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Advances in sustainable catalysis: from materials to energy and environmental applications

Mario J. Muñoz-Batista,*[a] Bo Weng,[bc] Choe Earn Choong,[de] Asim Bhaumik[f] and Damien P. Debecker[g]

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"Advances in sustainable catalysis: from materials to energy and environmental applications" is a comprehensive themed collection comprising more than 100 contributions published in both *Journal of Materials Chemistry A* and *Materials Advances*. This collection brings together recent advances in sustainable catalysis, which stand as a multidisciplinary approach that seeks to integrate environmental and economic dimensions to design catalytic processes viable in the long term. It focuses on the development of catalysts that enhance reaction efficiency and selectivity while minimizing environmental impact through environmentally friendly synthesis strategies, waste valorisation into high-value products, and the use of waste-derived materials. It also encompasses the optimization of catalytic processes to address key environmental challenges and reduce energy consumption through more efficient and synergistic use of energy. Several review articles are included in this collection, covering topics such as tribocatalysis, CO_2 reduction, carbon-based materials, single-atom catalysis, high-entropy alloys, and engineered heterostructures systems.[1–18] Given the breadth of the collection, and without intending to discuss each contribution in detail, the following sections highlight several overarching research themes addressed throughout the collection, citing some papers as representative examples.

[a]Department of Chemical Engineering, University of Granada, Avda. Fuentenueva s/n, Granada 18071, Spain. E-mail: mariomunoz@ugr.es
[b]State Key Laboratory of Advanced Environmental Technology, Institute of Urban Environment, Chinese Academy of Sciences, 1799 Jimei Road, Xiamen 361021, China
[c]University of Chinese Academy of Sciences, Beijing 100049, China
[d]Department of Environmental Engineering, Kwangwoon University, 20 Kwangwoon-Ro, Nowon-Gu, Seoul 01897, Republic of Korea
[e]Plasma Bioscience Research Center, Dasanjae 101, Kwangwoon University, 20 Kwangwoon-Ro, Nowon-Gu, Seoul 01897, Republic of Korea
[f]School of Material Sciences, Indian Association for the Cultivation of Science, Jadavpur, Kolkata, 700032, India
[g]Université Catholique de Louvain (UCLouvain), Institute of Condensed Matter and Nanosciences (IMCN), Place Louis Pasteur 1, Louvain-la-Neuve, Belgium

Innovation in advanced materials design

A major theme across the collection is the design of advanced material architectures as the foundation for sustainable catalytic processes. Significant progress has been achieved in the development of covalent organic frameworks (COF-based) and metal–organic frameworks (MOF-based), exploiting their high surface areas and tunable structures through strategies such as solvent-free synthesis, donor–acceptor architectures for enhanced photocatalytic hydrogen peroxide production, and two-dimensional MOF nanosheets with highly exposed active sites for improved catalytic performance.[19–24] Carbon nitride[25–28] and oxide/sulfide-based materials[29–36] also receive considerable attention for the sustainable thermo-, photo- and electrocatalytic process for energy conversion and environmental remediation. High-entropy alloys (HEAs), single-atom catalysts, and carbon-based structures (*e.g.* carbon nanotubes) can be mentioned as novel materials included in this collection.[10,12,14,16,37,38] Their complex electronic structures enable tunable multisite catalysis for key reactions, including oxygen reduction, hydrogen (H_2) evolution, and the electrocatalytic reforming of plastic-derived feedstocks, among other catalytic applications.

The hydrogen economy and energy conversion

Another major theme of the collection is the advancement of the H_2 economy through the development of efficient catalytic technologies for H_2 production and management.[32,39–41] Considerable efforts are devoted to water splitting, including the design of innovative catalysts such as hollow nickel ferrite nanofibers templated from waste expanded polystyrene for the H_2 evolution reaction, as well as piezocatalytic systems incorporating aromatic carbon rings to enhance charge separation.[32,42] Beyond conventional water electrolysis, alternative H_2 production routes are explored, including hydrazine oxidation over carbon-based catalysts as a low-energy pathway and the optimization of transition metal oxides for selective photoelectrochemical seawater splitting.[12,43] The collection also addresses H_2 management through advanced materials for efficient H_2 isotope separation,[44] highlighting the role of hydrophobic mesoporous silica catalysts in nuclear and industrial applications.

Atmospheric pollution mitigation and environmental remediation

The collection also highlights the central role of sustainable catalysis in addressing environmental challenges through greenhouse gas utilization, air pollution control, and wastewater remediation. Significant advances are reported in catalytic CO_2 conversion, including the hydrogenation of CO_2 to light olefins and the development of solid oxide electrolysis systems that couple renewable energy storage with CO_2 utilization.[45,46] Air purification is another major focus, with innovative catalytic systems for the integrated removal of NO_x and CO oxidation catalysts.[9,28,47] In parallel, numerous contributions demonstrate the potential of catalytic technologies for water treatment,[48,49] particularly through dual-functional photocatalytic systems that simultaneously produce H_2 and degrade organic contaminants,[15] as well as advanced oxidation processes capable of rapidly removing antibiotics and dyes.[50,51]

Valorisation of waste and biomass

The valorisation of waste and biomass represents another major research direction within the collection, reflecting the growing importance of circular economy strategies in sustainable catalysis. Some contributions demonstrate the conversion of waste streams into valuable chemical feedstocks, including the catalytic upcycling of plastic waste through the selective production of *p*-xylene from PET using modified cobalt phyllosilicate catalysts,[52] as well as the electrocatalytic reforming of polylactic acid (PLA) into value-added chemicals.[37] Biomass conversion is also extensively explored, with sustainable catalytic routes for the production of platform molecules such as limonene from renewable 1,8-cineole,[53] the upgrading of bioethanol into useful bulk chemicals,[54] and the hydrogenation of dimethyl oxalate to obtain oxygenated chemicals.[5] The collection highlights the potential of renewable feedstocks to replace fossil-derived resources in the chemical industry.

Conclusions

This themed collection demonstrates the strong and growing interest in sustainable catalysis as a central field for addressing global energy and environmental challenges. It highlights that the future of catalysis is rooted in the integration of advanced material design with sustainable process engineering. By combining innovations in catalyst development with considerations of material availability, operational stability, scalability, and end-of-life management, the studies compiled here outline a coherent pathway toward more sustainable and circular chemical technologies. Across the different contributions, it becomes evident that progress in catalysis is increasingly driven not only by activity and selectivity, but also by the design of systems that are efficient, durable, and compatible with environmental constraints. Collectively, these advances underscore how rational catalyst design, resource efficiency, and environmental responsibility converge to support a more resilient, low-impact, and truly sustainable chemical industry, reflecting the high relevance and interdisciplinary interest of the topics covered.

Author contributions

All: writing – original draft, writing – review and editing.

Conflicts of interest

There are no conflicts to declare.

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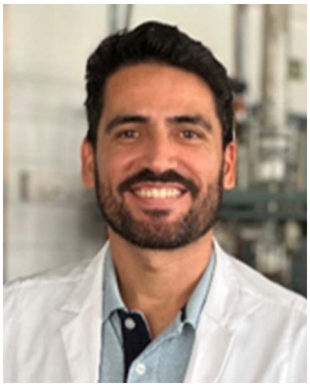

Mario J. Muñoz-Batista

Mario J. Muñoz-Batista is a professor at the University of Granada. He obtained his PhD in applied chemistry from the Autonomous University of Madrid – Institute of Catalysis and Petrochemistry (CSIC). His research expertise lies in the development of innovative methods for material preparation and the mathematical modelling of energy-efficient and environmentally sustainable chemical processes. His work spans a broad range of applications, from effluent treatment to novel pathways for chemical production, fuel generation, and the development of emerging energy vectors, with a strong emphasis on catalytic processes and waste valorization. He has authored more than 120 SCI-indexed articles (h-index = 40), holds two patents, and has contributed to several books and book chapters. He also serves in editorial roles for various leading journals in his field.

Bo Weng

Bo Weng is currently a professor at the Institute of Urban Environment, Chinese Academy of Sciences. He earned his PhD in physical chemistry from Fuzhou University, China, in 2018. Following his doctorate, he pursued postdoctoral research at Xiamen University and KU Leuven, supported by the European Union's Horizon 2020 program under the Marie Skłodowska-Curie Actions (Individual Fellowships) and the Research Foundation – Flanders (FWO) Postdoctoral Fellowships. His research primarily focuses on photo-assisted AOPs for environmental remediation. He has published 120+ papers, achieving an h-index of 48 and 7700+ citations (Google Scholar). As the first author or corresponding author, he has published 61 papers including in Nat. Rev. Clean Technol., Angew. Chem., Adv. Mater., and Nat. Commun. He has been invited to serve as a (Young) Editorial Board Member of NPJ Clean Water (IF 10.4), Chem (IF 19.1), Carbon Energy (IF 19.5), EcoMat (IF 10.4), Nexus, EcoEnergy, etc. He also serves as a reviewer of Nat. Water, Nat. Commun., J. Am. Chem. Soc., Angew. Chem., Adv. Mater., etc.

Choe Earn Choong

Choe Earn Choong is a research professor in the Environmental Engineering Department, Kwangwoon University, South Korea. In 2018, she received a PhD in Environmental Engineering from the University Malaya, Malaysia. Her research interests in developing nanomaterials include advanced oxidation catalysts, plasma catalysts, and adsorbents for water and wastewater treatment. She has published more than 70 scientific papers and was granted 10 patents in nanomaterial development for water treatment. In addition, she is one of the editors for Separation and Purification Technology and Journal of Water Process Engineering.

Asim Bhaumik

Asim Bhaumik is working as a senior professor in the School of Materials Sciences at the Indian Association for the Cultivation of Science, Kolkata, India. He obtained his PhD from CSIR-National Chemical Laboratory, Pune in 1997. After that he was a JSPS postdoctoral fellow at the University of Tokyo, Japan (1997–1999). Then, he was Associate Researcher at Toyota Central R&D Laboratories, Inc., Japan (1999–2001). His areas of research interest include designing novel porous COFs, POPs, MOFs, functionalized mesoporous materials for energy and environmental applications, such as H_2/CO_2 storage, adsorptive removal of heavy metals from polluted water resources, electrochemical water-splitting, photocatalysis, heterogeneous catalysis for CO_2 fixation reactions, biomass conversions, and synthesis of organic fine chemicals. He has published over 560 original research articles and 15 patents with citations over 31500 and an h-index of 96. Bhaumik is an associate editor of Green Chemistry and is a Fellow of the Royal Society of Chemistry (FRSC).

Damien P. Debecker

Damien P. Debecker is full professor at the University of Louvain (Belgium). He obtained his PhD in heterogeneous catalysis in 2010. His research focuses on the development of innovative heterogeneous catalysts for sustainable chemical processes, such as the greener synthesis of high-value chemicals, CO_2 hydrogenation, bio-based platform chemicals synthesis and upgrading, hydrogen production, etc. Original catalytic materials – often multifunctional – are notably obtained via advanced sol–gel processes (e.g. reactive aerosol) and by hybridization with enzymes. He has authored more than 190 papers in international peer-reviewed journals (h-index = 57), is a chair of the International Advisory Board of ChemCatChem (Wiley), and served as an Associate Editor of Chem & Bio Engineering (ACS).