Title: Earth-Abundant Metal Catalysts: Exploring the Potential of Iron, Cobalt, and Nickel for Sustainable Chemical Reactions and Energy Applications

Abstract

The development of effective and affordable catalysts based on earth-abundant metals abundant in the Earth, such as iron, cobalt, and nickel, is essential for realizing sustainable chemical production and energy conversion processes. These metals are a much more attractive alternative to the rare and expensive metals, which are currently used in many catalysts. This paper reviews recent advances in the development of earth-abundant metal catalysts, focusing on their application in various chemical reactions relevant to energy conversion and storage. Also, the challenges and future prospects for research in these areas are also discussed, emphasizing the need for interdisciplinary collaboration and innovative strategies for the design and optimization of these sustainable catalysts.

Introduction

Catalysts play a serious role in driving various chemical reactions by improving their efficiency and selectivity, and reducing the energy requirements (Crabtree, 2010). A lot of currently used catalysts are based on rare and expensive metals, such as platinum, palladium, and rhodium, which have limited availability and can be economically and environmentally unsustainable (Chirik, 2011). This can be contrasted with iron-based catalysts, like including iron, cobalt, and nickel, offer an attractive alternative for the development of sustainable catalysts because of their low cost, and widespread availability (Nishibayashi 2015). This paper focuses on the potential use of these earth-abundant metals as catalysts for various chemical reactions, including those relevant to energy conversion and storage.

Iron-Based Catalysts

Iron is the most abundant transition metal in the Earth’s crust and has been extensively studied as a potential catalyst for various and diverse chemical reactions (Bauer, 2015). One notable example is the Haber–Bosch process, which uses iron-based catalyst, which involves the synthesis of ammonium from nitrogen and hydrogen using an iron-based catalyst (Schrock, 2006). Iron-based catalysts have also been investigated for their application in the Fischer–Tropsch processes, which converts synthesis gas a mixture of carbon
monoxide and hydrogen) into hydrocarbons and oxygenates (Davis, 2011).

**New, up-to-date**

Recent research has focused on the development of iron-based molecular catalysts; that can mimic the active sites of natural enzymes—e.g., hydrogenases, nitrogenases, which are involved in the activation and conversion of small molecules (Rauchfuss, 2009). These biomimetic catalysts have been shown to be especially promising for the reduction of protons to hydrogen, nitrogen fixation, and the activation of carbon dioxide and other small molecules (Artero & Fontecave, 2013). But, however, improving the stability and activity of these iron-based molecular catalysts is still need to be improved for practical applications.

**Cobalt-Based Catalysts**

Cobalt is also a third earth-abundant metal that has been studied for its potential use as a catalyst in various chemical reactions (Anjana & Sreekanth, 2015). Cobalt-based catalysts have been widely used in the Fischer–Tropsch processes, they exhibit large activity and high selectivity for the production of long-chain hydrocarbons (Khodakov et al., 2007). In recent years, cobalt-based molecular catalysts have been investigated for their application in the electrochemical and photochemical reduction of protons to hydrogen (Sun et al., 2015). These catalysts have shown promising activity and stability under a wide range of various conditions, making them attractive candidates for the development of sustainable hydrogen production technologies (Artero et al., 2011). Cobalt-based catalysts have also been explored for their potential use in the electrocatalytic reduction of carbon dioxide to formate, a valuable chemical feedstock (Kumar et al., 2016, 2016). Further optimization of the catalytic performance and selectivity of these cobalt-based catalysts is needed for practical applications.

**Nickel-Based Catalysts**

Nickel is another earth-abundant metal that has attracted considerable attention for its potential use as a catalyst of various chemical reactions (Kumar and Jain, 2012). Nickel-based catalysts have been widely used in the hydrogenation process.
of hydrogenating unsaturated hydrocarbons, and the production of producing chemicals from biomass-derived feedstocks (Chen et al., 2014).

In recent years, nickel-based molecular catalysts have recently been developed for the electrochemical and photochemical reduction of protons to hydrogen, and also the oxidation of hydrogen to protons (Tard & Pickett, 2009). These catalysts exhibit high activity and stability under a variety of conditions, making them promising candidates for the development of sustainable chemistry (Canaguier et al., 2012).

Nickel-based catalysts have also been investigated for their potential use in the electrocatalytic reduction of carbon dioxide to carbon monoxide, a key intermediate in the production of liquid fuels and chemicals (Jouny et al., 2018). However, the development of more selective and efficient nickel-based catalysts for carbon dioxide reduction remains a challenge.

Challenges and Future Prospectives

The development of earth-abundant metal catalysts for sustainable chemical reactions and energy applications faces several challenges, including the need for a better understanding of the fundamental mechanisms of catalysis, the design of catalysts with the desired properties, and the scaling up of their production for practical applications (Chirik, 2011). Interdisciplinary research involving synthetic chemistry, materials science, computational chemistry, and engineering will be crucial in addressing these challenges and advancing the field of sustainable catalysis (Crabtree, 2010).

Future research should definitely focus on the development of innovative strategies for the design and optimization of earth-abundant metal catalysts, such as the use of ligands and supports to control their electronic and stereoelectronic properties, as well as and the application of computational methods to predict and design new catalysts with the desired properties (Nishibayashi, 2015). Also, research efforts should be directed towards the investigation of novel catalytic systems and reaction pathways that could lead to the development of more effective and selective processes for the conversion of sustainable resources to valuable chemicals and fuels (Davis, 2011).

Conclusion

The development of effective and affordable catalysts based on earth-abundant metals, such as iron, cobalt, and nickel, is critical for realizing sustainable energy.
sustainable chemical production and sustainable energy conversion processes. Recent advances in the development of these catalysts have shown promising results for various chemical reactions relevant to energy conversion and storage. However, further research is needed to address the challenges associated with the design, and optimization, and scale-up of these sustainable catalysts. Interdisciplinary collaboration and innovative strategies will be crucial for advancing the field of sustainable catalysis and unlocking the full potential of earth-abundant metal catalysts.

References


