Indian Journal of
Advances in Chemical Science

Review Article

A Review on Green Hydrogen: An Alternative of Climate Change Mitigation

Sakshee Rai, Mahima Habil Massey, David Daneesh Massey

Department of Chemistry, St. John's College, Agra, Uttar Pradesh, India

ABSTRACT

Climate change is one of our time's most pressing issues, posing significant challenges to our communities and the environment. Sea level rise, ice sheet and glacier shrinkage, catastrophic floods, and the effects of climate change are global in scope and unprecedented in scale. Adapting to these consequences in the future may be more difficult and costly if significant action is not taken today. Several causes, including the use of fossil fuels, contribute to climate change by releasing CO2 into the atmosphere, causing the planet to heat up and culminating in climate change. In the current context, green hydrogen (GH) plays a critical role in overcoming this challenge. GH is hydrogen fuel that is produced using renewable energy rather than fossil fuels. Every year, about 100 million of tons of hydrogen are generated for a variety of commercial applications. The huge majority of this industrial hydrogen is derived through coal gasification or steam methane reforming, both of which need a high level of strength and produce significant CO2 emissions. The electrolysis of water produces a significantly lesser percentage of hydrogen, which is a far more sustainable and clean approach if the energy is derived from renewable sources. A novel, green method of producing hydrogen could reduce global warming-causing greenhouse gas emissions and help countries to achieve their climate goals. The paper points out how the concerns of today, including climate change can be turned into the use of clean energy. The objective of this article is to give an overview of the current situation regarding green hydrogen and its applications.

Key words: Climate, Climate change, Fossil fuels, Green hydrogen.

1. INTRODUCTION

CO_2 emissions connected to energy account for two-thirds of worldwide greenhouse gas (GHG) emissions. Global net anthropogenic CO_2 emissions must decline by about 25% by 2030 from 2010 levels, before reaching net-zero by 2070, to have a fair chance of remaining below 2°C by 2100 (Figure 1). Carbon neutrality by the mid-twentieth century is required to keep global warming at 1.5°C, which the Intergovernmental Panel on Climate Change considers safe [1-4].

This goal is also stated in the Paris Agreement, which was signed by 195 countries, including the European Union [5]. Carbon neutrality refers to a strategy that strikes a balance between releasing carbon and absorbing it from the environment in carbon sinks. Carbon sequestration is the procedure of removing CO_2 from the atmosphere and storing it. To achieve net-zero emissions, all global GHG emissions will need to be offset by carbon sequestration. By the year 2100, the average global temperature will have risen by 3.5°C. However, if a firm commitment is made to bring global emissions to net-zero by 2060, the temperature rise may be brought down to 1.5°C by 2100 [4].

According to studies, the number of vehicles used for transportation would quadruple by 2050, surpassing 2.5 billion globally. To break the connection between economic growth and rising CO_2 emissions, the most forceful transformation is required. To meet the emission reduction objectives, a change in the production and use of healthy energy is required. As a result, Green hydrogen (GH) power is emerging as a viable alternative to fossil fuels and battery-powered mobility systems. In theory, it has the potential to do three things: store excess renewable energy when the grid can't handle it, assist in decarbonizing difficult-to-electrify sectors such as long-distance transportation and heavy industries, and replace fossil fuels as a zero-carbon feedstock in chemical and fuel manufacturing [4]. Hydrogen is a major intermediate in industry. But only around 6% of the produced hydrogen is for pure hydrogen demand, which indicates that it has a limited role in the global energy mix (Figure 2).

1.1. Why GH?

Hydrogen is the elementary form of all molecules; it has the lowest energy content by volume, but it has the highest power content material of any gas with the aid of weight. Due to the high energy content of hydrogen, it is laboring as a gas in applications that includes Fuel Cells and rockets [4].

Following up with the latest Petrofac bulletins supporting the primary UK CCS and hydrogen challenge, as well as aiding Australia's largest industrial scale GH assignment, Alex Haynes, head of business development, states that "Green hydrogen requires a primary source of energy to be produced—sun, electricity, hydro nuclear power, or gas—and the intricacies of the production system, including the power source used, decide whether hydrogen is green, blue, gray, pink, or yellow in actuality" [6] [Figure 3].

***Corresponding author:**
Email: saksheerai0@gmail.com

ISSN NO: 2320-0898 (p); 2320-0928 (e)
DOI: 10.22607/IJACS.2021.904016

Received: 12th October 2021;
Revised: 17th October 2021;
Accepted: 18th October 2021

Hydrogen is constituted of electrolysis of water with the electricity is made out of renewable resources is frequently called as GH energy. GH energy creates zero harmful emissions, which is one of the most considerable limitations of fossil fuels, and the heating content of hydrogen is 3 times higher than that of petroleum [7].

Blue hydrogen is a natural fuel that is converted into hydrogen and CO_2 using either Steam Methane Reforming or Auto Thermal Reforming; however, the CO_2 is collected and later stored. As GHG are collected, the environmental consequences on Earth are mitigated. The “capturing” is completed via a technique called as Carbon Capture Usage and Storage [6]. The process of producing GH is fueled by renewable energy sources such as wind or solar. As a result, GH is the most environment friendly option, with no hazardous emissions.

2. PRODUCTION OF GH

Hydrogen can be produced through the electrolysis of water, leaving not anything but oxygen as a byproduct. Electrolysis employs an electric present-day to split water into hydrogen and oxygen in an electrolyzer. If the power is produced via renewable energy, consisting of solar or wind, the resulting pollutant-free hydrogen is called GH. The hastily declining cost of renewable power is one purpose for the growing interest in GH [10]. Biological hydrogen production or biohydrogen is an interesting new area of fuel processing technology

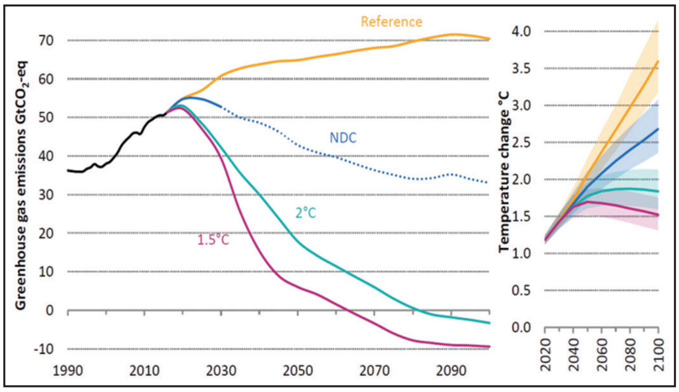


Figure 1: Greenhouse gas emissions and temperature rise [4].

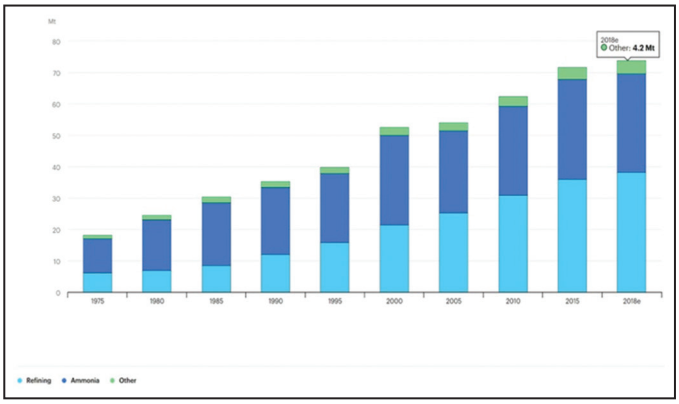
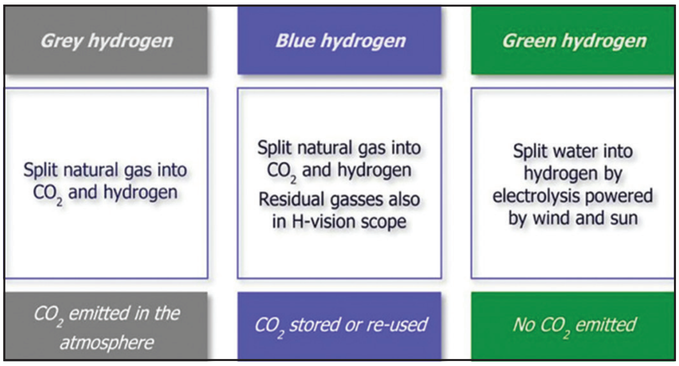


Figure 2: Global demand for pure hydrogen, 1975–2018 [8].



Grey hydrogen	Blue hydrogen	Green hydrogen
Split natural gas into CO_2 and hydrogen	Split natural gas into CO_2 and hydrogen Residual gasses also in H-vision scope	Split water into hydrogen by electrolysis powered by wind and sun
CO_2 emitted in the atmosphere	CO_2 stored or re-used	No CO_2 emitted

Figure 3: Types of hydrogen [9].

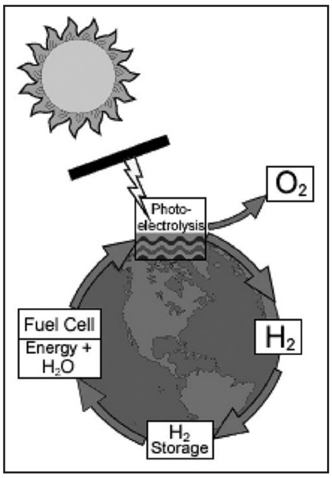


Figure 4: A renewable hydrogen cycle [11].

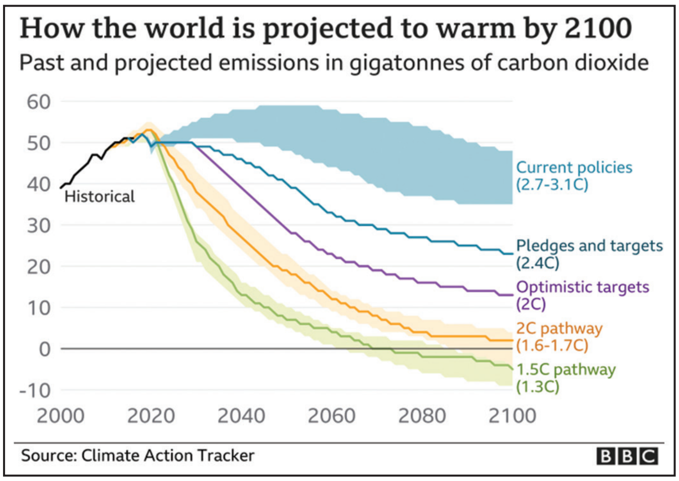


Figure 5: Past and projected emissions of CO_2.

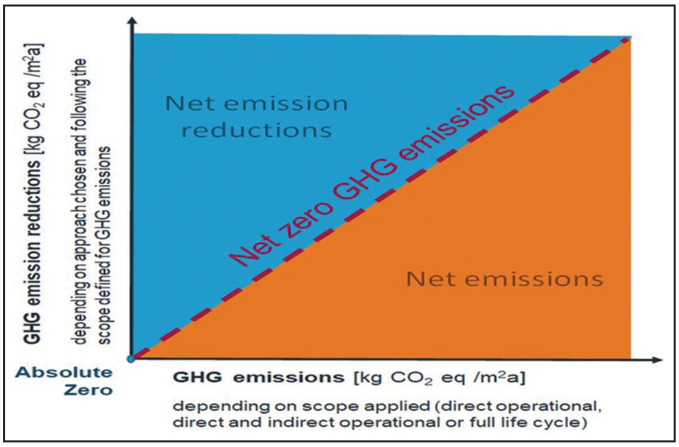


Figure 6: Greenhouse gas (GHG) emissions, GHG emission reductions and resulting net-zero GHG emissions [12].

that proposes hydrogen production from various renewable resources [13]. There are two renewable methods to produce H_2 i.e. by water and biomass [14-18].

2.1. Production of H_2 from Biomass

Biomass currently covers 14% of the total primary energy consumption [19] due to its abundance and ease of accessibility across many countries [20]. Nowadays, as a CO_2 neutral precursor, biomass is considered as an important renewable resource for hydrogen production [21]. Currently, the two main processes to produce hydrogen from biomass are through the thermochemical and biochemical process [22]. Thermo-chemical processes include pyrolysis, gasification, steam reforming, and supercritical gasification, whereas biochemical processes include bio-photolysis, bio-fermentation, and dark fermentation. In the biochemical process, biomass can be converted into biofuels through various processes including anaerobic or aerobic digestion, fermentation, and acid hydrolysis [23,24].

Relative to biological process, thermo-chemical methods are more flexible and provide a simpler approach as there is no need for added chemicals but instead heat and pressure are used to generate biofuels [25]. This can be done by pyrolysis or gasification. Gasification is a well-developed process where hydrogen-rich fuel gas (CO, H_2, and CH_4) is produced at 700–1200°C using gasification agents (O_2, CO_2, steam, and air [11,12,26-28].

$$\text{Biomass} \rightarrow H_2 + CO_2 + CO + N_2$$

H_2 can also be obtained via the pyrolysis of biomass at lower temperatures of 300–650°C, but, at such temperatures, the hydrogen yield is lowered and of ~18% by volume [29].

$$\text{Biomass} \rightarrow H_2 + CO_2 + CO + \text{hyrdrocarban gases}$$

2.2. Production of H_2 by Water Splitting

Depending on the energy source used, water electrolysis can be a fully sustainable and a clean way to generate hydrogen since no GHG is emitted. Hydrogen production from water splitting can be done by using several processes including electrolysis and photocatalysis [26]. During the photocatalysis process, a light excited semiconducting electrode with a suitable excitation bandgap [Figure 4], for example, TiO_2, is used to split water into hydrogen and oxygen. Unfortunately, TiO_2 strongly absorbs light in the UV spectrum ($\lambda < 350$ nm) only, and not in the visible light range (350 nm $< \lambda <$ 700 nm), and this results in bad photocatalytic activity under sunlight [30].

In water electrolysis, gaseous hydrogen and oxygen are generated from water in the following equation: $2H_2O(1) \rightarrow 2H_2(g) + O_2(g)$

This is an energy-demanding reaction with a change in Gibbs free energy (ΔG) of 237.2 kJ/mol at normal conditions [27]. If this reaction is done in an electrochemical cell, a potential difference of 1.23 Volt is mandatory at room temperature and standard pressure. Various electrochemical cell configurations have been investigated to generate hydrogen through water electrolysis. These technologies are at several stages of maturity and include the proton exchange membrane (PEM) [40], alkaline water, anion exchange membrane, solid oxide electrolysis, and microbial electrolysis cell technologies [31-36].

2.3. Net-zero Emission

The situation in which a country's GHG emissions are eliminated from the ecosystem through carbon absorption or sequestration is known as net-zero. Some nations have considered hydrogen fuel in their national recovery efforts in the aftermath of a pandemic. Net-zero objectives and climate risk declarations have been included into national legislation in Canada and the United Kingdom. The United Kingdom intends to meet the carbon net-zero objectives by 2050. The world is developing an international market for associated zero-carbon solutions by openly defining hydrogen's role [37].

According to a new study co-authored with the help of the former vice-chairman of the Planning Commission, Montek Singh Ahluwalia, India may achieve "net-zero" carbon emissions by 2065–70 as its greenhouse emissions rise through 2035 and if it stops coal consumption in the following 10 years [Figure 5]. The document titled "Getting Net-Zero Approach for India at CoP 26" strongly urges that India must proclaim its "net zero" goal year at the 2021 United Nations Climate Change Conference (CoP 26), which begins on October 31 in Glasgow, U.K [38].

According to a recent assessment by the Council on Energy, Environment, and Water, India should progressively convert to green steel, starting with a combination of green and grey hydrogen. "An overnight transition to fossil-free steelmaking will be highly expensive," Mallya added. According to the Council on Energy, Environment, and Water study, the lowest cost of making green steel in 2030 would still be 22% higher than coal-based steel [5]. Some nations have considered hydrogen fuel in their national recovery efforts in the aftermath of a pandemic [Figure 6].

3. GH BASED ECONOMY OF INDIA

India can decarbonize their power-intensive sector which includes industry, transport, and power through using GH. The probable surge in electricity demand from those sectors all through the post-pandemic economical recuperation can be met via the production of hydrogen from renewable electricity sources, as renewable power is getting increasingly inexpensive. Advanced economies such as the European Union, Australia, and Japan have already drawn a hydrogen roadmap to acquire inexperienced economic increase. A hydrogen economic system also improves air quality, mitigates carbon emissions, and fulfils the Atmanirbhar Bharat vision. India GH roadmap prepared by FTI Consulting (Figure 7) [39].

4. MERITS AND DEMERITS OF GH

4.1. Merits of GH

a. GH can help to decarbonize parts of the transportation industry, but its power zone interactions are not well known yet. It may

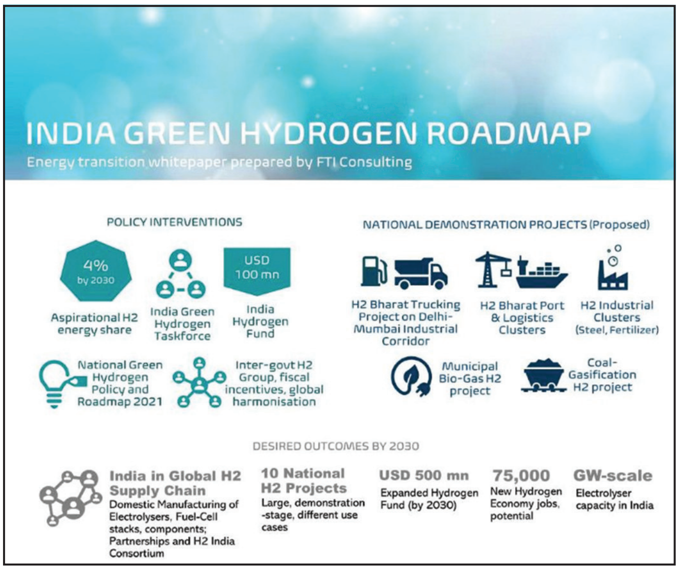


Figure 7: Green hydrogen roadmap of India [44].

also help to integrate variable renewable energy sources if manufacturing is sufficiently time-flexible [41]. GH emits non-polluting gases during combustion or production [42]

b. Hydrogen is easy to store, allowing it to be used later for other purposes and at times other than immediately after manufacturing [43]
c. It may be combined with natural gas at up to a 20% ratio and flow through the same gas pipes and infrastructure - exceeding this percentage may need altering separate parts within the existing fuel networks to make them compatible [44]
d. Increased hydrogen usage can assist to overcome problems in balancing intermittent renewables and reduce air pollution in cities, especially in hard-to-abate industries like steel and cement manufacturing, heavy-duty vehicles, shipping, and aviation [45].

4.2. Demerits of GH

a. Renewable energy, which is essential for creating GH via electrolysis, is more expensive to create, making hydrogen more expensive to get
b. The production of GH is trendy, and it takes more energy than conventional fuels
c. GH is extremely dangerous and combustible, necessitating extensive safety precautions to prevent leaks and explosion [44]. Eventual leakage of hydrogen in confined spaces frequented by motor vehicles poses a significant hazard [46]
d. GH deployment is currently in the experimental stage, and while many nations, like India, have proclaimed national hydrogen programs, no plans have been made for how it would be commercialized on a big scale.

5. ROLE OF GOVERNMENT

The exposure of a clean hydrogen financial system based on regulation (Figure 8 For distribution of policies in location mid-2019). "The largest assignment is getting the right policies in location," says Van Wijk. "We need to build up a hydrogen infrastructure. That is a big venture that needs political assist." The first-ever European hydrogen approach, introduced in July 2020 [47] goal to support the broader purpose of "sector integration." This originally implied using carbon-free power to help decarbonizes other sectors, viz. transport and industry.

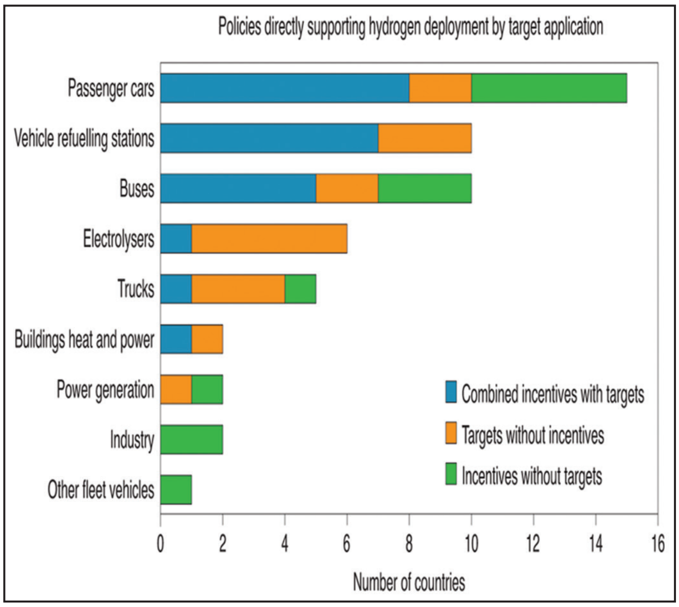


Figure 8: For distribution of policies in location mid-2019.

Below are some key steps the government can follow to construct a worldwide GH industry:

1. Similar to renewable energy, the government must establish ambitious national objectives for GH and electrolyzer potential by 2030. Existing hydrogen applications, such oil refining, and fertilizers, should be required to utilize a specific amount of GH, while new Greenfield hydrogen applications, like oil refinery and chemical fertilizers, should embrace GH as soon as feasible
2. Initiate an incentive scheme for the production of electrolyzers: Capital expenses account for around 30% of GH costs. To alleviate the severe global supply deficit, India could consider implementing an incentive scheme for the manufacturing of electrolyzers
3. Use generators that can promote higher cycles and spillover effects. One example could be hydrogen infrastructure for airport refueling, heating, and power generation
4. Hydrogen boilers make sense for heating in areas with existing gas pipeline infrastructure. Grid operators must choose to decarbonize the gas grid with regulator assistance before totally shutting it down. In the transportation industry, there are several cases where electrification is simply not possible, such as aviation applications, where kerosene-based jet fuels are currently used [48]
5. Establishing a procurement mandate for gas utilities to blend a minimum and safe level of GH in delivered gas to buildings [49].

Once a decision is made, hydrogen retains a comparative advantage, even after accounting for network technology upgrades and consumer home equipment upgrades [50].

6. CONCLUSION

Climate change is occurring, and it is primarily due to human activities. Its effects are already being seen, and unless we take action, they will intensify in the next decades. Global warming—as a result of CO_2 and other GHG emissions from human activities—has resulted in climate shifts and environmental degradation, as well as the spread of dangerous illnesses. GH is a multi-sectoral result with the potential to considerably reduce emissions in a variety of sectors. Given the present high pricing and a lack of supporting infrastructure, governments have a number of challenges in paving the way for this new kind of energy. Based at the effects from diverse studies within the literature, it's far clear that each renewable energy-primarily based techniques for hydrogen manufacturing are more environment friendly than fossil fuel-based hydrogen generation procedures. However, the price of hydrogen production using renewable energy requires to be further decreased so that you can be applied on a massive scale. In specific, under the identical assessment conditions as different research, the environment effect of hydrogen production via biomass electrolysis is smaller than the alternative techniques, making it a prospective candidate for an environment-friendly hydrogen power manufacturing method with low power intake.

REFERENCES

1. Available from: https://www.climateurope.eu/what-is-climate-and-climate -change [Last accessed on 2021 Oct 08].
2. O. Adedeji, (2014) Global climate change, ***Journal of Geoscience and Environment Protection***, **2**(**2**): 114.
3. Available from: http://ccir.ciesin.columbia.edu/nyc/pdf/q1a.pdf [Last accessed on 2021 Oct 08].
4. B. S. Thapa, B. Thapa, (2020) Green hydrogen as a future multi-disciplinary research at Kathmandu university, ***Journal of Physics: Conference Series***, **1608**(**1**): 012020.

5. S. van Renssen, (2020), The hydrogen solution? ***Nature Climate Change***, **10**(**9**): 799-801.
6. IEA, (2019) ***The Future of Hydrogen***, Paris, France: International Energy Agency.
7. Available from: https://scroll.in/article/1006344/explainer-what-is-green-hydrogen-and-how-can-it-help-india-mitigate-climate-change [Last accessed on 2021 Oct 08].
8. Available from: https://news.climate.columbia.edu/2021/01/07/need-green-hydrogen [Last accessed on 2021 Oct 09].
9. Available from: https://www.google.com/search?q=graph+for+net+zero+emissions+by+2050 [Last accessed on 2021 Oct 08].
10. W. W. 2nd Clark, J. Rifkin, (2006) A green hydrogen economy, ***Energy Policy***, **34**(**17**): 2630-2639.
11. S. Dunn, (2002) Hydrogen futures: toward a sustainable energy system, ***International Journal of Hydrogen Energy***, **27**(**3**): 235-264.
12. T. Lützkendorf, R. Frischknecht, (2020), (Net-) zero-emission buildings: A typology of terms and definitions, ***Buildings and Cities***, **1**(**1**): 662-675.
13. S. E. Hosseini, M. A. Wahid, (2016), Hydrogen production from renewable and sustainable energy resources: Promising green energy carrier for clean development, ***Renewable and Sustainable Energy Reviews***, **57:** 850-866.
14. T. R. Ayodele, J. L. Munda, (2019) Potential and economic viability of green hydrogen production by water electrolysis using wind energy resources in South Africa, ***International Journal of Hydrogen Energy***, **44**(**33**): 17669-17687.
15. I. Dincer, (2012) Green methods for hydrogen production, ***International Journal of Hydrogen Energy***, **37**(**2**): 1954-1971.
16. A. Kopteva, L. Kalimullin, P. Tcvetkov, A. Soares, (2021) Prospects and obstacles for green hydrogen production in Russia, ***Energies***, **14:** 718.
17. M. Pajak, G. Brus, J. S. Szmyd, (2021), Catalyst distribution optimization scheme for effective green hydrogen production from biogas reforming, ***Energies***, **14**(**17**): 5558.
18. N. Rambhujun, M. S. Salman, T. Wang, C. Pratthana, P. Sapkota, M. Costalin, K. F. Aguey-Zinsou, (2020) Renewable hydrogen for the chemical industry, ***MRS Energy and Sustainability***, **7:** 33.
19. R. Granados-Fernández, M. Cortés-Reyes, E. Poggio-Fraccari, C. Herrera, M. A. Larrubia, L. J. Alemany, (2020) Biomass catalytic gasification performance over unsupported Ni-Ce catalyst for high-yield hydrogen production, ***Biofuels, Bioproducts and Biorefining***, **14**(**1**): 20-29.
20. D. E. Resasco, B. Wang, D. Sabatini, (2018) Distributed processes for biomass conversion could aid UN sustainable development goals, ***Nature Catalysis***, **1**(**10**): 731-735.
21. R. M. Navarro, M. C. Sanchez-Sanchez, M. C. Alvarez-Galvan, F. Del Valle, J. L. G. Fierro, (2009) Hydrogen production from renewable sources: biomass and photocatalytic opportunities, ***Energy and Environmental Science***, **2**(**1**): 35-54.
22. B. Dou, H. Zhang, Y. Song, L. Zhao, B. Jiang, M. He, Y. Xu, (2019) Hydrogen production from the thermochemical conversion of biomass: Issues and challenges, ***Sustainable Energy and Fuels***, **3**(**2**): 314-342.
23. B. Pandey, Y. K. Prajapati, P. N. Sheth, (2019). Recent progress in thermochemical techniques to produce hydrogen gas from biomass: A state of the art review, ***International Journal of Hydrogen Energy***, **44**(**47**): 25384-25415.
24. M. Formica, S. Frigo, R. Gabbrielli, (2016) Development of a new steady state zero-dimensional simulation model for woody biomass gasification in a full scale plant, ***Energy Conversion and Management***, **120:** 358-369.
25. M. Saghir, M. Rehan, A. S. Nizami, (2018) Recent trends in gasification based waste-to-energy, ***Gasification for Low-Grade Feedstock*****, 1**: 97-113.
26. F. Safari, I. Dincer, (2020) A review and comparative evaluation of thermochemical water splitting cycles for hydrogen production, ***Energy Conversion and Management***, **205:** 112182.
27. P. Millet, N. Mbemba, S. A. Grigoriev, V. N. Fateev, A. Aukauloo, C. Etiévant, (2011) Electrochemical performances of PEM water electrolysis cells and perspectives, ***International Journal of Hydrogen Energy***, **36**(**6**): 4134-4142.
28. M. Carmo, D. L. Fritz, J. Mergel, D. Stolten, (2013) A comprehensive review on PEM water electrolysis, ***International Journal of Hydrogen Energy***, **38**(**12**): 4901-4934.
29. T. Hutsol, S. Glowacki, A. Tryhuba, N. Kovalenko, Z. Pustova, A. Rozkosz, O. Sukmaniuk, (2021) ***Current Trends of Biohydrogen Production from Biomass-Green Hydrogen***, Monograph.
30. M. Wang, G. Wang, Z. Sun, Y. Zhang, D. Xu, (2019) Review of renewable energy-based hydrogen production processes for sustainable energy innovation, ***Global Energy Interconnection***, **2**(**5**): 436-443.
31. A. Giaconia, M. Della Pietra, G. Monteleone, G. Nigliaccio, (2021) 5 Development perspective for green hydrogen production, ***Hydrogen Production and Energy Transition*****, 1**: 251-278.
32. C. S. W. Cheng, (2020) ***The Prospects of Blue and Green Hydrogen in Norway for Energy Export***, Norway: Master's Thesis, University of Stavanger.
33. L. Louvet, (2021) ***Green Hydrogen in the Energy Transition: A Review.*** Finland: **Aalto University, p**71.
34. P. Nikolaidis, A. Poullikkas, (2017) A comparative overview of hydrogen production processes, ***Renewable and Sustainable Energy Reviews***, **67:** 597-611.
35. F. Dawood, M. Anda, G. M. Shafiullah, (2020) Hydrogen production for energy: An overview, ***International Journal of Hydrogen Energy***, **45**(**7**): 3847-3869.
36. K. Zeng, D. Zhang, (2010) Recent progress in alkaline water electrolysis for hydrogen production and applications, ***Progress in energy and Combustion Science***, **36**(**3**): 307-326.
37. Available from: https://www.hindustantimes.com/india-news/india-can-achieve-net-zero-carbon-emissions-target-by-2067-70-study-101632076022693-amp.html [Last accessed on 2021 Oct 08].
38. Available from: https://www.petrofac.com/media/stories-and-opinion/the-difference-between-green-hydrogen-blue-hydrogen [Last accessed on 2021 Oct 08].
39. European Commission, (2020) ***A Hydrogen Strategy for a Climate-neutral Europe***, Brussels, Belgium: European Commission.
40. Available from: http://info.fticonsulting.com/indias-green-hydrogen-roadmap [Last accessed on 2021 Oct 10].
41. Available from: http://www.nature.com/scientificreports [Last accessed on 2021 Oct 08].
42. M. K. Kazi, F. Eljack, M. M. El-Halwagi, M. Haouari, (2021) Green hydrogen for industrial sector decarbonization: Costs and impacts on hydrogen economy in Qatar, ***Computers and Chemical Engineering***, **145:** 107144.
43. F. Stöckl, W. P. Schill, A. Zerrahn, (2021) Optimal supply chains and power sector benefits of green hydrogen, ***Scientific Reports***, **11**(**1**): 1-14.
44. Available from: https://www.iberdrola.com/sustainability/green-

hydrogen [Last accessed on 2021 Oct 08].

45. H. Dagdougui, A. Ouammi, R. Sacile, (2012) Modelling and control of hydrogen and energy flows in a network of green hydrogen refuelling stations powered by mixed renewable energy systems, ***International Journal of Hydrogen Energy***, **37**(**6**): 5360-5371.
46. Y. Hajji, M. Bouteraa, A. Elcafsi, P. Bournot, (2021) Green hydrogen leaking accidentally from a motor vehicle in confined space: A study on the effectiveness of a ventilation system, ***International Journal of Energy Research***, **45:** 18935-18943.
47. Available from: https://blog.sintef.com/sintefenergy/elegancy-tno-h-vision-project [Last accessed on 2021 Oct 08].
48. A. M. Oliveira., R. Beswick, Y. Yan, (2021) A green hydrogen economy for a renewable energy society, ***Current Opinion in Chemical Engineering***, **33:** 100701.
49. Available from: https://www.nrdc.org/experts/rachel-fakhry/green-hydrogen-critical-powering-carbon-free-future [Last accessed on 2021 Oct 10].
50. Available from: https://www.downtoearth.org.in/blog/pollution/amp/green-hydrogen-can-drive-india-s-transition-to-clean-energy-combat-climate-change-77685 [Last accessed on 2021 Oct 09].

**Bibliographical Sketch*

Ms. Sakshee Rai is perusing her M.Sc. in Chemistry from the Department of Chemistry, St. John's College, Agra. Her specialization is in Organic Chemistry. She has participated in many national seminars and online webinars in Chemistry and Air Quality. Her research Interest lies in Organic, Environmental, and Analytical Chemistry.

Dr. Mahima Habil Massey is an Assistant Professor in the Department of Chemistry, St. John's College, Agra. Her research interest lies in Environmental and Analytical Chemistry. She has also been a Post-Doctoral Fellow under the Fast Track scheme funded by SERB, DST. She is working on indoor and outdoor air pollution studies, namely indoor/outdoor air pollutants emission source characterization, personal exposure assessment, etc. She has worked on several projects funded by DST and UGC during her research and post-research duration. She has published many papers in international and national journals of high impact factors and also one book and three book chapters to her credit.

Dr. David Daneesh Massey is Assistant Professor in the Department of Chemistry, St. John's College Agra. He has been a Post Doc Fellow in CSIR Project. He is working on indoor and outdoor air pollution studies, namely indoor/outdoor air pollutants emission source characterization, personal exposure assessment, etc. He has worked on several projects funded by DST, UGC, and CSIR. He has published many research articles in several international and national journals of high impact factors. He has also published one book, two book chapters. He has more than thirteen years of teaching and research experience. Awards and Recognition: CSIR-SRF (2010), DST SRF (2009), DST JRF (2007-2009). Young Scientist Award (2009, 2019).