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Clean energy technology: materials, processes and devices for electrochemical energy conversion and storage

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Climate change is a major modern-day challenge that faces the human society. Developing clean energy technology requires near-term approaches and long-term strategy. A solution to meet the daunting challenge is for us to make a switch in energy use to various carbon-free, renewable sources. Due to the intermittency and geographical constraint of renewable energy supply, its broad application requires to develop smart energy storage and conversion technology. Distributed system, microgrid and clean vehicles are among the major society-level solutions that are actively considered. Electrochemical energy, if made in a highly efficient and clean manner, should greatly help in our ability to adapt to this change.

Transportation is one main area where both energy consumption and pollutant emission are high. Following the Paris Agreement in recent years, United Kingdom, France, Germany, Norway and other governments are making their strategic plans on alternative propulsion technology for transportation. Under such plans, we can envision a world that ushers in a new era of electric propulsion technology for vehicles, including fuel cells, batteries and hybrids of the two. While battery vehicles have been commercialized earlier, targeting the rela-

tively short distance transportation, fuel cell vehicles promise for long-range travel and heavy-duty transportation. During the past two decades, enormous progress has been made on fuel cell research. There are still however economical and technical barriers to overcome before the mass production of fuel cell vehicles becomes a reality. Thus, it is not inconceivable research efforts to address the challenges facing the fuel cell on cost, cell durability and a few other areas will intensify, while at the same time battery technology will continue to develop rapidly.

In this thematic issue, we feature 15 invited contributions focusing on the current and emerging technologies in electrochemical energy conversion and storage, most noticeably hydrogen-powered fuel cell and various battery systems. A central theme of technological innovation in hydrogen fuel cell is to address the cost and noble metal usage issues and those aspects at the system level (versus development of sole Pt-metal catalysts). Controlling the amount of noble metal in a low temperature fuel cell system is not only good for cost control but also helps minimizing a potential disruption in material supply chain (in this case, noble metal). In this context, **Zeng** and his co-workers review the latest development of electrocatalysts for oxygen reduction reaction (ORR) and future perspectives in this area. A key research aspect is the structural design of facet-controlled Pt-alloy catalysts for ORR, one of the most active research areas that have received enormous attentions in recent years. **Z. Shao** and his co-workers discuss a design and synthesis of Pt₃Ni nanowire ORR catalysts, which have exceptionally high activity due to multiple structural factors including composition, surface and strain. In the same vein, **M. Shao** and his colleagues show by controlling the shape of Pt-Ni catalysts, a high ORR mass activity of 0.81 A/mg_{Pt} was achieved at the potential of 0.9 V. **Li** group reports a facile synthesis of cubic Pt nanocatalysts on various types of active carbon. His research points to a high-level dependence

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of electrochemical surface area on the type of carbon supports. Besides Pt-containing catalyst, **Ge** examines the formation of Pd nanoparticles on N-doped carbon support and identifies that uniform deposition of metal catalysts can be achieved when nitrogen dopant level is high in the support. Finally, **Adzic** group presents an *in-situ* X-ray absorption spectroscopy (XAS) study of electrocatalysts with a focus on understanding the effect of interatomic distance and coordination number of elements on the performance of ORR catalysts.

An important future direction in hydrogen fuel cell research has related to the problems that high catalyst performance has not readily been realized at the component to system levels. This is because the high activity observed based on the rotating disk electrode (RDE) test can not translate into an equally impressive improvement in power performance in low temperature polymer electrolyte membrane fuel cell (PEMFC) system due to the large difference in testing conditions and other factors. The goal for US Department of Energy near term target of 0.44 A/mg-Pt @0.9 V iR free has not been reached with reasonable durability and power density performance because the mass transport loss can be significant. In this special issue, **J. B. Zhang** and his colleagues review the critical issues in design and preparation of fuel cell catalyst layer in PEMFCs. **Hou** approaches the system-level study of PEMFCs from an industrial perspective with an emphasis on failure mode analysis and durability. Remedies in addressing the issues relevant to the sources of these problems lead to visible large enhancement in durability of cell performance. **Pan** contributes a paper on durability study based on the membrane electrode assembly (MEA) for PEMFCs. Yet another system level approach is to run the fuel cell under alkaline condition. In this regard, **Mustain** contributes a full paper on examining the alkaline exchange membrane fuel cell (AEMFC) using a Pd-Cu catalyst.

Another burgeoning research area for hydrogen-powered PEMFCs is to develop non-noble metal fuel cell catalysts. Since the high cost and low abundance of noble metals, a PEMFC system without the use of noble metal will greatly reduce the pressure on cost and impact of expensive metals. Carbon-based materials have been considered as a key in such efforts, especially nitrogen or other main group element-doped systems. **Wu** reviews the state-of-the-art platinum-group metal (PGM)-free cathode catalysts for PEMFCs. A major challenge in this topical area is the lack of good understanding and precise control of active sites; thus, opportunities for future research and development exist in both theory and experimental design.

Besides fuel cell technology, this special issue also showcases research on several types of batteries, including Li ion battery, redox flow battery and energy storage systems. To understand the mechanisms

related to the capacity fade of Li ion battery containing LiMn_2O_4 cathode, **Lastoskie** et al. applied reactive force field (ReaxFF)-based molecular dynamics to investigate the reactions occurring at the cathode surface and the process of manganese dissolution. **Chen** et al. contribute a paper on cathode materials for Li ion battery, which involved coating $\text{LiNi}_{0.5}\text{Mn}_{1.5}\text{O}_4$ materials with Li_4SiO_4 . **Teng** and his colleagues report the synthesis of highly pure layered Mn_5O_8 nanoparticles and their use in making electrodes, which are important for aqueous electrochemical energy storage (EES) system. Last but not least, **Ramani** and his coworkers show the use of $\text{Ni}(\text{OH})_2$ nanoparticle suspension as the cathode materials in a flow battery system.

We hope you will find from this collection of review and research articles the electrochemical conversion and storage technology represents a major endeavor of our search for sustainable, clean use of energy. Our coverage is limited in scope and means to inspire broader explorations of new electrochemical materials, processes and devices for energy conversion and storage.

Editor's bio sketches:

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1968. His research interest covers alkaline fuel cell, molten carbonate fuel cell, PEMFC, regenerative fuel cell, direct methanol fuel cell and solid oxide fuel cell. In the research on fuel cell materials, he invented reinforced composite membrane, self-humidifying membrane, hydrocarbon membrane, and novel preparation methods of electrocatalyst and electrode. For the components of fuel cells, he developed composite bipolar plate, feasible method for stack assembling. For the fuel cell system, he developed humidifier and system integration technologies. As the leader of the Fuel Cell Research Group at Dalian Institute of Chemical Physics, Dr. Yi has not only accomplished greatly on fundamental research, but also transferred the technology into fuel cell product development. Dr. Yi is the founder of Dalian Sunrise Power Co. Ltd.. The fuel cell systems made by the company have been used in the demonstration buses for the 2008 Beijing Olympic Game and cars for the 2010 Shanghai World Expo. He also led the effort to set up the China Fuel Cell Test Centre and established the test criteria. His work propels the development of fuel cell technology in China and around the worldwide. E-mail: blyi@dicp.ac.cn