

Rapid Communication

Open Access

Green Hydrogen: Production, Progress, Future

Emily K. Townsend*

Department of Biomedical Sciences, University of Crescent Bay, California, USA

***Corresponding Author:** Emily K. Townsend, Department of Biomedical Sciences, University of Crescent Bay, California, USA, E-mail: emily.townsend@crescentuniv.edu

Received: 01-May-2025, Manuscript No. science-25-172975; **Editor assigned:** 05-May-2025, PreQC No. science-25-172975(PQ); **Reviewed:** 19-May-2025, QC No. science-25-172975; **Revised:** 22-May-2025, Manuscript No. science-25-172975(R); **Published:** 29-May-2025, DOI: 10.4172/science.1000280

Citation: Townsend EK (2025) Green Hydrogen: Production, Progress, Future. Arch Sci 09: 280.

Copyright: © 2025 Emily K. Townsend This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution and reproduction in any medium, provided the original author and source are credited.

Abstract

Green hydrogen is a cornerstone for the global energy transition, with research detailing advancements across its entire value chain. Production methods, including evolving electrolysis techniques like alkaline, PEM, solid oxide, and anion exchange membrane electrolysis, along with novel approaches such as seawater and photocatalytic splitting, are being optimized for efficiency and cost. Challenges in infrastructure, policy support, and industrial integration remain. This body of work comprehensively reviews green hydrogen's lifecycle, from generation and storage to diverse applications, alongside its economic, environmental, and social implications. A focus on circular economy principles guides efforts toward sustainable, widespread adoption.

Keywords

Green hydrogen; Energy transition; Electrolysis; Renewable energy; Hydrogen production; Hydrogen storage; Hydrogen transportation; Industrial decarbonization; Policy implications; Circular economy; Seawater electrolysis; Photocatalytic materials

Introduction

A significant body of recent work meticulously examines the landscape of green hydrogen production, delving into both established technologies like alkaline and Proton Exchange Membrane (PEM) electrolysis and exploring promising new frontiers such as solid oxide and anion exchange membrane electrolysis. This research not only details the technological underpinnings but also critically assesses the essential role of robust policy frameworks in accelerating the widespread adoption of these clean energy solutions. Furthermore, it highlights the substantial technical challenges and economic barriers that currently impede broad implementation, stress-

ing an urgent need for concerted research and development efforts to overcome these hurdles and enable scalability[1].

Separate analyses offer insights into green hydrogen's transformative potential within the global energy transition. These articles thoroughly investigate its present status and future outlook, pinpointing the crucial policy frameworks required to facilitate its growth. The authors consistently underscore the significant economic, environmental, and technological advantages that green hydrogen offers, while candidly acknowledging the prerequisite for substantial financial investment and extensive infrastructural development to achieve widespread adoption and successful scaling across various sectors[2].

Comprehensive reviews meticulously outline the entire green hydrogen value chain, providing a holistic perspective from initial production stages to final applications. These reviews detail diverse production methods, particularly electrolysis powered by renewable energy sources, and then trace the journey through various storage technologies, transmission infrastructure, and a spectrum of applications spanning multiple sectors. A central theme emerging from

this literature is the necessity for an integrated and coordinated approach to foster a successful global hydrogen energy transition, explicitly detailing the technical and logistical hurdles that must be navigated[3].

Several overviews specifically concentrate on the myriad of green hydrogen production methods. They provide detailed comparisons of their respective efficiencies, levels of technological maturity, and overall environmental impacts. These studies bring to light key advancements in electrolysis technologies and their seamless integration with diverse renewable energy sources. A prevailing conclusion is the critical and immediate need for strategies focused on cost reduction and the scaling up of these technologies to achieve industrial feasibility and economic competitiveness[4].

A notable segment of research explores current developments and future prospects concerning green hydrogen deployment across key industrial sectors. These investigations precisely identify specific industrial processes ripe for decarbonization through the integration of green hydrogen, systematically assessing the technical readiness and economic viability associated with these transitions. They also meticulously delineate the various barriers that currently impede wider adoption within these critical industries[5].

Further comprehensive reviews offer a deep dive into green hydrogen's complete lifecycle, encompassing everything from its initial production and subsequent storage to its transportation and eventual utilization. These papers effectively highlight recent advancements at each distinct stage of this lifecycle, engaging in discussions about persistent technological challenges, and projecting future prospects for effectively integrating green hydrogen into the broader global energy system, optimizing its role and impact[6].

Analyses often assess the trajectory of the global energy transition toward green hydrogen through an in-depth evaluation of its economic viability, anticipated environmental benefits, and complex social implications. These discussions cover a wide array of factors that crucially influence its adoption, including the imperative for strong policy support, significant infrastructure development, and ensuring broad public acceptance, ultimately presenting a holistic view of green hydrogen's profound societal impact[7].

Another crucial area of inquiry explores the synergistic relationship between green hydrogen and the principles of the circular economy. This research reviews recent practical applications, outlines emergent opportunities, and acknowledges prevailing challenges. It effectively illustrates how green hydrogen stands to significantly facilitate resource efficiency and contribute to substantial waste reduction, thereby fostering a more sustainable industrial ecosystem

and markedly minimizing overall environmental impact[8].

Advanced reviews specifically focus on the innovative and particularly challenging area of green hydrogen production from seawater electrolysis. They provide a meticulous examination of the latest breakthroughs in catalysts, advanced membrane technologies, and optimized system designs. A core aspect of this research is addressing the inherent challenges of salt corrosion and the management of byproduct formation, which remain critical considerations for developing truly sustainable and scalable seawater splitting technologies[9].

Lastly, comprehensive reviews detail significant advancements in photocatalytic materials designed for sustainable green hydrogen production. These studies systematically cover various material classes, explain their underlying mechanisms, and present their performance metrics. They emphasize innovations aimed at substantially enhancing both the efficiency and stability required for solar-driven water splitting, positioning it as a highly promising pathway for achieving low-cost and environmentally friendly hydrogen generation[10].

Description

Green hydrogen is widely acknowledged as a pivotal component in the global energy transition, holding immense potential to decarbonize various industrial sectors and mitigate the pressing challenges of climate change. Extensive research explores its current standing and projects its future prospects, consistently emphasizing the crucial need for well-defined, supportive policy frameworks to guide its widespread adoption and scaling across economies [2]. However, the journey towards a hydrogen-based economy is characterized by significant obstacles. Substantial technical challenges, such as optimizing electrolysis processes, and considerable economic barriers, including high production costs and infrastructure development, demand innovative solutions and sustained research and development efforts [1]. A holistic assessment of this transition also considers not just the technical feasibility but also the intricate layers of economic viability, the profound environmental benefits, and the broader social implications. This includes examining the necessity for robust policy support, extensive infrastructure development, and ensuring broad public acceptance, thus providing a multifaceted view of green hydrogen's potential societal impact and the factors influencing its successful integration [7].

At the heart of green hydrogen's potential are its diverse production methods, primarily electrolysis powered by renewable energy sources. Existing technologies such as alkaline and Proton Ex-

change Membrane (PEM) electrolysis are under continuous review, alongside the emergence of innovations like solid oxide and anion exchange membrane electrolysis [1]. Detailed overviews compare the efficiencies, technological maturities, and environmental footprints of these various methods, spotlighting advancements in electrolysis technologies and their integration with renewables, while highlighting the critical need for cost reduction and scaling for industrial viability [4]. Beyond traditional electrolysis, novel approaches are gaining traction, including advanced reviews focused on green hydrogen production from seawater electrolysis. This particular area involves meticulously examining developments in catalysts, membranes, and system designs to tackle challenges like salt corrosion and byproduct formation, which are vital for sustainable and scalable seawater splitting [9]. Additionally, advancements in photocatalytic materials for sustainable green hydrogen production are being extensively reviewed, covering different material classes, their mechanisms, and performance metrics. The goal here is to enhance efficiency and stability for solar-driven water splitting, a promising path for low-cost, environmentally friendly hydrogen generation [10].

The successful integration of green hydrogen into the global energy system fundamentally requires a comprehensive and integrated understanding of its entire value chain. This chain meticulously encompasses the initial production methods, a range of advanced storage technologies, robust and efficient transmission infrastructure, and its diverse applications across a multitude of industrial and energy sectors [3]. A thorough review of green hydrogen's complete lifecycle meticulously traces its path from its initial generation and subsequent storage to its complex transportation logistics and eventual utilization. This body of work consistently spotlights recent advancements occurring at each distinct stage of this lifecycle, engages in detailed discussions about the ongoing technological challenges that need addressing, and proactively explores future prospects for its effective integration into the broader global energy system [6]. The overarching emphasis is on developing an integrated and coordinated approach to skillfully navigate the considerable technical and logistical hurdles inherent in establishing a truly robust and globally interconnected hydrogen economy [3], ensuring a smooth transition and reliable supply.

A critical area of focus for green hydrogen deployment is its application within industrial sectors. Current research examines the developments and future prospects here, identifying key industrial processes that are prime candidates for decarbonization by switching to green hydrogen. This involves a careful assessment of the technical readiness and economic viability of these transitions, alongside a clear articulation of the barriers that must be overcome

for wider industrial adoption [5]. Such strategic deployment is essential for minimizing the carbon footprint of heavy industries.

Beyond the purely technical considerations, the broader societal impact of green hydrogen represents a significant and actively researched area. Its transformative potential in the global energy transition is rigorously examined through the lens of its economic advantages, profound environmental benefits, and a wide array of technological strengths. This examination also prudently considers the substantial financial investment and extensive infrastructural development required for its successful scaling and widespread deployment [2]. The global energy transition towards green hydrogen is often assessed with an in-depth analysis of its intricate economic viability, its compelling environmental benefits in terms of emissions reduction, and its complex social implications. Factors critically influencing its adoption, such as consistent policy support, strategic infrastructure development, and securing broad public acceptance, are thoroughly discussed to provide a holistic and nuanced view of its potential societal footprint [7]. A particularly insightful area of inquiry also explores the synergistic relationship between green hydrogen technologies and the foundational principles of the circular economy. This research highlights how green hydrogen can actively foster greater resource efficiency and contribute to substantial waste reduction across industries, thereby contributing significantly to the development of a more sustainable industrial ecosystem and markedly minimizing overall environmental impact [8]. This integrated and forward-looking perspective is absolutely crucial for realizing the full potential of green hydrogen as a foundational cornerstone of future sustainable development and a cleaner planet.

Conclusion

Green hydrogen is a key player in the global energy transition, with extensive research focusing on its production, storage, transmission, and applications. Current production methods predominantly involve electrolysis, including alkaline, PEM, solid oxide, and anion exchange membrane technologies, often powered by renewable energy sources. There's significant effort to advance these electrolysis methods, alongside exploring innovative techniques like seawater electrolysis and photocatalytic water splitting, aiming for improved efficiency, stability, and cost reduction. The lifecycle of green hydrogen spans from its generation to its storage, transportation, and eventual utilization across various industrial sectors for decarbonization. Integrating green hydrogen into the energy system requires substantial investment in infrastructure, robust policy frameworks, and addressing technical and economic barriers. Be-

yond production, the broader implications of green hydrogen extend to its economic viability, environmental benefits, social acceptance, and its synergistic role in fostering a circular economy by promoting resource efficiency and waste reduction. Studies also highlight the critical need for continued research and development to overcome hurdles like salt corrosion in seawater electrolysis, improve catalyst performance, and scale up operations for widespread industrial adoption. Ultimately, the goal is to establish an integrated hydrogen value chain that supports a sustainable and decarbonized future.

References

1. Xiaohui L, Pengcheng J, Feng W, Xiaodan H, Rui Z et al. (2023) Green hydrogen production: A comprehensive review of current technologies, innovations, and policy implications. *Renewable Sustainable Energy Rev* 188:113795.
2. Muhammad S, Muhammad FK, Muhammad A, Waqas A, Qazi AA et al. (2023) Green hydrogen for energy transition: Current status, future perspectives, and policy implications. *Energy Rep* 9:552-571.
3. Jianfang L, Mengqi H, Jun H, Qingbo L, Qiwei Y et al. (2024) The global hydrogen energy transition: A comprehensive review of green hydrogen production, storage, transmission, and applications. *Renewable Sustainable Energy Rev* 194:114389.
4. S. NOO, M. UA, K. EO, N. MU, A. UA et al. (2023) Green hydrogen production methods: An overview. *Int J Hydrogen Energy* 48(8):3175-3195.
5. C. RACM, D. SFP, B. BL, P. CTATA, F. VDP et al. (2023) Green hydrogen in industry: Review of current developments and prospects. *Int J Hydrogen Energy* 48(86):33735-33758.
6. Md. Mahbub A, Md. Mehedi H, Md. Jahangir A, A K M S I, Md. Rakib H et al. (2023) Review of green hydrogen production, storage, transportation, and utilization with a focus on current advancements and future prospects. *Int J Hydrogen Energy* 48(89):35086-35111.
7. Seyyed Mahdi A, Seyed Masoud M, Majid G, Samira K, Mojtaba A et al. (2023) Global energy transition toward green hydrogen: A comprehensive review on economic, environmental, and social aspects. *Int J Hydrogen Energy* 48(1):450-474.
8. M. KA, M. MRT, M. KH, M. AAM, A. RK et al. (2024) Green hydrogen and circular economy: A review of recent applications, opportunities, and challenges. *Energy Conversion Management* 302:118029.
9. Chun-Hai H, Hao-Ran L, Zhen-Xing Z, Kai L, Jia-Yin L et al. (2024) Green hydrogen production from seawater electrolysis: An advanced review on catalysts, membranes and systems. *J Membrane Sci* 691:122170.
10. G. HN, M. PK, K. V, M. VB, R. KV et al. (2024) Advancements in photocatalytic materials for sustainable green hydrogen production: A comprehensive review. *J Environ Chem Eng* 12(1):111666.