ABSTRACT:

Performance Enhancement of Heterogeneous Catalysts: Challenges and Strategies for Sustainable Hydrogen and Chemical Production

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Nanostructured heterogeneous catalysts play a central role in numerous industrial processes, yet substantial research efforts are still needed to further enhance their performance. These challenges become especially critical when non-noble metals are used and when biomass-derived feedstocks replace conventional fossil-based resources. In this context, the integration of catalytic testing with in-situ/operando characterizations and modeling is essential for guiding the design of advanced catalysts capable of withstanding demanding reaction environments associated with the variable composition of renewable feedstocks and with the presence of impurities potentially noxious to the catalysts, while still meeting industrial requirements [1].

Several strategies can be adopted to enhance the activity and stability of heterogeneous catalysts, among which the use of promoters is particularly effective, as it enables targeted modification of key parameters governing catalytic performance. For instance, indium has is as a valuable promoter for hydrogen production from biomass-derived sources, showing strong synergy with copper [2] and nickel [3]. In these systems, indium facilitates water activation and mitigates coke incorporation into the active-phase nanoparticles, respectively. As a result, the catalysts exhibit markedly improved activity and stability, even approaching the performance typically associated with noble-metal-based formulations.

However, the use of promoters can also introduce drawbacks, such as increased costs or suboptimal control over reaction pathways. An alternative approach involves tailoring the catalyst composition and/or treatments to tune the intrinsic properties of the active phase. For example, adjusting the electronic density of metal nanoparticles can steer reactant adsorption [4], while modulating the surface composition can enable the catalyst to carry out multiple elementary steps or parallel reactions simultaneously.

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