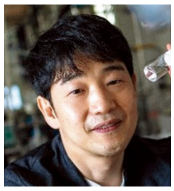
Beyond precious metals: Redefining catalysis with ubiquitous metals



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Abstract

The transition of chemical industries from reliance on precious and rare metals to technologies rooted in abundant and sustainable elements represents one of the major challenges in modern society. This study successfully addressed this issue by developing iron phosphide nanocrystals (Fe_2P NC) that overcome the inherent limitations of conventional iron catalysts, including low activity and oxidative deactivation. Fe_2P NC demonstrated high performance in hydrogenation of nitriles and reductive amination of aldehydes/ketones, outperforming traditional iron catalysts and achieving remarkable durability under mild conditions. Furthermore, the design concept established with Fe_2P was also applicable to iron carbides, where ε-Fe_2C nanoparticles exhibited excellent activity and high selectivity in reductive amination, highlighting the generality of this catalyst-design strategy. By simultaneously achieving high activity and stability, this research establishes a novel design paradigm for air-stable and highly active iron catalysts, broadening the scope of applications for iron-based catalysts and laying a strong foundation for sustainable chemical processes.

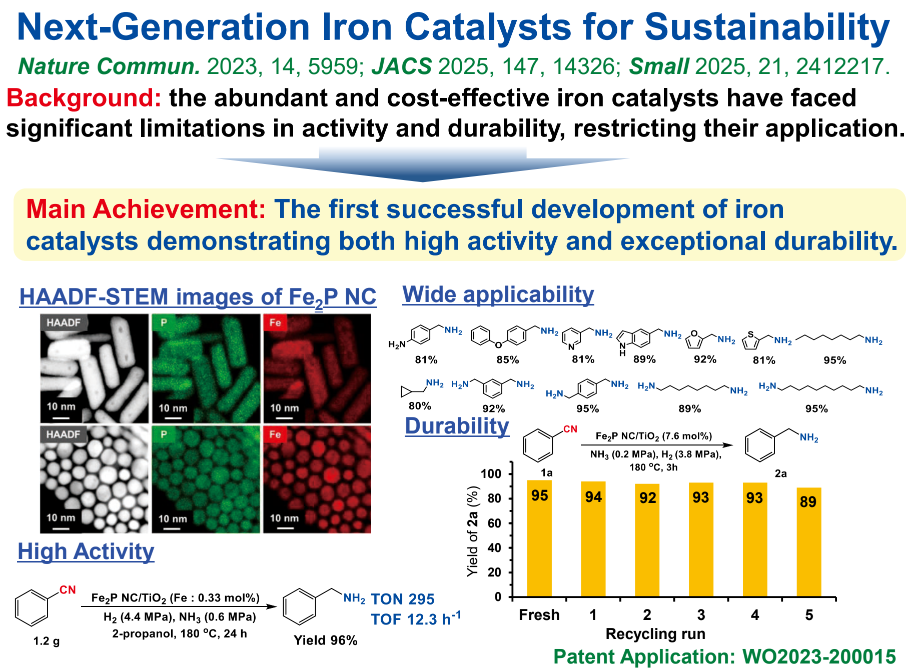
Background & Results

Iron, a ubiquitous and low-toxicity element, has long been considered a promising resource for catalysts. However, the inherent low activity and susceptibility to oxidative deactivation have limited its catalytic applications. This research overcomes these challenges by synthesizing iron phosphide nanocrystals (Fe_2P NC) using a liquid-phase thermal decomposition method. The Fe_2P NC catalysts achieved both air stability and high catalytic activity. In nitrile hydrogenation, Fe_2P NC outperformed conventional iron catalysts, demonstrating high activity and durability under mild conditions. Additionally, the remarkable air stability of Fe_2P NC enabled its integration with various metal oxides, resulting in further improvements in catalytic performance. Specifically, composites of Fe_2P NC with TiO_2 exhibited a significant enhancement in activity, maintaining high performance even after multiple reuse cycles. This stability also eliminated the need for oxygen-free environments or high-temperature pretreatment with H_2, simplifying and streamlining catalytic processes.

These results present a novel design principle for non-precious metal catalysts, greatly expanding the functional scope of iron catalysts. By harnessing the inherent potential of iron-based materials, this research is a robust foundation for advancing sustainable chemical processes.

Significance of the research and Future perspective

This research represents the transformative potential of iron, a ubiquitous element, as a sustainable alternative to precious metals. The developed catalysts offer significant advancements in energy efficiency, cost reduction, and environmental impact. Additionally, the simplification of catalytic processes enhances their industrial applicability. Future efforts will focus on expanding these catalysts' applications to pharmaceutical intermediate synthesis and environmentally friendly chemical processes, advancing the practical implementation of next-generation sustainable technologies.



Patent

Treatise
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Keyword catalyst, Green Chemistry, resource self-sufficiency, nanoparticles, non-precious metals