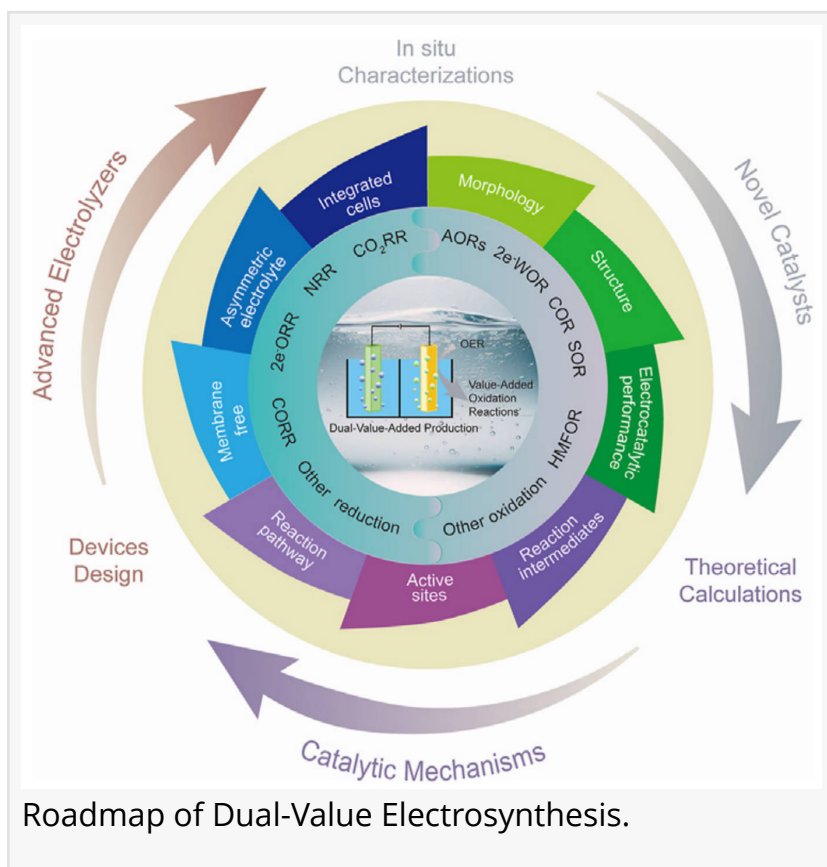


Smarter electrolysis: pairing reactions for sustainable energy and chemistry

GA, UNITED STATES, October 21, 2025 /EINPresswire.com/ -- Electrochemical synthesis in aqueous solution has emerged as a sustainable strategy to replace traditional fossil-fuel-driven chemical production, but it is often limited by the sluggish oxygen evolution reaction (OER) that wastes energy and yields low-value products. Recent advances are transforming this challenge into an opportunity by replacing OER with faster, value-added oxidation reactions paired with reduction processes beyond hydrogen production. This review highlights cutting-edge catalysts, hybrid electrolyzers, and in situ characterization tools that enable the simultaneous generation of two valuable products in a single electrochemical process. Such integrated systems not only enhance efficiency and economic viability but also pave the way for greener chemical manufacturing aligned with global net-zero goals.



For more than two centuries, fossil fuels have dominated global energy and chemical production, accounting for over 80% of consumption and driving a steep rise in CO₂ emissions. This reliance has contributed to climate change, energy insecurity, and environmental degradation. Although renewable energy investment has grown rapidly, conventional chemical processes remain carbon-intensive and economically inflexible. Electrochemistry powered by renewables offers a promising pathway: mild operating conditions, abundant feedstocks, and scalable systems. However, inefficiencies in oxygen evolution at the anode limit its potential and add costs. Due to these problems, there is an urgent need to develop integrated electrosynthesis systems that replace oxygen evolution reaction (OER) with efficient, value-added reactions to achieve dual benefits.

A research team from Jiangsu University, the Chinese Academy of Sciences, Hasselt University, and MIT has published a comprehensive review (DOI: [10.1016/j.esci.2024.100333](https://doi.org/10.1016/j.esci.2024.100333)) in eScience (online July, 2025) examining how electrosynthesis is evolving from water electrolysis to dual-value-added production. The study analyzes catalysts, electrolyzers, and reaction mechanisms that enable coupling of alternative oxidation reactions with reduction processes such as CO₂, nitrogen, and organic molecule conversion. By highlighting both progress and challenges, the authors provide a roadmap for advancing electrochemical systems that simultaneously yield clean fuels and market-relevant chemicals.

The review emphasizes that replacing the sluggish OER with alternative oxidation reactions—such as methanol, glycerol, or sulfide oxidation—dramatically improves system efficiency while producing useful by-products like formic acid, acetic acid, hydrogen peroxide, or elemental sulfur. When paired with reduction reactions beyond hydrogen evolution, such as CO₂ reduction (CO₂RR), CO reduction (CORR), or nitrogen reduction (NRR), these systems achieve dual outputs with lower energy consumption.

Catalyst development is central to this progress. Advances in nanostructured materials, including alloyed, doped, and defect-engineered catalysts, have expanded active sites and boosted selectivity. The deployment of self-supported electrodes and gas-diffusion electrodes further enhances stability and conversion rates. Hybrid electrolyzers, evolving from H-type cells to flow cells and membrane electrode assemblies, are enabling industrial-scale current densities.

Equally important are advanced in situ and operando techniques—such as infrared spectroscopy, Raman spectroscopy, X-ray absorption, and electron microscopy—that allow direct monitoring of catalytic intermediates and structural evolution. Alongside computational methods like density functional theory (DFT) and machine learning, these tools clarify mechanisms, optimize reaction pathways, and accelerate rational catalyst design. Together, these innovations mark a major leap toward sustainable and economically viable electrosynthesis.

“Electrochemical systems that simultaneously produce two valuable outputs represent a paradigm shift for green chemistry,” said co-authors Prof. Zhenhai Wen, Prof. Hao Zhang and Prof. Nianjun Yang. “By coupling OER alternatives with reduction reactions, we can not only lower the energy barrier but also generate high-value chemicals alongside clean fuels. The integration of advanced catalysts, novel electrolyzer architectures, and powerful characterization techniques provides unprecedented opportunities to design scalable, efficient processes. This dual-benefit approach is crucial for moving closer to a truly sustainable and circular chemical industry.”

The development of dual-value electrosynthesis systems holds significant promise for energy, environment, and industry. Beyond reducing carbon emissions, these systems enable the cost-effective production of green hydrogen, fuels, fertilizers, and chemical feedstocks, addressing both climate and resource challenges. Coupling reactions such as CO₂ reduction with alcohol

oxidation or waste remediation provides added economic and ecological value. In the longer term, the combination of advanced catalysts, computationally guided design, and industrial-scale electrolyzers could transform chemical manufacturing into a low-carbon, energy-efficient process. This strategy directly contributes to global net-zero ambitions while creating new opportunities for renewable-driven industrial chemistry.

DOI

10.1016/j.esci.2024.100333

Original Source URL

<https://doi.org/10.1016/j.esci.2024.100333>

Funding information

This work was financially supported by the National Natural Science Foundation of China (No. 22209183, 22225902, U22A20436, 52436005), the National key Research & Development Program of China (2022YFE0115900, 2021YFA1501500), the CAS-Commonwealth Scientific and Industrial Research Organization (CSIRO) Joint Research Projects (121835KYSB20200039), Advanced Talents of Jiangsu University, China (Grant No. 23JDG027), and Natural Science Foundation of Fujian Province (2021J05100).

Lucy Wang

BioDesign Research

[email us here](#)

This press release can be viewed online at: <https://www.einpresswire.com/article/860118461>

EIN Presswire's priority is source transparency. We do not allow opaque clients, and our editors try to be careful about weeding out false and misleading content. As a user, if you see something we have missed, please do bring it to our attention. Your help is welcome. EIN Presswire, Everyone's Internet News Presswire™, tries to define some of the boundaries that are reasonable in today's world. Please see our Editorial Guidelines for more information.

© 1995-2025 Newsmatics Inc. All Right Reserved.