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Green Hydrogen Production: A Sustainable Pathway for Future Energy Systems

With the accelerating global energy transition and the pursuit of carbon neutrality, green hydrogen has emerged as a clean, efficient, and storable energy carrier, playing an increasingly important role in future energy systems. Green hydrogen production mainly relies on renewable energy sources, such as wind, solar, and hydro, to generate hydrogen through water electrolysis, providing a low-carbon pathway from energy supply to hydrogen production. Compared to conventional fossil-fuel-based hydrogen, green hydrogen significantly reduces greenhouse gas emissions and can be synergistically integrated with renewable energy, mitigating the intermittency of renewable power generation and supporting a sustainable, low-carbon energy system.

Technologically, water electrolysis is the core method for green hydrogen production, including alkaline electrolysis, proton exchange membrane (PEM) electrolysis, and high-temperature solid oxide electrolysis. Alkaline electrolysis is mature and cost-effective but has lower efficiency and slower response; PEM electrolysis offers high efficiency and rapid response, suitable for variable renewable energy scenarios, though at higher material costs; high-temperature solid oxide electrolysis presents high energy utilization potential but is still in early industrial development. Furthermore, coupling electrolysis with wind, solar, or biomass energy can optimize energy production and hydrogen output, improving overall system economics and energy utilization efficiency.

The sustainable development of green hydrogen depends not only on technology but also on economics, policy support, and environmental assessment. Key factors include production cost, energy supply stability, storage and transport safety, and life-cycle carbon emissions. Policy incentives, green financing, and infrastructure development can facilitate large-scale adoption of hydrogen technologies and their application in transportation, industry, and power storage.

This study aims to systematically analyze green hydrogen production technologies and application patterns, assessing their role and potential in future low-carbon energy systems. The research focuses on technology comparison, energy coupling and dispatch optimization, economic analysis, and environmental sustainability evaluation, providing theoretical support and practical guidance for large-scale deployment of

green hydrogen and sustainable energy system development.