Status and Challenges in Electrochemical Energy Storage Technologies for Stationary Applications

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Energy consumption is currently dominated by fossil fuels including coal, oil, and natural gas. While abundant coal reserves may maintain the current consumption level for a long period of time, oil and natural gas production is predicted to peak over the next few decades. Burning fossil fuels, however, generates greenhouse gases that are widely considered as the cause of global warming. Meanwhile, worldwide energy demand is predicted to double by 2050 and triple by the end of the century. The concerns over the environmental consequences of using fossil fuels and their resource constraints, along with worries over energy security, have led to growing interest in alternative energy, including renewable wind and solar power. However, the variable and stochastic nature of renewable sources makes solar and wind power difficult to manage, especially at high levels of penetration. To effectively use the intermittent renewable energy and enable its delivery demands electrical energy storage (EES). The same technologies are also tools to improve the reliability, stability, and efficiency of the electrical grid. As such the EES technologies are considered as a critical enabler to the future grid that is expected to be able to provide fuel (i.e., electricity) to plug-in hybrid vehicles and allow two-way communication and digital balancing of demand and supply (i.e., a smart grid).

A number of EES technologies exist that are potential candidates for sta-

tionary applications. Among the most promising ones are batteries that store electrical energy via electrochemical conversion and release it according to demands. But all the existing battery technologies are facing challenges in cost and performance for the particular applications. To advance the technology and accelerate market penetration requires substantial progress in advanced materials and chemistries, along with design and engineering. Given this is a relatively new field to the materials community, this issue of *JOM* includes a topic on stationary electrical energy storage, with a focus on the needs, requirements, status, and challenges in technologies.

The first paper by Z. Yang et al. examines the benefits and challenges of EES, in particular electrochemical storage technologies or batteries, and discusses the fundamental principles, economics, and feasibility of the storage technologies. It intends to provide an understanding of the needs and challenges of electrical storage technologies for stationary applications and offer general directions of research and development to the materials community.

As an example, two technologies are reviewed in the next two papers, regarding principles, status, and challenges. T. Xu et al. discuss the applications of lithium-ion batteries for stationary energy storage. Currently available lithium-ion battery electrode materials and their combinations are identified for such stationary applications. The paper also explores limitations and future research directions in lithium-ion for the particular applications. The authors point out that, along

with battery cell design, electrode materials with inherent physical stability need to be chosen for large stationary lithium-ion battery energy storage system. Among various electrode material candidates, the combination of LiFePO_4 cathodes and anatase TiO_2 or $\text{Li}_4\text{Ti}_5\text{O}_{12}$ anodes appears promising. The lithium-ion insertion/extraction in both LiFePO_4 and anatase $\text{TiO}_2/\text{Li}_4\text{Ti}_5\text{O}_{12}$ electrode shows minimum lattice distortion and volume change, indicating a thermodynamically highly reversible redox reaction with minimum heat generation compared to other unstable electrode materials. Thus the unique lithium-ion batteries potentially offer safe, stable cycling performance and a low lifecycle cost.

X. Lu et al. offer an overview on the sodium-beta batteries that store electricity via Na^+ transport across a $\beta''\text{-Al}_2\text{O}_3$ membrane electrolyte that separates a molten sodium anode and molten sulfur or metal halide cathode. The sodium-beta batteries have received increasing attention due to their feasibility and performance at scales up to MWs/MWhs. While the solid oxide membrane batteries have been extensively developed for a few decades with encouraging progress achieved, several issues remain for broad applications and market penetration. This paper offers a review on materials of electrodes and electrolytes for the batteries and discusses the challenges ahead for further technology improvement.

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