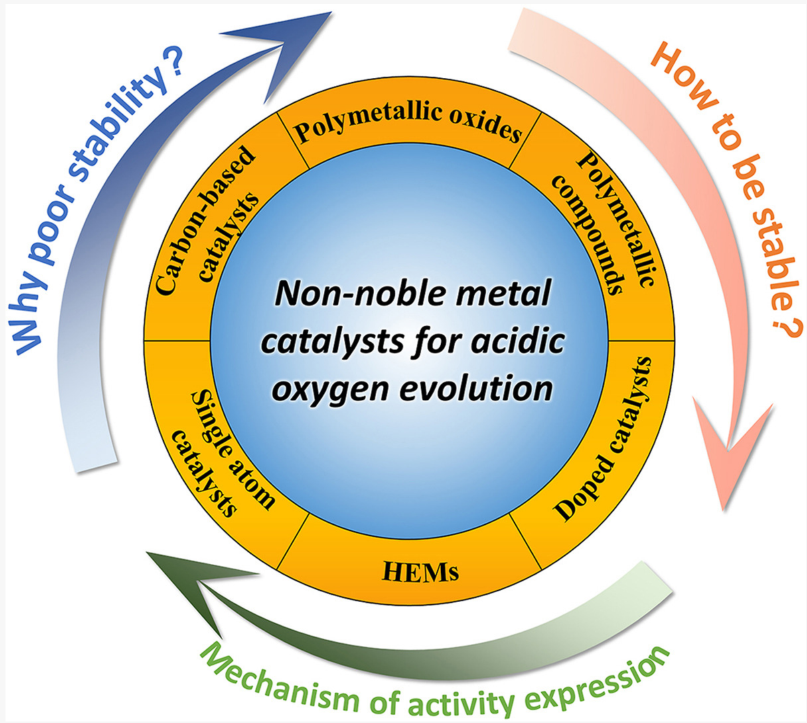
Green hydrogen goes affordable: rethinking catalyst design

GA, UNITED STATES, August 15, 2025 /EINPresswire.com/ -- Green hydrogen holds immense promise for decarbonizing energy systems, yet when produced via water electrolysis, it relies heavily on rare and expensive noble metals. This study delves into the emergence of non-noble metal catalysts (NNMCs) as a transformative alternative for the oxygen evolution reaction (OER) in acidic environments. By unpacking the underlying mechanisms, performance bottlenecks, and degradation routes, the authors offer a roadmap to designing high-performing, stable NNMCs. The review also explores the latest innovations in catalyst engineering—from electronic tuning to surface reconstruction—that enable these cost-effective materials to rival their noble metal counterparts in water-splitting performance.



Strategic Roadmap for Noble Metal-Free Catalysts in Acidic Oxygen Evolution.

As the world pivots toward carbon neutrality, hydrogen has emerged as a clean, versatile energy carrier. Among various production pathways, [proton exchange membrane water electrolyzers] (PEMWE) are favored for delivering high-purity hydrogen using renewable electricity. However, widespread deployment is hindered by the use of iridium and ruthenium—noble metals that are both scarce and prohibitively expensive. While non-precious metal alternatives show promise, they struggle to meet the combined activity and durability requirements for acidic oxygen evolution reaction (OER). These shortcomings in both performance and long-term stability underscore the urgent need for deeper investigation into novel design strategies and degradation mechanisms to enable practical implementation of non-noble metal catalysts (NNMCs).

A collaborative research team from the Changchun Institute of Applied Chemistry, Chinese Academy of Sciences has published a comprehensive review in eScience (February 2025), examining noble metal-free electrocatalysts for acidic water oxidation. The article investigates both fundamental and applied aspects of non-precious metal catalysts for practical application in PEMWE systems. Through a deep dive into catalytic pathways, stability concerns, and material innovations, the review offers fresh insights into building cost-effective and durable alternatives to noble metals in hydrogen energy technologies.

The study begins by dissecting the key mechanistic pathways of acidic oxygen evolution, focusing on two major routes: water hydrogen atom abstraction (WHAA) and direct coupling mechanism (DCM). These processes involve complex intermediate steps that are sensitive to surface structure and electronic configuration. The authors argue that understanding these mechanisms is essential for guiding rational catalyst design. However, conventional thermodynamic models fall short in capturing real-time kinetics, emphasizing the need for in situ characterization and molecular simulations.

Beyond activity, the review identifies stability as a critical hurdle. Noble metal-free catalysts often degrade under acidic conditions due to metal ion dissolution or irreversible oxidation. To address this, researchers have devised innovative strategies: self-healing catalysts that regenerate active components, incorporation of acid-stable metal oxide phases, and doping with high-oxidation-potential anions. The review highlights several recent breakthroughs—such as Co–Mn oxides, F-doped MnO_2, and high-entropy alloys—that demonstrate both strong OER activity and enhanced durability. These developments suggest that with the rational structural and electronic tuning, NNMCs can deliver performance comparable to traditional noble metal catalysts in real-world electrolysis systems.

"To replace noble metals in acidic electrolysis, we must first understand what limits the performance of alternative materials," said Dr. Meiling Xiao, co-corresponding author of the review. "Our work consolidates years of fragmented research into a coherent framework that identifies where the true challenges lie—whether in electronic structure, surface stability, or reaction dynamics. By mapping the degradation pathways and pairing them with actionable design principles, we hope to accelerate the transition toward practical, affordable, and scalable hydrogen technologies."

The insights from this review could significantly impact the global hydrogen economy by lowering the cost of clean energy technologies. Developing NNMCs that can endure acidic OER conditions will unlock the commercial viability of PEMWE systems—offering high current densities, long lifespans, and reduced reliance on critical raw materials. These catalysts can be integrated into fuel cells, hydrogen refueling infrastructure, and energy storage systems. Moreover, the design strategies outlined in this work—such as high-entropy material selection and electronic structure tuning—can serve as a blueprint for other catalytic processes, paving the way for more sustainable and economically feasible energy conversion technologies.

References
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