the reservoir of fossil fuels, which otherwise is limited. Our current energy system can be represented through Fig.1.

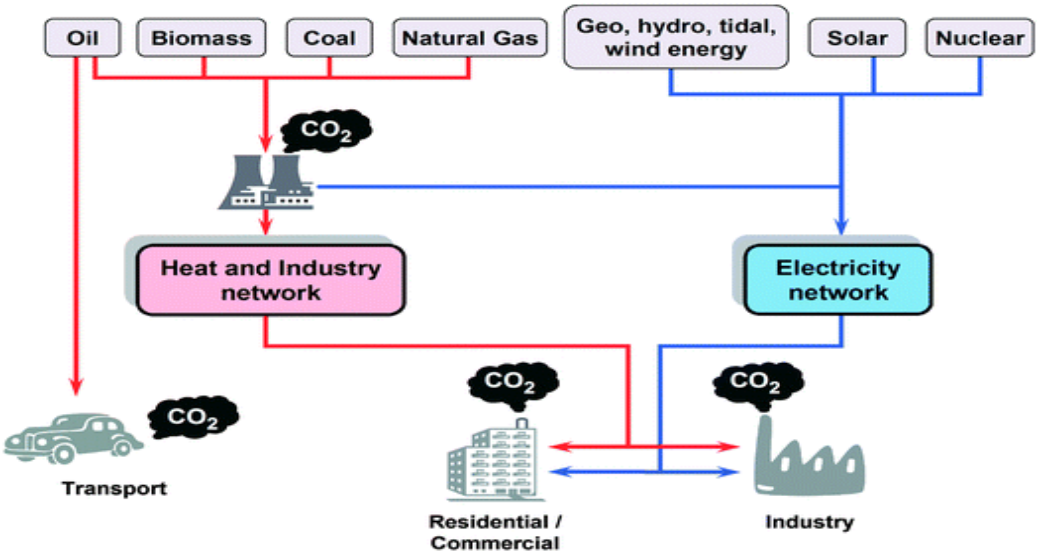


Fig 2: the overwhelming needs of energy are met by carbon and hydrocarbon fuels. In the diagram the red arrows depicts energy system based on fossil fuels and blue arrow represents non carbon A. Sartbaeva et al. [1].

Hydrogen Economy has become a new concept which capture the mind of business and political leaders now looking non-myopic beyond the realm of scientist and engineers. Government will have to take initiative to build hydrogen economy similarly as they played the role of being catalytic in terms of internet. The most important consequences of hydrogen economy can be replacing the 20th century "hydrocarbon society" which is no good for the society by and large, but the production of hydrogen is complex problem, and alone it is not going to solve the entire problem. Seth Dunn (2002) [2], for some hydrogen might be a means of balancing the system and life for others it might be a way to facilitate major changes at

societal level. William McDowall et al. (2007) [3]. The idea of sustainable future has evolved over a period of time where needs of living organisms are met while keeping a balance with nature. There are various challenges when it comes to sustainability and integration of many elements in long term - energy being one of them. At the same time generating hydrogen out of renewable sources would drive its production system towards a sustainable trajectory in the long run. L Barreto (2003) et al. [4].

One of the major challenges which have been encountered is the production and transportation costs. It is considered as major bottleneck and challenges in international market in terms of wider adoption of hydrogen, this is the reason why Hydrogen Credit was proposed by the research agency Zhao Yang Dong (2022) et al. [5]. At the same time there are various notions about providing green and clean sustainable energy by 2030, so here renewable source (hydrogen) could be a major contributor to sustainable clean energy production M. Mohsin et al.(2018) [6]. Many hydrogen production techniques have been discussed, compared and demonstrated over years. The main four ways of producing hydrogen is: electrolysis, photolysis, biolysis and thermolysis. Renewable Energy (RE) resource plays a key role in the transition to clean and sustainable energy system. The main challenge in transitioning renewable energy is variable and intermittent nature of these resources. The major problem is balancing supply chain and varying demand for energy, which in turn raises the need for huge energy demand. Hydrogen is one of the REs which is storable, transportable and utilisable. Furat Dawood et al. (2020) [7].

The global demand for energy is, now-a-days, mainly fulfilled by non–renewable natural resources. To meet the demand of power, fossil fuels are being used in abundance which causes serious detrimental externalities and environmental dilapidation. Adeel Ahmed et al. (2016) [8], few studies have shown that Hydrogen cannot be the immediate remedy to Global warming and risk associated with climate but it can be a potential long-term solution.

Talking purely in the context of INIDA, Taxation policy is essential for Hydrogen penetration into the market. Climate policy will benefit INDIA in many ways by diversifying energy imports from EUROPE, especially will help in decreasing crude-oil imports, and increasing indigenous coal and natural resources in the transportation sector. It will also improve the urban air quality. Hydrogen energy is often mentioned as a potential solution to the global-energy issues.

The first advantage of using hydrogen is that it improves air quality. Secondly, by enabling (decentralized) manufacturing, hydrogen diversifies the energy supply. The latter could assist in reducing dependency on imports of oil from abroad (Dunn, 2001; Lovins, 2003). Hydrogen economy has also been explained in this article. The article says that in the long run hydrogen can complement renewable-sources utilized to generate electricity. It can be a keystone to a 100% renewable future, Alexandra M Oliveira et al. (2021) [9]. The devastating effects witnessed in the last few decades, causing ecological imbalance, have led towards energy consumption without harming the natural ecosystem. Mukul K Shrivastava et al. (2020) [10]. A new concept has come into existence to restore such imbalances caused by fossil fuel, known as TIMER (Targets IMage Energy Regional) Model. In the twenty-first century are inextricably intertwined with the production, transportation, storage, and consumption of energy.

The issue of climate change is the most directly related to the usage of fossil fuels, although acidification and oil spills are also mainly caused by fossil fuel consumption. Trends in the energy system are thus tremendously essential - both for the economy and for the environment. The TIMER-model, which simulates the energy system through combination of bottom-up engineering information and unique rules and procedures, thus governing investment behaviour and technology. The result is rather a thorough representation of how energy intensity, fuel costs, and competing non-fossil supply methods evolve over time. TIMER model on global energy permits an exploration of what might happen with the energy systems in these regions if hydrogen technologies are assumed to become available, Bas van Ruijven et al. (2008) [11]. Hydrogen production can be done by electrolysis, extraction from oil, gasoline. Besides, it can also be produced directly with sunlight and water by biological organisms, Das (1998) [12], thus lowering the cost of hydrogen production and storage making it the most prominent future renewable energy source, Suilma M. Fernández Valverde (2002) [13].

Sector-Specific Applications of Hydrogen in India

The adoption of hydrogen energy in India has promising prospects, particularly in hard-to-abate sectors like steel, cement, and heavy transport. According to Sontakke & Jaju (2021) [14], hydrogen can replace coal and other carbon-intensive fuels in steel production, which contributes significantly to India's emissions. Additionally, the use of hydrogen in fuel cells for transport offers an alternative to diesel and petrol, particularly in long-haul trucking and buses (Shiva Kumar & Lim, 2022)[15]. Researchers such as Medisetty et al. (2020) [16], also highlight hydrogen's role in enhancing energy security by serving as an energy carrier for power generation, especially in combination with renewable energy sources.

Methodology for Hydrogen Generation:

Hydrogen when combined with oxygen to produce water has potential to generate electricity. We can see in the diagram and understand the entire cycle of hydrogen generation.

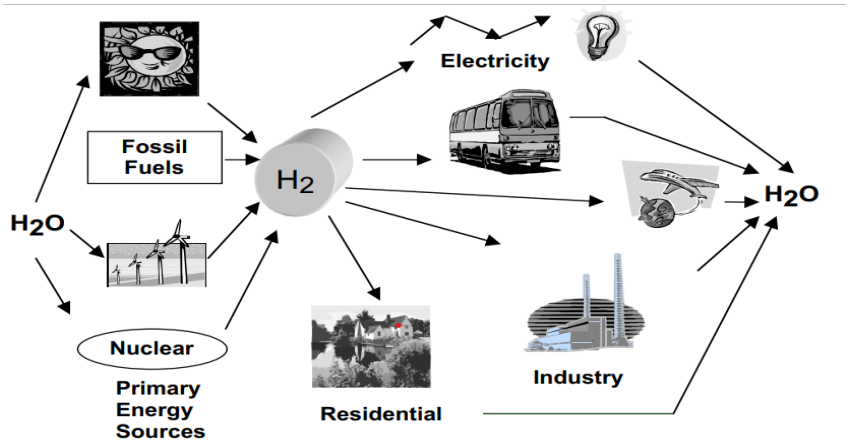


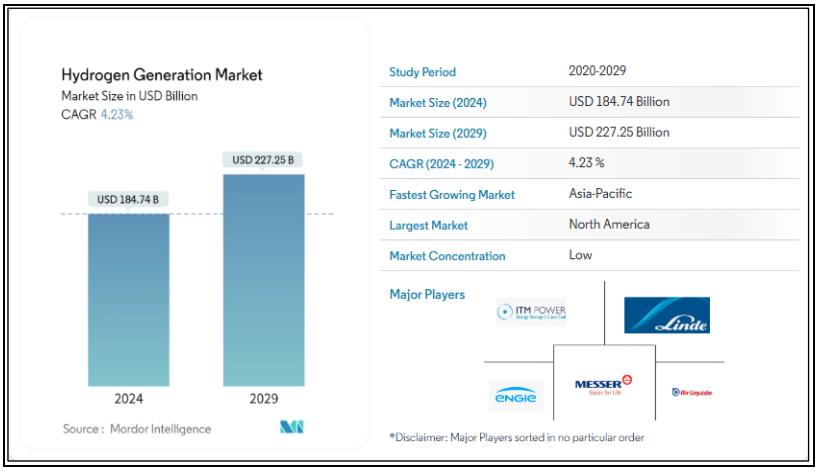
Fig 3: Water could be separated by a primary energy source and then could be stored to be utilized as energy carrier. Hydrogen, when utilized, produces energy and water and so the cycle can be repeated. Suilma M. [17]

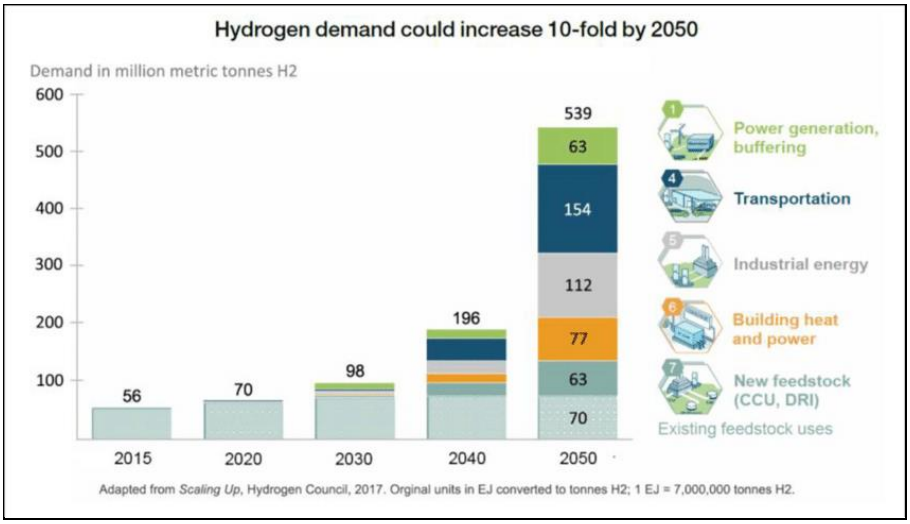
HYDROGEN MARKET GLOBALLY

Hydrogen and energy have come a long way together, right from powering the earliest internal combustion engines almost 200 years ago to evolving as a necessary cog in today's industry. However, for hydrogen to make a meaningful contribution to clean energy transition, it must be adopted in areas where it is currently absent such as transport sector, real-estate, power generation. The demand for hydrogen has increased many-a-fold since 1975.

Hydrogen could be extracted from fossil fuels, biomass, water or a combination of the two. At present, natural gas is the primary source of generation of hydrogen. Natural gas accounts for nearly 75% of the annual hydrogen production of approximately 70 million tonnes (MT) which is around 6% of global natural gas usage. In China, hydrogen production is through natural gas which is followed by coal and a minor fraction is produced through other methods.

The production cost of hydrogen using natural gas is impacted by technological as well as economic factors.





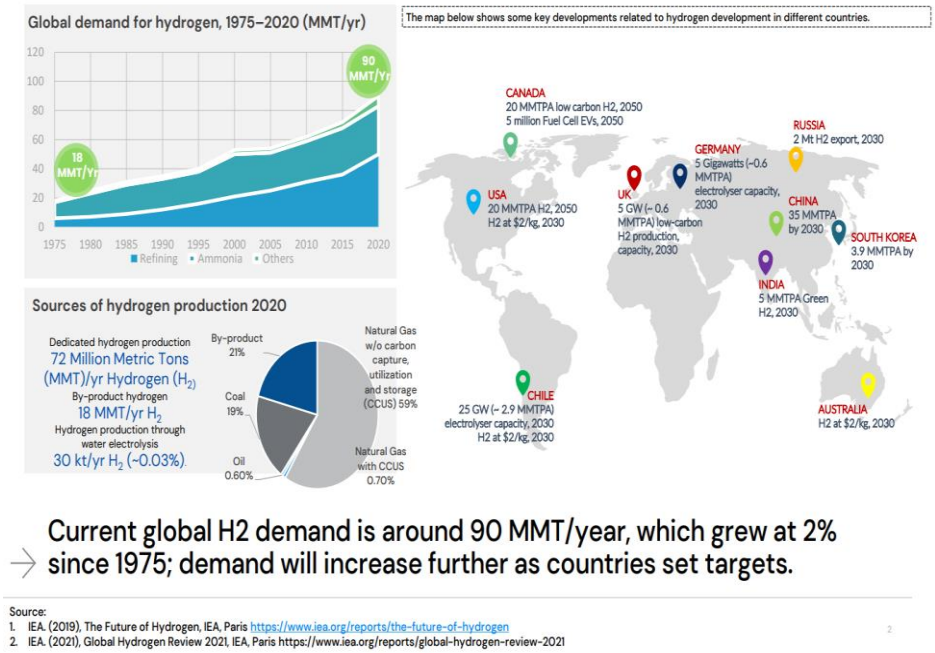


Fig: 4 Depicts the overall Hydrogen demand in units and development related to Hydrogen in different countries:

Drivers of HYDROGEN energy

1. Climate Change alarmingly
2. Energy Security due to ever-growing demand
3. Air Pollution due to emission, and
4. Price and quality Competitiveness

3. Analysis and Discussions:

This paper explores the process which tells us about the sustainability while competing for hydrogen as energy-source in future. Unquestionably, hydrogen can make the significant contribution to the transition to clean energy in various sectors, viz; Transportation, Buildings and Power generation [18]. Many literatures say that Hydrogen is an energy carrier and not a source of energy. Hydrogen is a storable, transportable, and usable fuel that can be substitutable as an alternative energy storage.

The study also entails that our major reliance on fossil fuels is being blamed for global warming. Growing public and government concerns over energy security as well as price-stability can help all the sectors to transition away from the fossil fuel usage towards an eco-friendly economy.

Limitations and further development

The current effort is towards hydrogen storage, hydrogen production and distribution infrastructure. The cost incurred on transportation vehicles, competitive technologies and safety is yet to be addressed in INDIA. These limits and impediments can be overcome by enhancing current level of hydrogen production and subsequent storage eco-system. Further, moving towards competitive production cost and increasing public acceptance through dissemination of information about upcoming projects and its benefits.

India has enormous potential of renewable energy sources. Government has specific department, Ministry of New and Renewable Energy (MNRE) [19], with extensive plans for the development of renewable energy sources. The Government has devised major frameworks which might work against all the odds.

Results: Appraising the sustainability through hydrogen resource in India

The creation of hydrogen network and the storage facilities are significant barriers for the hydrogen economy. Financial security and safety are other major issues that must be resolved via the application of evolving technologies and research. Regulations and policies of the government will be crucial to the overall development. The Indian government offers subsidies for electric vehicles via the FAME (Faster Adoption and Manufacturing of Hybrid and Electric) [20] India program in an effort to raise public knowledge and adoption of the technology. If provided, these generous subsidies will promote the development of a market for hydrogen fuel cell automobiles and hydrogen infrastructure. Recently, in New Delhi, the transportation department DTC did pilot-run 10 buses with hydrogen fuel cell. The buses are powered by fuel cells based on polymer electrolyte membrane. They have four tanks with a total capacity of 30 kg and can be refilled in 10-12 minutes, which is similar to petrol or diesel vehicles. The executives claim a range of 350 km with four full tanks of hydrogen.

4. Conclusion: Roads to Hydrogen Economy

India's green hydrogen energy initiatives play a pivotal role in achieving sustainability, reducing global warming and lowering the nation's carbon footprints. The National Green Hydrogen Mission 2023, along with pilot projects and ongoing research and development efforts, constitute significant steps toward realizing a cleaner and sustainable energy future in INDIA. Although challenges persist, addressing them can position India as a global leader in clean energy. It provides India a transformative pathway to achieving energy security, reducing carbon emissions, and driving sustainable growth.

Hydrogen is an emerging energy carrier that is being used to help decarbonize the global energy and industrial sectors; thus, creating hydrogen from renewable energy sources is of great interest today. The transition to a hydrogen economy in India holds immense promise, offering solutions for energy security, decarbonization, and economic growth. With its abundant renewable energy resources, skilled workforce, and growing industrial base, India is well-positioned to become a global leader in hydrogen production and utilization. However, realizing this potential requires a multi-faceted approach: substantial investments in infrastructure, consistent policy frameworks, robust public-private partnerships, and advancements in technology.

Key enablers like scaling up green hydrogen production, developing efficient storage and distribution networks, and fostering research and innovation will be critical. Additionally, creating demand in sectors such as transportation, industry, and power generation is essential for achieving economies of scale.

In conclusion, while challenges such as high initial costs, technology gaps, and policy coordination exist, India's commitment to its net-zero targets and energy transition goals provides a strong foundation. By leveraging its renewable energy potential and fostering collaboration across stakeholders, India can pave the way for a sustainable and inclusive hydrogen economy.

References

1. Sartbaeva, A., Kuznetsov, V. L., Wells, S. A. and Edwards, P. P. (2008). Hydrogen nexus in a sustainable energy future. Energy and Environmental Science, (pp 79-85). Available at : DOI: 10.1039/B810104N , https://doi.org/10.1039/B810104N
2. Dunn, S (2002). Hydrogen futures: toward a sustainable energy system. International journal of hydrogen energy (pp 235-264), Volume No. 27(3). Available at : https://doi.org/10.1016/S0360-3199(01)00131-8
3. McDowall, W and Eames, M. (2007). Towards a sustainable hydrogen economy: A multi-criteria sustainability appraisal of competing hydrogen. International journal of hydrogen energy (pp – 4611-4626) 32 (18). Available at : https://doi.org/10.1016/j.ijhydene.2007.06.020
4. Barreto, L., Makihira, A. and K Riahi (2003). The hydrogen economy in the 21st century: a sustainable development. International Journal of Hydrogen Energy (pp 267-284) 28(3). Available at : https://doi.org/10.1016/S0360-3199(02)00074-5
5. Yang Dong, Z., Yang, J., Li Yu , Daiyan, R., Amal, R. (2022). A green hydrogen credit framework for international green hydrogen trading towards a carbon neutral future. International journal of hydrogen Energy (pp 728-734). 47 (2). Available at : https://doi.oeg/10/1016/j.ijhydene.2021.10.084
6. Mohsin, M., Rasheed, A.K., and Saidur, R. (2018). Economic viability and production capacity of wind generated renewable hydrogen. International journal of hydrogen energy (pp 2621-2630) 43 (5). Available at : https://doi.org/10.1016/j.ijhydene.2017.12.113
7. Dawood Martin Anda, F., and Shafiullah, G.M., (2020). Hydrogen production for energy: An overview. International Journal of Hydrogen energy (pp 3847 – 3869) 45(7). Available at : https://doi.org/10.1016/j.ijhydene.2019.12.059
8. Ahmed, A., Quasem Al-Amin, A., Ambrose, Angelina F. and Saidur, R. (2016). Hydrogen fuel and transport system: A sustainable and environmental future. International Journal of Hydrogen Energy (pp 1369-1380) 41(3). Available at: https:// https://doi.org/10.1016/j.ijhydene.2015.11.084
9. Oliveira, Alexandra M., Beswick, Rebecca R., and Yan, Yushan, (2021). A green hydrogen economy for a renewable energy society, Current opinion in Chemical Engineering 33. Available at : https://doi.org/10.1016/j.coche.2021.100701
10. Shrivastava, M. K., Priya, A., Saxena, T., Pande, B., & Sharan, V. D. (2020). Green technology and consumer behaviour: An analysis. Solid State Technology, 63(6), 11452–11467
11. Van Ruijven, B., Hari, L., van Vuuren, D. P., & de Vries, B. (2008). The potential role of hydrogen energy in India and Western Europe. Energy Policy, 36(5), 1649–1665. https://doi.org/10.1016/j.enpol.2008.01.020
12. Shrivastava, M. K., & Mittal, V. (2022). Hara Bhara Atmanirbhar Bharat. European Journal of Molecular & Clinical Medicine, 7(11), 6553–6572. ISSN 2515-8260.

13. Fernández Valverde, S. M. (2002). Hydrogen as an energy source to avoid environmental pollution. Geofísica Internacional, 41(3), 223–228.
14. Sontakke, U., & Jaju, S. (2021). Green hydrogen economy and opportunities for India. IOP Conference Series: Materials Science and Engineering.
15. Shiva Kumar, S., & Lim, H. (2022). An overview of water electrolysis technologies for green hydrogen production. Energy Reports, 8, 13793–13813. https://doi.org/10.1016/j.egyr.2022.10.127
16. Medisetty, V. M., Kumar, R., Ahmadi, M. H., et al. (2020). Overview on the current status of hydrogen energy research and development in India. Chemical Engineering & Technology, 43(4), 613–624. Available at: https://doi.org/10.1002/ceat.201900496
17. Warner, K. J., & Jones, G. A. (2019). The 21st century coal question: China, India, development, and climate change. Atmosphere (Basel), 10, 1-17.
18. Dawood, F., Anda, M., & Shafiullah, G. M. (2020). Hydrogen production for energy: An overview. International Journal of Hydrogen Energy, 45(7), 3847–3869. https://doi.org/10.1016/j.ijhydene.2019.12.059.
19. Ahmed, A., Al-Amin, A. Q., Ambrose, A. F., & Saidur, R. (2016). Hydrogen fuel and transport system: A sustainable and environmental future. International Journal of Hydrogen Energy, 41(3), 1369–1380. https://doi.org/10.1016/j.ijhydene.2015.11.084
20. Ministry of Power, Government of India. (2021). Power sector at a glance: All India. Ministry of Power. https://powermin.gov.in/en/content/power-sector-glance-all-india
21. Department of Science and Technology, Government of India. (2020). India country status report on hydrogen and fuel cells.
22. Arunkumar, M., & Dhanakumar, S. (2019). Vehicular pollution and its implications. Pollution Research, 38, 634–647.
23. Warner, K. J., & Jones, G. A. (2019). The 21st century coal question: China, India, development, and climate change. Atmosphere (Basel), 10, 1–17. https://doi.org/10.3390/atmos10080476.
24. Joshi, P., Roe, A., & Chernyakhovskiy, I. (2022). Role of renewable energy, storage, and demand response in Karnataka's power sector future. Energy Research, [Online]. https://doi.org/10.2172/1881906.
25. Sontakke, U., & Jaju, S. (2021). Green hydrogen economy and opportunities for India. IOP Conference Series: Materials Science and Engineering. Available at : https://doi:10.1088/1757-899X/1206/1/012005
26. Shrivastava, M. K., & Mittal, V. (2020). Consumer acceptance of green: A socio-economic analysis. Journal of the Maharaja Sayajirao University of Baroda, 54(2), 109–117. ISSN 0025-0422.
27. Ross, D. K. (2006). Hydrogen storage: The major technological barrier to the development of hydrogen fuel cell cars. Vacuum, 80(10), 1084–1089. Available at: https://doi.org/10.1016/j.vacuum.2006.03.030.
28. Ross, D. K. (2006). Hydrogen storage: The major technological barrier to the development of hydrogen fuel cell cars. Vacuum, 80(10), 1084-1089.
29. Sharma, P., Soni, S., & Kumar, A. (2022). India’s position in the global hydrogen economy. Journal of Sustainable Development, 14(1), 12-24.
30. https://www.iea.org/reports/the-future-of-hydrogen
31. https://www.iea.org/repots/the-future-of-hydrogen