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Editorial

Editorial for the Special Issue "Advanced Catalysts for Energy Conversion and Environmental Protection"

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The transition toward sustainable energy systems and cleaner industrial processes requires catalytic materials that are not only highly active but also stable, cost-effective, and adaptable to realistic operating conditions [1]. Catalysis has become a central technology in addressing two closely related global challenges: the efficient conversion of renewable or waste-derived resources into fuels and chemicals, and the removal of persistent pollutants from air and water [2–4]. The collection of articles in this issue reflects the breadth and interdisciplinary nature of current catalyst research, covering catalytic ozonation, electrochemical CO_2 conversion, photoelectrochemical water oxidation, photothermal CO_2 reduction, catalytic combustion, hydrogen storage, and advanced oxidation processes. A major theme emerging from these contributions is that catalyst development is increasingly moving beyond the preparation of a single active phase [5]. Instead, effective catalysts are designed as integrated functional systems in which composition, morphology, support structure, interfaces, and operating environment are carefully coordinated [6,7].

For environmental protection, membrane fouling remains a major obstacle to the long-term operation of membrane-based water treatment systems. The construction of a $CoFe_2O_4$-impregnated ceramic membrane with catalytic ozonation capability represents an important strategy for addressing this problem. In such a system, the membrane is no longer regarded merely as a physical separation medium; it also functions as a catalytic reactor. The incorporation of $CoFe_2O_4$ can facilitate ozone activation and the generation of reactive oxygen species, while the ceramic membrane provides mechanical strength, chemical resistance, and a structured environment for catalytic reactions [8,9]. This multifunctional design may help mitigate irreversible fouling and improve membrane regeneration. More broadly, it illustrates the value of combining separation and catalytic oxidation in a single platform. The modification of MnO_2 with Ru highlights the importance of electronic structure regulation and active-site engineering in pollutant removal [10]. However, catalytic activity alone is insufficient for evaluating practical water-treatment materials. The identification of reactive species, the influence of water matrices, catalyst stability, metal leaching, and the toxicity of transformation products are equally important [3,11]. Future research should therefore combine reaction-performance measurements with comprehensive mechanistic and environmental safety assessments.

Several contributions focus on the catalytic conversion of CO_2, an area that connects environmental remediation with renewable-fuel production. Low-cost CuSn catalysts for the electrochemical conversion of CO_2 and water to syngas demonstrate the importance of alloy composition and active-site cooperation [12]. Copper-based catalysts are attractive because of their relatively low cost and ability to promote the formation of carbon-containing products. The introduction of Sn can modify the electronic structure of Cu, alter

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intermediate adsorption, and influence product selectivity [12,13]. Nevertheless, the electrocatalytic reduction of CO_2 remains highly sensitive to local pH, electrolyte composition, mass transfer, catalyst morphology, and applied potential [13].

Photothermal CO_2 reduction over geopolymer/$Ag_9(SiO_4)_2NO_3$ catalysts modified by photoreduced Co^{2+} provides another example of multifunctional catalyst design. This type of catalyst integrates a geopolymer support, a visible-light-responsive silver-containing phase, and cobalt-related surface modification. Such a combination may improve light absorption, charge separation, thermal activation, and CO_2 conversion [14]. It also emphasizes the growing importance of coupling photochemical and thermal effects in catalytic reactions. However, the contributions of photothermal heating, hot carriers, surface defects, and metal active sites must be carefully distinguished [15].

In the field of solar energy conversion, Al-doped anisotropic $SrTiO_3$ crystals are used to improve the photoelectrochemical oxygen evolution reaction. This study exemplifies how dopant incorporation and crystal anisotropy can be used simultaneously to regulate charge transport and surface reaction kinetics. The effectiveness of such strategies depends not only on the dopant concentration but also on its spatial distribution, defect chemistry, crystal orientation, and interface with the electrolyte [16]. For photoelectrochemical materials, photocurrent should be evaluated together with onset potential, incident photon-to-current efficiency, charge-transfer efficiency, surface recombination, gas evolution, and operational stability [17].

Catalytic combustion and hydrogen storage address two additional aspects of the energy transition. The development of highly active and stable $SmMnO_3$ perovskite catalysts demonstrates the continuing potential of structurally flexible oxide materials for oxidation reactions. Perovskites can accommodate multiple oxidation states and oxygen vacancies, allowing their redox properties to be tailored through composition and thermal treatment. Yet, resistance to thermal sintering, poisoning, and redox cycling remains critical for industrial combustion applications [4]. Similarly, the enhancement of hydrogen desorption from AlH_3 through MXene catalysis illustrates the role of two-dimensional materials in hydrogen-storage systems. MXenes may provide active interfaces, facilitate hydrogen diffusion, and reduce the temperature required for hydrogen release [18]. The key challenges are to clarify the catalytic mechanism, prevent oxidation or structural degradation of the MXene, and evaluate cycling stability under practical conditions. A reduction in desorption temperature is meaningful only when it is accompanied by acceptable hydrogen capacity, reversibility, safety, and durability.

Taken together, the articles in this issue demonstrate that future catalyst research should pursue three interconnected objectives. First, catalyst design must become more precise, using compositional, structural, and interfacial engineering to control reaction pathways. Second, catalytic evaluation should include stability, regeneration, selectivity, energy efficiency, and environmental risk. Third, laboratory-scale discoveries need to be translated into robust, scalable, and economically viable catalytic systems. The most promising catalysts will therefore not necessarily be those with the highest initial activity, but those that combine high performance with durability, low cost, controllable synthesis, and reliable operation under realistic conditions. By connecting rational material design with mechanistic understanding and process-level evaluation, catalyst research can make a more substantial contribution to sustainable energy conversion and environmental protection.

Conflicts of Interest: The author declares no conflicts of interest.

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