West Science Nature and Technology
Vol. 4, No. 01, March 2026, pp. 39~47

Evolution of Renewable Energy Research 2000–2026: A Bibliometric Exploration of Hot Topics and Knowledge Networks

Loso Judijanto[1], Karnoto[2], Susatyo Handoko[3], Susatyo Handoko[4], Bambang Irjanto[5]
[1] IPOSS Jakarta, Indonesia
[2]Department of Electrical Engineering Diponegoro University, Semarang, Indonesia
[3]Departemen Teknik Elektro, Fakultas Teknik, Universitas Diponegoro
[4,5]Universitas Proklamasi 45

Article Info

Article history:

Received March, 2026
Revised March, 2026
Accepted March, 2026

Keywords:

Renewable energy; Bibliometric analysis; Hydrogen production; Electrocatalysis

ABSTRACT

This study aims to examine the evolution of renewable energy research from 2000 to 2026 using a bibliometric approach to identify key trends, emerging topics, and the intellectual structure of the field. Data were collected from the Scopus database and analyzed using VOSviewer to generate co-occurrence, overlay, and density visualizations. The results reveal a substantial increase in publication output over time, indicating growing global attention to renewable energy as a response to climate change and sustainability challenges. Keyword co-occurrence analysis shows that renewable energy research is structured around several major themes, including energy systems and policy, hydrogen production technologies, and electrochemical processes such as water splitting and hydrogen evolution reactions. Overlay visualization indicates a shift toward emerging topics such as machine learning, optimization, and energy system integration, reflecting the increasing role of digital technologies in enhancing energy efficiency. Density analysis further highlights the dominance of hydrogen-related research as a core hotspot within the field. Overall, the findings suggest that renewable energy research is becoming increasingly interdisciplinary, integrating engineering, environmental science, and data-driven approaches. This study contributes to a comprehensive understanding of the development and future direction of renewable energy research, providing valuable insights for researchers, policymakers, and practitioners in advancing sustainable energy transitions.

Corresponding Author:

Name: Loso Judijanto
Institution: IPOSS Jakarta
Email: losojudijantobumn@gmail.com

1. INTRODUCTION

The increasing global demand for energy, coupled with the environmental impacts of fossil fuel consumption, has intensified the need to develop sustainable energy alternatives. Renewable energy has emerged as one of the most important solutions to address climate change, energy security, and sustainable development challenges. Sources such as solar, wind, hydro, geothermal, and biomass offer environmentally friendly alternatives that can significantly reduce greenhouse gas emissions compared with conventional fossil fuels. As a result, governments, international organizations, and academic institutions have increasingly promoted research and innovation in renewable energy technologies to accelerate the transition toward a low-carbon energy system. This transition has also been strongly aligned with global initiatives such as sustainable development strategies and climate mitigation policies aimed at reducing environmental degradation and ensuring long-term energy sustainability [1], [2].

Over the last two decades, renewable energy research has expanded rapidly in response to technological advances and growing policy support. The early 2000s marked a period when renewable energy technologies began to receive substantial attention from researchers due to concerns over fossil fuel depletion and the environmental consequences of traditional energy systems. Since then, scientific publications related to renewable energy have increased significantly, reflecting the growing interest in improving energy efficiency, developing innovative technologies, and understanding the socio-economic implications of clean energy transitions. Bibliometric evidence shows that the number of research outputs in renewable energy has grown consistently over time, demonstrating the expanding academic engagement with renewable technologies and sustainability topics.

In recent years, the growth of renewable energy research has also been driven by the rapid development of new technologies and interdisciplinary approaches. Researchers have explored not only engineering solutions such as solar photovoltaic systems, wind turbines, and bioenergy technologies but also broader themes including energy policy, environmental management, and green finance. This interdisciplinary nature has expanded the scope of renewable energy research, integrating fields such as economics, environmental science, and social policy. As a result, renewable energy research has evolved from a purely technical discipline into a broader field that examines the complex interactions between technology, society, and sustainability.

Another important aspect of renewable energy research development is the growing international collaboration among scholars, institutions, and countries. Scientific cooperation plays a crucial role in accelerating innovation and knowledge dissemination within the energy sector. Collaborative research networks allow researchers to share expertise, resources, and data, thereby enhancing the overall impact and efficiency of renewable energy studies. In addition, the geographical distribution of research activities has expanded significantly, with emerging economies and developing countries increasingly contributing to scientific outputs. These collaborative networks reflect the global nature of energy challenges and highlight the importance of collective efforts in advancing renewable energy technologies and policies.

Despite the rapid expansion of renewable energy research, the field continues to evolve with emerging topics and shifting research priorities. Recent studies show that the number of publications related to renewable energy has increased dramatically, with annual outputs growing substantially in the past decade. For example, analyses of renewable energy literature reveal a remarkable increase in publications over time, demonstrating the accelerating pace of knowledge production in this domain. This rapid growth has also led to the emergence of new research hotspots such as energy storage systems, hybrid renewable systems, smart grids, hydrogen energy, and sustainable energy management. Understanding these evolving themes is essential for identifying research gaps, guiding future studies, and supporting evidence-based policymaking in the energy sector.

Although renewable energy research has expanded significantly over the past two decades, the rapid growth of publications has created challenges in understanding the overall structure, development patterns, and emerging trends within the field. The large volume of scientific literature makes it difficult for researchers and policymakers to identify the most influential topics, key contributors, and collaborative networks that shape the development of renewable energy knowledge. Furthermore, existing studies often focus on specific technologies or regional analyses rather than providing a comprehensive overview of the global research landscape. Consequently, there remains a need for systematic approaches capable of mapping the intellectual structure and evolution of renewable energy research over time. Bibliometric analysis offers a powerful method to address this gap by quantitatively examining publication data, citation patterns, and keyword relationships to reveal research hotspots and knowledge networks within the field. The objective of this study is to explore the evolution of renewable energy research from 2000 to 2026 using a bibliometric approach.

2. METHODS

This study employs a bibliometric research design to systematically examine the development of renewable energy research between 2000 and 2026. Bibliometric analysis is widely used to evaluate large bodies of scientific literature by applying quantitative techniques to publication and citation data. Through this approach, it becomes possible to identify research trends, influential publications, prominent authors, and collaboration patterns within a particular field of study. In the context of renewable energy, bibliometric methods provide a structured way to explore how research topics have evolved over time and how knowledge networks have formed among scholars and institutions. By combining descriptive statistical analysis with science-mapping techniques, this study aims to provide a comprehensive overview of the intellectual landscape of renewable energy research.

The data for this study are collected from a major academic bibliographic database, such as Scopus or Web of Science, which are widely recognized for their extensive coverage of peer-reviewed scientific publications. Relevant publications are retrieved using keyword searches related to renewable energy, including terms such as "renewable energy," "solar energy," "wind energy," "bioenergy," and other related concepts. The search is limited to publications published between 2000 and 2026 to capture the evolution of research within this period. Only peer-reviewed journal articles and review papers written in English are included to ensure the quality and consistency of the dataset. After retrieving the data, the bibliographic information—including titles, authors, publication years, affiliations, abstracts, keywords, and citation counts—is exported and organized for further analysis. Data cleaning procedures are conducted to remove duplicate records and standardize variations in author names and keywords.

3. RESULTS AND DISCUSSION

3.1 Keyword Co-Occurrence Network Visualization

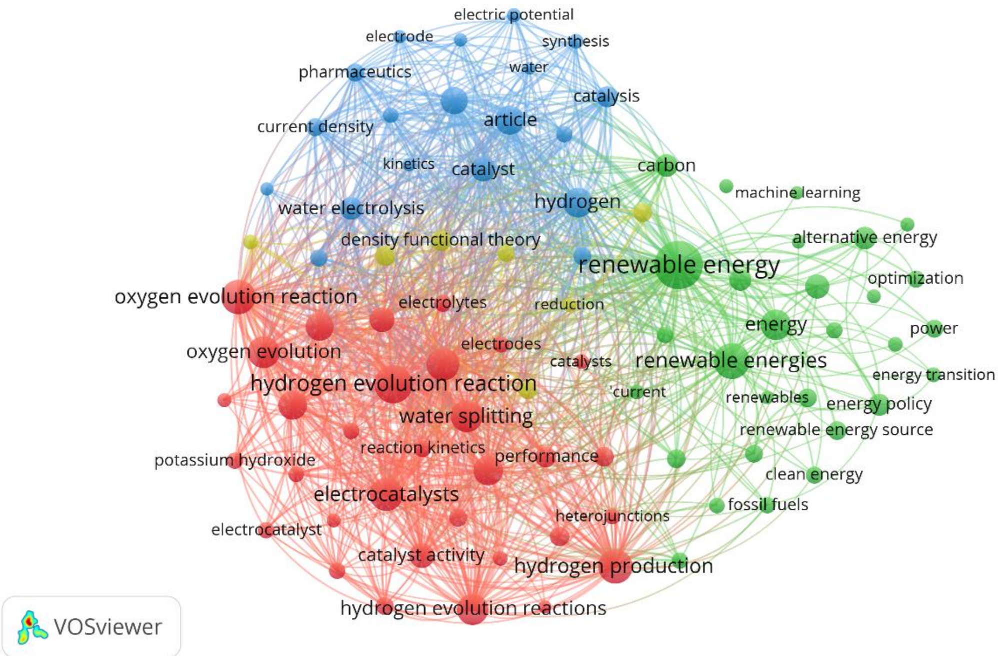

Figure 1. Network Visualization
Source: Data Analysis, 2026

Figure 1 presents a keyword co-occurrence network that reveals the intellectual structure of renewable energy research, with a strong emphasis on hydrogen-related technologies. The network is divided into several color-coded clusters, each representing a thematic area. The size of the nodes indicates the frequency of keyword occurrence, while the links between nodes reflect the strength of co-occurrence relationships. From the overall structure, it is evident that the field is highly interconnected, with "renewable energy" acting as a central bridging concept across different research domains.

The green cluster represents the broader energy systems and policy-oriented perspective. Keywords such as renewable energy, energy, energy policy, energy transition, and clean energy dominate this cluster, indicating a macro-level focus on sustainability transitions and energy system optimization. The presence of terms like machine learning and optimization suggests that recent studies increasingly integrate digital technologies to enhance renewable energy systems. This cluster highlights the interdisciplinary nature of renewable energy research, where engineering, policy, and data science converge.

The red cluster is heavily centered on hydrogen production and electrochemical processes, particularly hydrogen evolution reaction (HER) and water splitting. Keywords such as electrocatalysts, catalyst activity, performance, and reaction kinetics indicate a strong experimental and materials science orientation. This cluster reflects the growing importance of hydrogen as a clean energy carrier, with significant research dedicated to improving efficiency and reducing costs of hydrogen generation technologies. The density of connections within this cluster suggests a mature and highly specialized research area.

Meanwhile, the blue cluster focuses on the fundamental scientific and chemical aspects underlying these technologies. Keywords like catalysis, electrode, electrolyte, kinetics, and water electrolysis point to foundational research in electrochemistry and material science. This cluster provides the theoretical and experimental backbone that supports advancements in hydrogen production and renewable energy systems. Its strong connections with the red cluster indicate that applied research in hydrogen technologies is deeply rooted in fundamental scientific exploration.

Additionally, smaller transitional nodes and overlapping areas—such as carbon, hydrogen, and functional theory—act as bridges between clusters, illustrating the integration of different research streams. The proximity between clusters suggests that renewable energy research is evolving toward a more integrated framework, combining materials science, chemical engineering, and system-level analysis.

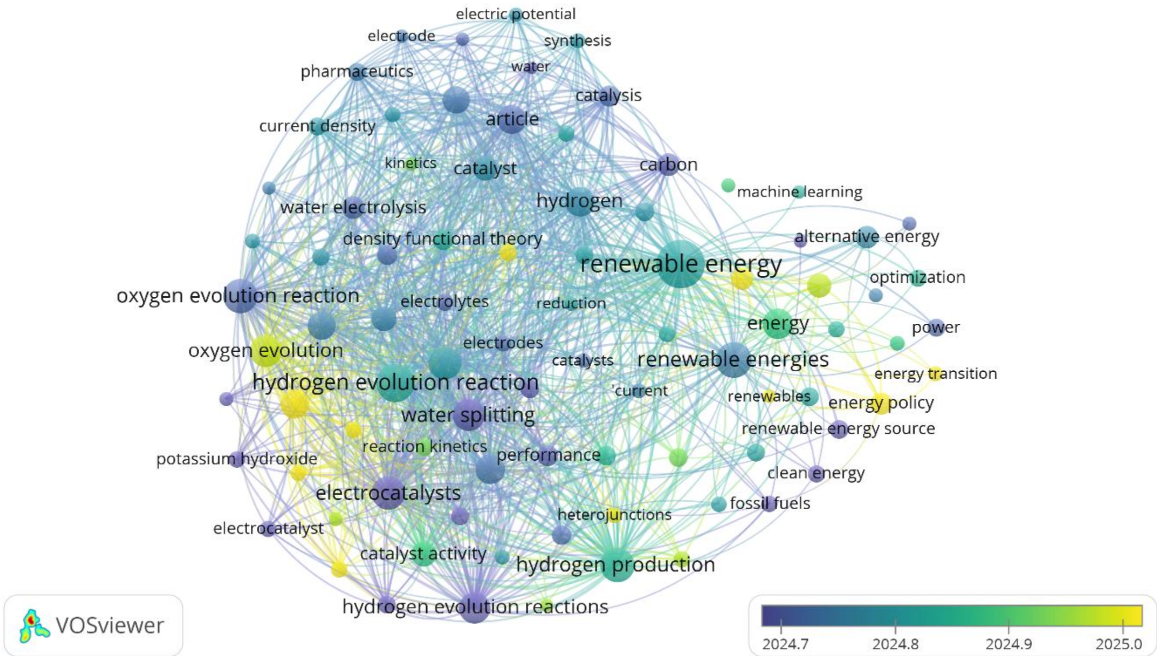

Figure 2. Overlay Visualization

Source: Data Analysis, 2026

Figure 2 illustrates the temporal evolution of keywords in renewable energy research, where color represents the average publication year (from earlier in blue to more recent in yellow). The network shows that renewable energy remains the central and most influential node, connecting various subfields. Surrounding it are terms like renewable energies, energy policy, and energy transition, indicating that the field continues to expand at the systems and policy level while maintaining strong links to technological innovation.

A notable pattern is the shift toward emerging and recently developed topics, highlighted in yellow. Keywords such as hydrogen evolution reaction, oxygen evolution, electrocatalysts, and water splitting appear in warmer colors, indicating that hydrogen-related electrochemical processes are among the most current research frontiers. This suggests that recent studies are increasingly focused on improving efficiency and sustainability in hydrogen production technologies. In contrast, more foundational terms such as catalysis, electrodes, and kinetics are shown in cooler colors (blue–green), reflecting their earlier establishment in the literature as the scientific basis for these newer developments.

Additionally, the visualization reveals the growing integration of digital and optimization approaches in renewable energy research. Keywords like machine learning and optimization, which appear in relatively recent color tones, indicate a shift toward data-driven and computational methods to enhance system performance and energy management. The presence of bridging terms such as carbon, hydrogen, and energy further demonstrates the convergence of environmental concerns, advanced materials, and intelligent systems.

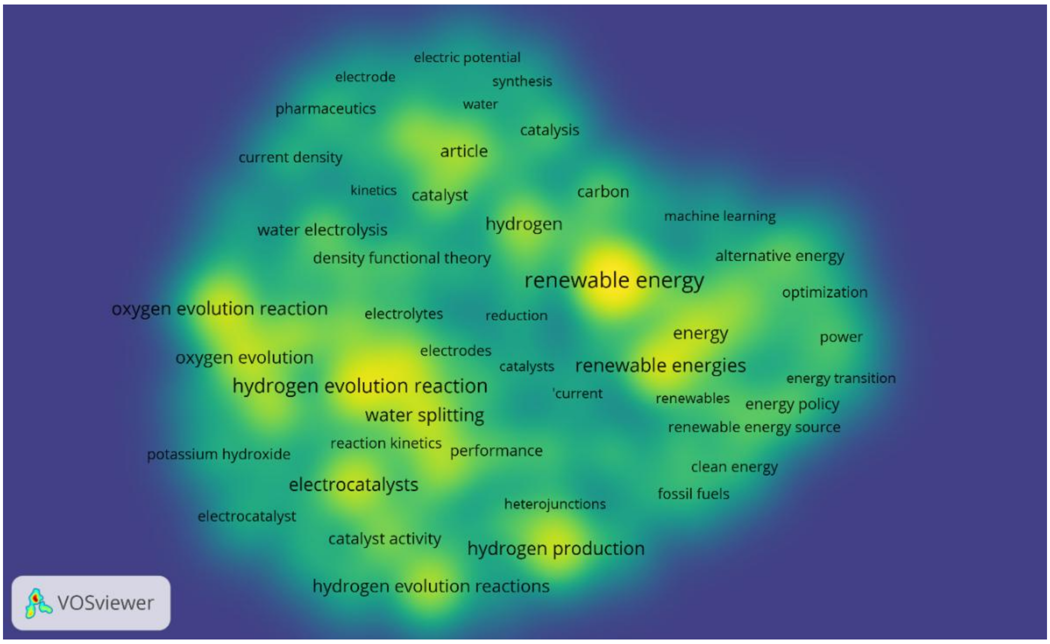

Figure 3. Density Visualization

Source: Data Analysis, 2026

Figure 3 highlights the most intensively researched and frequently occurring topics in renewable energy literature. Areas shown in bright yellow represent high-density regions, indicating strong research concentration. The term renewable energy appears as the central and most dominant hotspot, surrounded by closely related keywords such as renewable energies, energy, and energy policy. This suggests that the core of the field is heavily oriented toward broad energy system discussions, sustainability transitions, and policy frameworks. Additionally, the presence of hydrogen and hydrogen production near these high-density zones indicates their growing strategic importance within the overall renewable energy discourse.

Another major hotspot is located around hydrogen evolution reaction, water splitting, and electrocatalysts, reflecting a strong concentration of research in electrochemical hydrogen production technologies. These topics are tightly clustered with terms like oxygen evolution reaction, catalyst activity, and reaction kinetics, indicating a mature and highly specialized subfield focused on improving catalytic efficiency and performance. Meanwhile, surrounding areas with moderate density (green) include emerging interdisciplinary topics such as machine learning, optimization, and alternative energy, suggesting expanding research directions that integrate computational methods with energy systems.

3.2 Citation Analysis

Table 1. Top Cited Documents

Citations	Authors and year	Title	Source
5,595	[3]	Noble metal-free hydrogen evolution catalysts for water splitting	Chemical Society Reviews, 44(15), pp. 5148–5180
5,286	[4]	Co_3O_4 nanocrystals on graphene as a synergistic catalyst for oxygen reduction reaction	Nature Materials, 10(10), pp. 780–786
4,849	[5]	MoS_2 nanoparticles grown on graphene: An advanced catalyst for the hydrogen evolution reaction	Journal of the American Chemical Society, 133(19), pp. 7296–7299
3,027	[6]	Recent advances in transition metal phosphide nanomaterials: Synthesis and applications in hydrogen evolution reaction	Chemical Society Reviews, 45(6), pp. 1529–1541
2,898	[7]	Solar energy supply and storage for the legacy and nonlegacy worlds	Chemical Reviews, 110(11), pp. 6474–6502
2,847	[8]	A review on g-C3N4-based photocatalysts	Applied Surface Science, 391, pp. 72–123
2,741	[9]	Recent advances in electrocatalytic hydrogen evolution using nanoparticles	Chemical Reviews, 120(2), pp. 851–918
2,660	[10]	An advanced Ni–Fe layered double hydroxide electrocatalyst for water oxidation	Journal of the American Chemical Society, 135(23), pp. 8452–8455
2,658	[11]	Roles of cocatalysts in photocatalysis and photoelectrocatalysis	Accounts of Chemical Research, 46(8), pp. 1900–1909
2,355	[12]	A reflection on lithium-ion battery cathode chemistry	Nature Communications, 11(1), 1550

Source: Scopus, 2026

Discussion

The findings of this bibliometric study reveal that renewable energy research has undergone a significant transformation over the period 2000–2026, evolving from a predominantly technology-focused domain into a highly interdisciplinary field. The dominance of keywords such as renewable energy, energy, and energy policy indicates that the research landscape is no longer limited to technical innovation but increasingly incorporates broader systemic and policy-oriented perspectives. This shift reflects the global urgency to address climate change and achieve sustainable energy transitions, where technological development must be aligned with regulatory frameworks, economic feasibility, and environmental considerations.

A central insight from the co-occurrence and density analyses is the prominent role of hydrogen-related research, particularly in areas such as hydrogen evolution reaction, water splitting, and electrocatalysts. These topics form one of the most concentrated and interconnected clusters, suggesting that hydrogen has emerged as a key focal point in renewable energy research. The strong linkage between these keywords and fundamental concepts such as catalysis, reaction kinetics, and electrochemical processes highlights the continued importance of foundational scientific research in driving applied technological advancements. This indicates that innovation in renewable energy is deeply rooted in material science and chemical engineering breakthroughs.

Furthermore, the temporal overlay analysis demonstrates a clear transition toward more recent and emerging topics, including machine learning, optimization, and energy system integration. The appearance of these keywords in more recent timeframes suggests that renewable energy research is increasingly leveraging digital technologies to enhance efficiency, predictability, and scalability. This trend aligns with the broader movement toward smart energy systems and digital transformation, where data-driven approaches are used to optimize energy production, distribution, and consumption. As such, the integration of artificial intelligence and computational tools is likely to become a defining characteristic of future research in this field.

Another important observation is the strong interconnectedness between clusters, which indicates a high level of knowledge integration across different research domains. The proximity between hydrogen-related technologies, energy systems, and policy-oriented research suggests that the field is moving toward a more holistic and systems-based approach. Rather than operating in isolation, different subfields are increasingly converging to address complex challenges such as energy security, decarbonization, and sustainability. This convergence also highlights the importance of cross-disciplinary collaboration among researchers from engineering, environmental science, economics, and data science.

The study highlights several opportunities for future research. While core areas such as electrochemical hydrogen production remain highly developed, emerging topics such as digital optimization, hybrid energy systems, and carbon-neutral technologies offer promising avenues for further exploration. Additionally, there is a need for more research that bridges the gap between technological innovation and real-world implementation, particularly in developing countries where energy challenges are most acute.

4. CONCLUSION

This bibliometric study demonstrates that renewable energy research from 2000 to 2026 has evolved into a dynamic, interdisciplinary field characterized by strong integration between technological innovation, scientific foundations, and policy-oriented perspectives. The analysis highlights the central role of renewable energy systems and the increasing prominence of hydrogen-based technologies, particularly electrochemical processes such as water splitting and hydrogen evolution reactions. At the same time, the emergence of data-driven approaches, including machine learning and optimization, signals a shift toward smarter and more efficient energy systems. The interconnected structure of the research landscape further indicates a convergence of multiple disciplines in addressing global energy challenges. This study provides a comprehensive overview of the intellectual structure and emerging directions in renewable energy research, offering valuable insights to guide future studies and support the transition toward sustainable and low-carbon energy systems.

REFERENCES

[1] R. Chen, M. Ramzan, M. Hafeez, and S. Ullah, “Green innovation-green growth nexus in BRICS: does financial globalization matter?,” *Journal of Innovation & Knowledge*. Elsevier, 2023.

[2] A. A. Almulhim and A. A. Aljughaiman, “Corporate Sustainability and Financial Performance: The Moderating Effect of CEO Characteristics,” *Sustain.*, vol. 15, no. 16, Aug. 2023, doi: 10.3390/su151612664.

[3] X. Zou and Y. Zhang, “Noble metal-free hydrogen evolution catalysts for water splitting,” *Chem. Soc. Rev.*, vol. 44, no. 15, pp. 5148–5180, 2015.

[4] Y. Liang *et al.*, “Co3O4 nanocrystals on graphene as a synergistic catalyst for oxygen reduction reaction,” *Nat. Mater.*, vol. 10, no. 10, pp. 780–786, 2011.
[5] Y. Li, H. Wang, L. Xie, Y. Liang, G. Hong, and H. Dai, “MoS2 nanoparticles grown on graphene: an advanced catalyst for the hydrogen evolution reaction,” *J. Am. Chem. Soc.*, vol. 133, no. 19, pp. 7296–7299, 2011.
[6] Y. Shi and B. Zhang, “Recent advances in transition metal phosphide nanomaterials: synthesis and applications in hydrogen evolution reaction,” *Chem. Soc. Rev.*, vol. 45, no. 6, pp. 1529–1541, 2016.
[7] T. R. Cook, D. K. Dogutan, S. Y. Reece, Y. Surendranath, T. S. Teets, and D. G. Nocera, “Solar energy supply and storage for the legacy and nonlegacy worlds,” *Chem. Rev.*, vol. 110, no. 11, pp. 6474–6502, 2010.
[8] J. Wen, J. Xie, X. Chen, and X. Li, “A review on g-C3N4-based photocatalysts,” *Appl. Surf. Sci.*, vol. 391, pp. 72–123, 2017.
[9] J. Zhu, L. Hu, P. Zhao, L. Y. S. Lee, and K.-Y. Wong, “Recent advances in electrocatalytic hydrogen evolution using nanoparticles,” *Chem. Rev.*, vol. 120, no. 2, pp. 851–918, 2019.
[10] M. Gong *et al.*, “An advanced Ni–Fe layered double hydroxide electrocatalyst for water oxidation,” *J. Am. Chem. Soc.*, vol. 135, no. 23, pp. 8452–8455, 2013.
[11] J. Yang, D. Wang, H. Han, and C. A. N. Li, “Roles of cocatalysts in photocatalysis and photoelectrocatalysis,” *Acc. Chem. Res.*, vol. 46, no. 8, pp. 1900–1909, 2013.
[12] A. Manthiram, “A reflection on lithium-ion battery cathode chemistry,” *Nat. Commun.*, vol. 11, no. 1, p. 1550, 2020.