Prayogik Rasayan

Transitioning towards Green Hydrogen: Challenges, Learnings and Opportunities

M. S. Santosh

Coal to Hydrogen Energy for Sustainable Solutions (CHESS) Division, CSIR – Central Institute of Mining and Fuel Research (CIMFR), Digwadih Campus, PO: FRI, Dhanbad – 828108, Jharkhand, India.
Email: santoshms@cimfr.nic.in

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Abstract

Hydrogen is considered to play a very important role in the universal energy transition and in the mitigation of greenhouse gases. Being the most abundant element, Hydrogen is not so freely available but locked up in the form of fossil fuels, water and gases. A large amount of energy is required to generate hydrogen, either in the blue or green form. It is estimated that by 2050, 70% of the hydrogen produced will be green i.e., through renewable electricity via electrolysis. Renewable energy sources should ideally be employed to phase out coal and natural gas from being used to produce electricity due to the significant energy losses involved in producing green hydrogen. Since hydrogen is a crucial type of energy storage for intermittent renewable sources, there will likely be some overlap in actual use. Although different forms of producing hydrogen are known, the world is determined to increase support for the generation of green hydrogen through water splitting using renewable energy sources because of its low-carbon emissions. Despite the fact that hydrogen appears to be expensive compared to direct electrification, it is impossible to electrify some of the high-carbon emitting industries such as shipping, aviation, cement, and thermal industries. However, the automobile and transportation industries are also keen to switch over to hydrogen-powered vehicles than electric vehicles because of the long-range, easy and quick refueling, and zero carbon emissions. As the existing hydrogen-based technologies are still at their infancy expect a few application areas, a lot of research and testing has to be carried out in order to ensure the efficiency, reliability and cost-effectiveness of hydrogen-based solutions. Some of the developed nations such as Japan, UK, USA, Korea is already in the race to manufacture hydrogen-powered automobiles which are perceived as the technology of the future. Yet, none of these governments have realized the implications of switching over to hydrogen in quick time and haven't made any guidelines for their manufacturing, use and servicing. One such example in this regard is that of hydrogen filling stations in a futuristic society like the UK that fell short of their potential even before their introduction, as not many cars are on road to generate substantial revenue as anticipated by their investors. Being a new phase shift in the society, it takes some time for the public and other stakeholders to understand the technology, its pros and cons and then make up their mind to buy a hydrogen fuelled car. All these aspects need sufficient time, and multiple rounds of testing, policy discussion, policy implementations, stakeholder meets, marketing, etc. to reach a profitable level. Nevertheless, in spite of all the odds, hydrogen-based technologies have a promising outlook and foresee huge opportunities in the near future as the technology matures into a realistic and feasible alternative to the currently used fossil fuel based or EV based technologies.

Keywords: Green hydrogen, fossil fuel, clean energy, industries, automobiles.

1. Introduction

Decarbonization has been one of the major discussions in the global platforms and has garnered significant attention to reducing greenhouse gas emissions. In this direction, Prime Minister Narendra Modi has vowed to drive India's energy sector towards achieving a net zero by 2070.[1] Carbon-free hydrogen will be essential for enabling deep decarbonization in several industries, including those that produce large amounts of CO_2 such as iron and steel, fertilizers, petroleum refining, cement, maritime shipping, etc.[2] Apart from these, other sectors like trucks, automobiles, and aviation industries are keen to transition from fossil fuels to hydrogen. As a result, there is an increasing thrust globally for hydrogen and hydrogen-based technologies, especially green hydrogen, which is produced by electrolyzing water with electricity derived from renewable sources.[3] The global demand for hydrogen is expected to see an upsurge by almost 400% by 2050, driven by industry and transportation, as the urgency to reduce carbon emissions grows.[4] Green hydrogen is the most competitive form of hydrogen over the long term because of India's distinct advantage in producing affordable renewable energy. Being the most abundant element, hydrogen accounts for nearly 75% of all matter and is being used as a feedstock by many chemical industries and refineries.[5] Extending the use of hydrogen to mobility, transportation, building, and residential heating is a futuristic opportunity towards which the world is already venturing. Despite being emission-free for end-use applications, the process of hydrogen production mainly relied on fossil fuels, categorizing them into grey, blue, and green hydrogen (Table 1). Grey hydrogen is produced from methane or natural gas and this process contributes to nearly 2% of global emissions. Similar to grey hydrogen, blue hydrogen is produced but employs carbon capture and storage, reducing CO_2 emissions by 70%.[6] Unlike the other two, green hydrogen is produced by the electrolysis of water, where the water splits into oxygen and hydrogen using electricity generated from renewable sources such as solar and wind.

Less than 2% of all hydrogen produced currently is green due to the high cost of production. Recent developments, however, suggest that over the next few decades, this will significantly increase.[7] According to the International Energy Agency (IEA),[8] switching to green hydrogen could reduce annual CO_2 emissions by 830 million tonnes. In this direction, India is positioned to produce green hydrogen on par with any other nation in the world. The green hydrogen thus produced must be stored efficiently for later use, but unfortunately, the storage technologies of today are not capable of storing hydrogen effectively. Although there are efforts to store hydrogen in solid, liquid, and gaseous states under varied conditions, their commercial viability has been a concern globally as none of the present technologies is conducive for commercialization.[9] Overcoming the existing limitations and making storage technologies market ready is a herculean task that needs to be worked out in parallel with hydrogen production technologies, as both are mutually dependent.[10,11a] Efforts are being made both in terms of hydrogen generation and its storage so as to cater to the needs of the industries, who are eagerly awaiting to adopt the clean energy source so that the tag of greenhouse gas emitters can be minimized and can efficiently contribute to the green energy initiatives of the government, society, and stakeholders in general.

Table 1. Different hydrogen terminologies, the type of technology, their feedstock or source, and their greenhouse gas footprint (source: Global Energy Infrastructure)[11b].

	Terminology	Technology	Feedstock/ Electricity source	Greenhouse Gas Footprint
PRODUCTION VIA ELECTRICITY	GREEN HYDROGEN	Electrolysis	Wind | Solar| Hydro Geothermal| Tidal	Minimal
	PURPLE/ PINK HYDROGEN		Nuclear	
	YELLOW HYDROGEN		Mixed-origin grid energy	Medium
PRODUCTION VIA FOSSIL FUELS	BLUE HYDROGEN	Natural gas reforming + CCUS Gasification + CCUS	Natural gas| Coal	Low
	TURQUOISE HYDROGEN	Pyrolysis	Natural gas	Solid Carbon [By-Product]
	GREY HYDROGEN	Natural Gas reforming		Medium
	BROWN HYDROGEN	Gasification	Brown coal (lignite)	High
	BLACK HYDROGEN		Black coal	

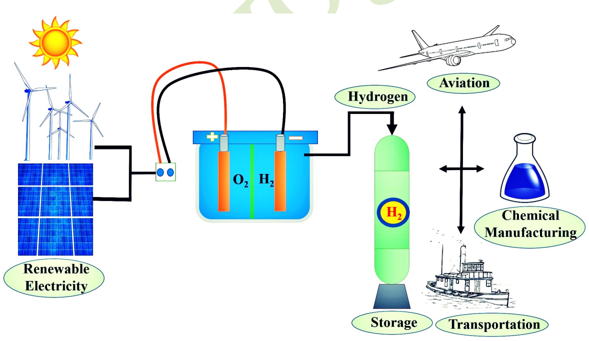

Fig. 1. Pictorial representation of the process of electrolysis through which green hydrogen is being produced and their use in various industries.

In view of these aspects, this article attempts to provide an overview of green hydrogen production and its utilization scenario by taking up a case study that describes the entry of an international oil giant into a developed society and showcases huge potential and promise to be the first entrants into the futuristic domain but eventually had to fade away as the stakeholders were not ready yet to adopt and implement the green hydrogen technology for transportation and mobility (Fig. 1). In addition, efforts are also made to propose potential solutions for successful technology deployment and the measures that can make the technology's realization convenient.

2. Evaluation of Specific Case

Earlier in 2017 and 2019, global oil giant Shell announced, through big fanfare public events, the setting up of their hydrogen filling stations in the UK (Fig. 2).[12] But in a span of 3 years, they

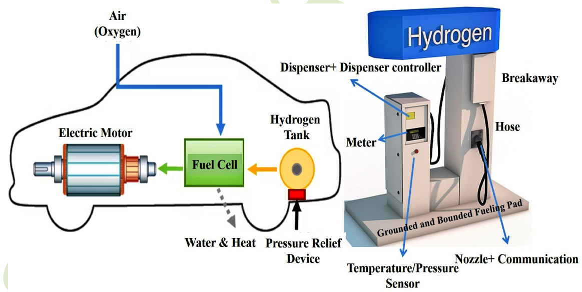

Fig. 2. Schematic representation of the hydrogen-powered car and the hydrogen filling station with the indication of important parts.

have closed them all without making much noise. In the whole of the UK, there are only about 11 public hydrogen pumps as compared to 57,000 public electric vehicle charging points. Hydrogen facilities at Gatwick Airport, Cobham, and Beaconsfield were closed in consensus with Shell's partner company Motive, owned by the UK electrolyzer maker ITM Power which supplies green hydrogen. The hydrogen pumps were partially funded and supported by the European Fuel Cell Hydrogen Joint Undertaking and the UK's Office of Low-Emission Vehicles and these filling stations were established at an overall cost of nearly $2 million. However, these filling stations underwent a huge loss due to insufficient hydrogen-powered vehicles on UK roads. But it was said that as the technology used in these hydrogen filling stations were Shell's first-generation prototypes which reached their end of life, they decided to shut them off. On the other hand, Motive also closed its 4th hydrogen pump in Swindon due to unsatisfactory performance and low footprints that wouldn't enable them to upgrade the technology for larger vehicles. Having already invested nearly $2.8 million, sustaining small filling stations without profits is difficult, and hence, Motive decided to close them. This has been due to the lack of hydrogen cars, especially in the UK, where only two hydrogen-powered car models i.e., the Toyota Mirai and the Hyundai Nexo, were sold with a total sale of 209 and 275 units, respectively.

Also, perceptions by some analysts say that it is expensive to build, maintain and run a hydrogen-fuelled vehicle and predicts that only 0.01% of the cars will run on hydrogen globally by 2050. This is because the propulsion of fuel-cell electric vehicles (FCEVs) is significantly less effective, more complicated, and therefore more expensive than that of battery electric vehicles. Another school of thought involving the International Renewable Energy Agency, hydrogen truck maker Hyzon Motors and other logistics operators favor hydrogen-fueled vehicles over EVs, especially for long-haul transports. Due to the inability of electricity grids to handle multiple battery trucks being fast-charged at the same time and the fact that an all-electric system for lorries/trucks would require eight times as many charging points due to the long charging times, hydrogen is the only practical carbon-free solution for long-haul vehicles.

Considering the above thoughts, it can be concluded that hydrogen-based technologies are still in their infancy and needs more time for commercialization and to be understood by their potential users for large-scale deployment and usage. Hence, it is better to wait for at least a year or two to observe the change in the global automobile dynamics and its trend and then make a decision instead of basing the thoughts on a single available case.

3. Proposed Solutions

As an emerging technology, Hydrogen-powered systems have to be optimized from various aspects such as technology, integration, fuel efficiency, production process, maintenance, servicing, filling stations and finally, the cost. These are some of the important challenges that need to be addressed before hydrogen-powered vehicle technologies are released into the market.[13] Considering the need, demand, and importance of switching to clean energy technology to reduce carbon emissions, the following points are being proposed as potential solutions:

1. The developed technology has to be made people-friendly and understandable before they even invest in buying vehicles based on this new technology.
2. The performance and safety aspects have to be stressed to ease the concerns in people's minds.
3. To ensure global accessibility of the technology, it is crucial to strategize and implement comprehensive marketing initiatives such as advertisements, test rides, and promotional events. These efforts are essential to effectively disseminate the technology to every corner of the world.
4. Gradually increasing the number of hydrogen filling stations based on the sale of vehicles should be planned so that the investors for such filling stations are not burdened and undergo loss.
5. Once the green hydrogen production cost is lowered, the cost of the vehicle decreases eventually, subject to improvements in the hydrogen-based fuel cell technology.
6. Sufficient manpower has to be trained to handle, rectify and attend to the concerns of the hydrogen-powered vehicles as they are released into the market.

With the above aspects, a sustainable approach towards implementation of the hydrogen-powered technology will be introduced into the market globally and more stakeholders/end users will be educated about the technology for adaptation and deployment.[14,15]

4. Conclusions

Green hydrogen is a new and upcoming clean energy fuel that has the potential to minimize carbon emissions and increase sustainability across the globe. Based on this promising technology, investments into hydrogen-based technologies have seen an upsurge in recent times and technologies based

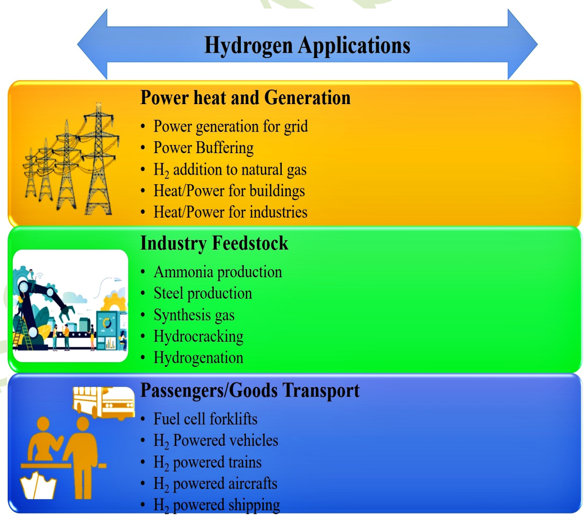

Fig. 3. Schematic representation of industry-wise applications of hydrogen in different sectors.

on hydrogen, such as industrial units, automobiles, and transportation sectors, are in the course of adopting this technology subject to its efficiency, reliability, safety and cost-effectiveness (Fig. 3). Projections in this direction are being made through various modes universally with a primary focus on the production of green hydrogen through water splitting using a renewable energy source. However, the technologies to store the produced hydrogen is still a distant dream which needs immediate attention and global impetus. Although technologies to produce hydrogen are well-established, the cost of green hydrogen production has not reached the expected target of $2 per kg. Efforts are being made in this direction, and hydrogen-powered vehicles have already made their way into the market but with less success.

An evident case of an unsuccessful venture was that of the hydrogen filling stations established by the major oil company Shell in the UK, which eventually had to close, citing losses due to an insufficient number of vehicles on the roads. Arguments were made both from the positive and not-so-encouraging dimensions to support the emerging hydrogen-based technology and to counter it from a batterypowered electric vehicles sector. However, some of the important takeaways from such case studies and discussions are that the technology is still premature and establishing filling stations in large numbers without understanding the market dynamics is a major reason for unsuccessful investment. A few important parameters such as technology optimization, stakeholder understanding, promotion, performance, safety, production costs and trained manpower are key aspects that need to be investigated before upscaling and commercializing the hydrogen-powered technology. Finally, with a positive outlook, India and other countries across the world look forward to this clean energy technology to revolutionize the industrial, transport and automobile sectors soon with optimized costs and sustainable approaches, making the country a hub for green hydrogen production, storage and deployment.

Recommendations

The following are some of the key recommendations for the successful implementation of green hydrogen-based technologies:

1. **A clear long-term pathway:** Identify bottlenecks that are limiting the implementation of green hydrogen technologies and provide a clear pathway for industries and investors so that they gain confidence and orient the entire value chain towards achieving the goals of the National Hydrogen Mission.[13,14]
2. **Minimize the cost of green hydrogen production:** Support early technology developers and encourage scaling of green hydrogen production technologies by easing out transportation charges between states, lowering taxes and surcharges, special permissions who cut carbon emissions, provide carbon credits which can be redeemed for other expenses like electricity bills, water consumption, etc.
3. **Enhance green hydrogen production capacity:** Encourage the blending of hydrogen with natural gas in slightly higher percentages and maximize the use of hydrogen in steel, automobile, and chemical industries by offering suitable incentives. Implement a centralized supply of green hydrogen blended gas to households and industries for heating, cooking and other industrial productions.
4. **Develop Green Hydrogen Storage Technologies:** Industrially scalable storage technologies such as lightweight composite pressure vessels that can substitute the current heavy metallic cylinders can be more advantageous. Create testing facilities for such high pressures and enable certifications within the country to minimize dependency on foreign certifications and outsourcing for testing.
5. **Create standards for green hydrogen implementation:** Through governmental policies, standards and metrics must be set for the production of green hydrogen and their implementation to prevent misleading in the name of green hydrogen.
6. **Export of green hydrogen and products derived out of them:** Enable an ecosystem to export green hydrogen to the needy, developing and underdeveloped countries at affordable costs to enhance the use of green hydrogen and to increase the country's revenue. Adopt strategies that will position India as a global leader in green hydrogen production, storage, and implementation.
7. **Enhance skill development and capacity building:** Industries, academia, and R&D laboratories should be encouraged to enhance skills related to green hydrogen production and storage to apply them in various capacities in professional environments under trained experts and technological leaders.

Implementation

In order to implement hydrogen-based technologies, a collective, collaborative, and sustained approach needs to be adopted by the technology developers, manufacturers, investors, stakeholders and users.[15-17] A gradual progression in this regard has to be made to effectively implement clean energy processes that are cost-effective, sustainable, and realizable in the days to come. Policies for the effective deployment of such hydrogen-powered technologies have to be in place by the governments to enable easy and reliable implementation of green hydrogen technologies.

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7. About the author(s)

Dr. M. S. Santosh is currently working as a Senior Scientist and Head of the Coal to Hydrogen Energy for Sustainable Solutions (CHESS) Division, CSIR – Central Institute of Mining and Fuel Research (CIMFR), Dhanbad, Jharkhand. He holds a Ph.D in Chemistry from National Institute of Technology Karnataka (NITK), Surathkal and pursued his Postdoctoral research at the University of Wisconsin-Madison, USA. His research interests are in the areas of Nano/Bio Materials, Energy Storage Technologies, Membrane Technologies and Wastewater Treatment and has research collaborations spanning different countries & continents. He has published 90+ research articles in international journals of high repute. He has successfully completed projects funded by SERB, DST, CEFIPRA, DRDO, KCTU and has a few ongoing projects funded by the European Union and DST. He had successes under various bilateral programs involving France, Russia, Belarus, Sweden, Singapore, Egypt and Vietnam. With his novel technologies, he is consulting a few industries as well. He is a recipient of several national and international awards such as the INSA Summer Research Fellowship, DST Young Scientist Award, BIRAC-SRISTI Innovation Award, BRICS Young Scientist Award, Commonwealth & Hungarian Fellowships, Global Shaper Award, Swedish Institute's Guest Scholarship, IUPAC's Junior Researcher Award. He is a member of the Indian National Young Academy of Sciences (INYAS) and a Fellow of the Royal Society of Chemistry. He has also served as the Chief Operating Officer of a DST-ALSTOM funded Incubation Centre. He is also a TEDx Speaker, has trained several Students on various Life Skills, and conducted several workshops for Teachers and Faculty members. He is also a Visiting Scientist to CSIR, South Africa and NUST, Russia. His research works have been featured in the "Times of India, Vijayavaani, Dainik Bhaskar and he was interviewed by Doordarshan Programs.

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