CORPUS PUBLISHERS

Environmental Sciences and Ecology: Current Research (ESECR)

ISSN: 2833-0811

Volume 7 Issue 3, 2026

Article Information

Received date : May 13, 2026

Published date: May 19, 2026

*Corresponding author

Siddique MNI, Faculty of Ocean Engineering Technology, Universiti Malaysia Terengganu (UMT), Terengganu, Malaysia

DOI: 10.54026/ESECR/10129

Keywords

Green Hydrogen; Electrolysis (specifically PEM, Alkaline, and Solid Oxide); Optimization; Renewable Energy; Biomass Gasification

Mini Review Article

An overview of renewable hydrogen generation methods and optimisation strategies

Siddique MNI*, **Rasit NS**, **Ibrahim ZB**

Faculty of Ocean Engineering Technology, Universiti Malaysia Terengganu (UMT), Terengganu, Malaysia.

Abstract

Green hydrogen provides a viable alternative to conventional energy, providing a sustainable technique to lower carbon emissions and strengthening electricity protection. This overview explores key production pathways, specializing in electrolysis and biomass-based strategies and hybrid renewable energy and cogeneration systems to improve efficiency and grid stability. In addition, it explores the feature of synthetic intelligence (AI) in H_2 production, especially in renewable energy forecasting, system optimization, and fault diagnostics. The optimization guarantees value-effectiveness and system reliability, and enhances hydrogen production efficiency with the aid of identifying premier operational parameters and minimizing system inefficiencies. The newness of this examines lies in integrating hybrid renewable power and hydrogen manufacturing optimization, an attitude not substantially covered in previous research. Furthermore, it provides a comprehensive analysis of optimized applications, consisting of predictive upkeep and fault detection, to enhance hydrogen device reliability. A distinguished contribution of this study is its attention to real-global case research of hydrogen production and application, demonstrating its viability across transportation, strength generation, and industrial sectors. Via addressing key technical and financial challenges, this evaluation outlines a scalable method for lower-priced and sustainable H_2 manufacturing, encouraging a greater resilient and sustainable energy future.

Introduction

The production of green hydrogen has evolved from a gap alternative to a vital pillar of global decarbonization strategies for 2026. Unlike "grey" or "blue" hydrogen, green hydrogen is characterized by using a carbon-impartial footprint accomplished by splitting water using renewable energy resources like solar, wind, and hydropower [1-2].

Green Hydrogen Production Pathways

Electrolytic pathways (water splitting)

Modern-day studies categorize hydrogen production into conventional, organic, electrolytic, and emerging photocatalytic pathways (Figure 1) [3-4]. Proton Exchange Membrane (PEM): preferred for its fast device reaction, permitting it to "ramp" up or down to fit the intermittency of variable renewable power (VRE) like wind and solar [5-7]. Alkaline Water Electrolysis (AWE): A properly set up, low-value technology. Current optimizations of the usage of novel Ru-Ta-Ti alloy electrodes have achieved efficiencies exceeding ninety-five % while maintaining superior longevity in comparison to conventional nickel-based electrodes [8-10].stable Oxide Electrolysis (SOEC): running at high temperatures (>seven hundred°C), SOEC is noticeably efficient (up to 88% LHV) and is especially appropriate for heavy industries like metal or ammonia synthesis, where waste heat may be recycled to generate steam [11-12].

(Figure 1): Types of hydrogen and methods of synthesis [19].

How to cite this article : Siddique MNI*, Rasit NS, Ibrahim ZB (2026) An overview of renewable hydrogen generation methods and optimisation strategies . Environ Sci Ecol: Curr Res 7: 10129

Thermochemical & organic pathways

Biomass Gasification: This pathway converts agricultural residues and waste into hydrogen. Whilst it gives a circular economic system advantage, it faces challenges concerning feedstock variability and the want for rigorous carbon control to make sure low carbon emissions [14-15]. Photocatalytic Water Splitting: A rising "direct" approach that makes use of semiconductor catalysts to break up water using sunlight without intermediate power generation. Recent breakthroughs in heterojunction photocatalysts have advanced visible-mild absorption and hydrogen evolution rates [16].

Optimization Techniques

Maximizing the efficiency and economic viability of green hydrogen calls for state-of-the-art optimization across the complete value chain (Table 1).

(Table 1): Current hydrogen manufacturing strategies are compared.

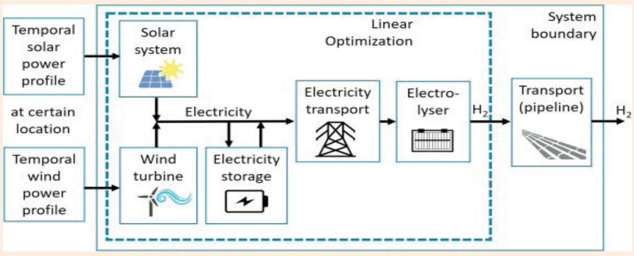
Optimization Factor	Technique	Impact
Energy Supply	VRE Integration & Forecasting	Improved system reliability and lower LCOH.
Material Science	Ru-Ta-Ti Alloy Electrodes	>95% efficiency and increased electrode life.
System Scale	Modular Stamping (e.g., 2.6 MW)	Zero-downtime maintenance and scalability.
Thermal process	Waste Heat Recovery (SOEC)	Maximized energy utilization in heavy industry.

Techno-monetary Optimization

The Levelized Value of Hydrogen (LCOH) is the primary metric for optimization. Key techniques include: most useful Sizing & site selection: the usage of hybrid structures (e.g., wind/PV) to limit surplus ability and fluctuations. As an example, research suggests that "clipping" surplus power from renewable plants for hydrogen manufacturing can decrease charges to about $1.98/kg [17]. Dynamic production making plans: implementing Python-based forecasting tools and Power Purchase Agreements (PPAs) to schedule manufacturing throughout periods of low energy charges and high renewable availability [18].

Method & Operational Optimization

Heat integration: In techniques like green ammonia synthesis, adjusting running temperatures (e.g., decreasing from 482.five°C to 368.nine°C) and using multistage compressors can extensively increase yield and decrease cumulative energy demand (Figure 2).



(Figure 2): Taken into account the system border and its components [1].

Stack engineering: For massive-scale applications, optimizing stacking arrangements in electrolyzer cells (above five MW) is vital to reducing corrosion and overpotential at the electrodes.

References

1. Timmerberg S, Kaltschmitt M (2019) Hydrogen from renewables: Supply from North Africa to Central Europe as blend in existing pipelines - Potentials and costs, Appl Energy 237(1): 795-809.
2. Adessi A, De Philippis R (2014) Photobioreactor design and illumination systems for H_2 production with anoxygenic photosynthetic bacteria: a review, Int. J. Hydrogen Energy 39(7): 3127-3141.
3. Afsar N, Özgür E, Gürgan M, Akköse S, Yücel M, et al. (2011) Hydrogen productivity of photosynthetic bacteria on dark fermenter effluent of potato steam peels hydrolysate, Int. J. Hydrogen Energy 36(1): 432-438.
4. Khalid ZB, Siddique MNI, Nasrullah M, Singh L, Wahid AW, Fadhli AM (2019) Application of solar assisted bioreactor for biogas production from palm oil mill effluent co-digested with cattle manure, Environmental Technology and amp, Innovation 16: 100446.
5. Siddique MNI, Muhammad Nomani Kabir ZBK (2019) Progressive two-stage efficient co- digestion of food waste and petrochemical wastewater for higher methane and hydrogen production. Asian Journal of Chemistry 31(11): 2575-2578.
6. Hanley ES, Deane JP, BÓP Gallachóir (2018) The role of hydrogen in low-carbon energy futures-A review of existing perspectives, Renew Sustain Energy Rev 82(3): 3027-3045.
7. Argun H, Kargi F (2010) Photo-fermentative hydrogen gas production from dark fermentation effluent of ground wheat solution: Effects of the light source and light intensity, Int. J. Hydrogen Energy 35(4): 1595-1603.
8. Bongartz D, Doré L, Eichler K, Grube T, Heuser B et al. (2018) Comparison of light-duty transportation fuels produced from renewable hydrogen and green carbon dioxide, Appl Energy 231(1): 757-767.
9. Argun H, Kargi F, Kapdan IK (2008) Light fermentation of dark fermentation effluent for bio-hydrogen production by different rhodobacter species at different initial volatile fatty acid (VFA) concentrations, Int. J. Hydrogen Energy 33(24): 7405-7412.
10. Brynolf S, Taljegard M, Grahn M, Hansson J, (2018) Electrofuels for the transport sector: A review of production costs, Renew Sustain Energy Rev 81(2): 1887-1905.
11. Argun H, Kargi F, Kapdan IK, Oztekin R, (2008) Batch dark fermentation of powdered wheat starch to hydrogen gas: Effects of the initial substrate and biomass concentrations, Int. J. Hydrogen Energy 33(21): 6109-6115.
12. Parkinson B, Balcombe P, Speirs JF, Hawkes AD, Hellgardt K (2019) Levelized cost of CO_2 mitigation from hydrogen production routes, Energy Environ Sci 12(1): 19-40.
13. Asadi N, Karimi Alavijeh M, Zilouei H (2018) Biological hydrogen production by enterobacter aerogenes: Structural analysis of treated rice straw and effect of substrate concentration, Int. J. Hydrogen Energy 43(18): 8718-8728.
14. Pandey A, Sinha P, Pandey A (2021) Hydrogen production by sequential dark and photofermentation using wet biomass hydrolysate of Spirulina platensis: Response surface methodological approach, Int J Hydrogen Energy 46(10): 7137-7146.
15. Policastro G, Panico A, Fabbricino M (2021) Improving biological production of poly(3-hydroxybutyrate-co-3-hydroxyvalerate) (PHBV) co-polymer: A critical review, Rev Environ Sci Biotechnol 20: 479-513.
16. Ahmad S, Ullah A, Samreen A, Qasim M, Nawaz K, et al. (2024) Hydrogen production, storage, transportation, and utilization for the energy sector: A current status review, Journal of Energy Storage 101(Part A): 113733.
17. Yacine Benchenina, Abderrahim Zemmit, Mohammed Moustafa Bouzaki, Abdelouadoud Loukriz, Salah K Elsayed (2025) Advancing green hydrogen production in algeria with opportunities and challenges for future directions, Scientific Reports (15): 5559.
18. Abdalla AM, Hossain S, Nisfindy OB, Azad AT, Dawood M, et al. (2018) Hydrogen production, storage, transportation and key challenges with applications: A review, Energy Conversion and Management 165(1): 602-627.
19. Shanmugasundaram S, Thangaraja J, Rajkumar S, Ashok SD, Sivaramakrishna A, et al. (2025) A review on green hydrogen production pathways and optimization techniques. Process Saf Environ Prot 197: 107070

Citation: Siddique MNI*, Rasit NS, Ibrahim ZB (2026) An overview of renewable hydrogen generation methods and optimisation strategies . Environ Sci Ecol: Curr Res 7: 10129