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Materials Science

Special Topic: Key Materials for Carbon Neutrality

Materials science empowers carbon neutrality

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Climate change is a global issue faced by humanity. With the drastic increase in carbon dioxide (CO_2) emissions worldwide, greenhouse gases are accumulating at a horrendous rate, exposing the ecosystem to serious threats. Countries across the world are consistently striving to reduce greenhouse gas emissions through global agreements. Towards the global goal of carbon peaking and carbon neutrality, it is essentially critical to reduce dependence on fossil fuels and accelerate the energy structure transformation. A wide variety of clean energy sources including hydrogen, solar, and wind energy are thus under vigorous exploitation, rendering energy conversion and storage with growing efficiency.

Materials are the cornerstone of human societal progress. The iterative update of advanced materials has served as direct driving force for green energy development, leading the essential path towards carbon neutrality. In the solar energy area, photovoltaic materials are indispensable for enhancing the energy conversion efficiency of solar cells. Highly active catalytic materials and safe hydrogen storage materials are both in demand in the hydrogen industrial chain. Towards carbon capture, utilization, and storage (CCUS), carbon capture materials that directly absorb CO_2 from combustion have become one research hotspot. Thus, transformative material technologies will undoubtedly lay a solid foundation for the realization of the dual carbon goal.

Herein, to demonstrate the key role and future prospects of advanced materials in the sustainable development of clean energy, we have organized a special topic on “Key Materials for Carbon Neutrality” in *National Science Open* (NSO). Seven representative reviews and articles are included, focusing on the latest research progress and critical challenges in the frontier research fields of heterogeneous catalysis, advanced energy storage systems, and thermal management materials and devices.

Catalysis plays a fundamental role in many clean energy technologies such as water splitting, advanced battery systems, and CCUS. Efficient and stable catalysts are the core to supporting sustainable energy conversion and storage. Wang *et al*. [1] systematically reviewed the underlying theory and catalytic significance of cutting-edge pulsed electrochemistry technique in terms of catalyst surface modulation and local interface environment management, highlighting its transformative potential in boosting various electrocatalytic reactions. In pursuit of efficient direct conversion of atmospheric CO_2 or flue gases, Li's group [2] provided in-depth views on the emerging strategy of (bi)carbonate electrolysis regarding its gas diffusion electrode design, membrane species comparison, as well as experimental parameter and flow optimization. Wang *et al*. [3] comprehensively dissected the specific roles of covalent organic frameworks (COFs) featured with diverse morphologies in chemo-, chemodynamic, photodynamic, photothermal, and combination therapies, emphasizing their nano-catalytic treatment functions via reactive oxygen species (ROS) generation. With more advanced catalysts designed and applied in critical chemical reactions, the traditional chemical industries will be substantially updated, fostering new energy industries at a faster pace.

Energy storage technology is an effective approach to solving the volatility and intermittency issues of wind and solar-dominated clean energy systems. With the continuous improvement in safety and economy, advanced batteries with elongated service duration and rapid charging capabilities are expected to dramatically boost low-carbon transportation and stable power supply. Lu *et al*. [4] proposed an effective strategy of surface cobaltization (Co) to achieve improved kinetics and excellent stability of nickel-rich layered cathodes, paving a new way for Co usage optimization towards high-performance lithium-ion batteries. Hu's group [5] delivered insights into the inhibition methodology of competitive hydrogen evolution reaction (HER) in alkaline Al-air batteries (AABs), figuring out the prospective developing direction for large-scale utilization of AABs. By virtue of high energy density, decent response speed, potentially scalable production and easier maintenance, the future application scenarios of electrochemical energy storage systems will be considerably broadened.

Thermal management, which is indispensable in effective regulation of heat distribution, storage and conversion within confined space, is widely adopted in various fields of daily life and industrial applications. With extreme climate occurring more frequently, it is highly urgent to develop advanced thermal management materials to back efficient heating and cooling with less fossil fuel dependence. Zhu *et al*. [6] demonstrated a passive temperature regulator that integrates the functionalities of harvesting, storage, and release of passive solar heat and space coldness through a tailored sandwich structure, promising excellent temperature stabilization at extreme climate condition. Towards high-efficiency thermo-electric energy conversion, Zhao *et al*. [7] cast deep-seated perspectives on inorganic thermoelectric fibers along with their thermal drawing method, providing valuable guidance on flexible thermoelectric device design. With the rapid expansion of the fifth-generation mobile communication technology (5G), the demand for high-density integration, high-power output and continuous operation of 5G equipment will elevate high-performance thermal management materials in an increasingly important position.

This Special Topic aims at reflecting the recent progress achieved in clean energy materials towards carbon neutrality, although it cannot cover all relevant research being carried out worldwide. We believe that this topic will deliver valuable perspectives and meaningful insights on the advancement of carbon neutrality-oriented materials science. Through original innovation, frontier exploration, multidisciplinary integration, and practical application of advanced materials, we're bound to create a sustainable future. Finally, we would like to express our gratitude to all the authors, reviewers, and editorial staff for their continuous effort and strong support on this topic preparation.

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