Investigation of Redox-Active Organic Molecules for Non-aqueous Flow Batteries

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Over the past decade large investments have been made worldwide to design, build and install renewable energy producing systems. Unfortunately, the full benefit of these technologies cannot be realized without distributed energy storage to control and meter energy delivery to and from the electrical grid [1]. Redox flow batteries may provide the best combination of cost, efficiency, and scalability to enable these applications. Present aqueous flow battery technologies have low energy densities (< 40 Wh/L) as a consequence of low solubilities of redox species and operating voltages that are bounded by water electrolysis. This, in turn, leads to prohibitively high total installation ($1200-$3310/kW) and operating costs ($300-$830/kWh) which hamper widespread adoption [2]. Indeed, for broad commercialization, the Department of Energy has established goals of $100/kWh and $250/kW [3]. Meeting these targets requires a paradigm shift in our approach to energy storage rather than incremental improvements to current technologies.

Employing non-aqueous solvents offers a wider window of electrochemical stability, as compared to water, that enables cell operation at dramatically higher potentials (> 3V). Higher cell voltage leads to higher energy density and typically higher roundtrip efficiency, which together reduce energy cost. Moreover, to achieve the same output as an aqueous system, fewer stack layers, lower flow velocities, smaller tanks, and fewer ancillaries would be required, significantly reducing hardware costs and enhancing system reliability. As a result, non-aqueous flow batteries have been the subject of increasing interest in both academia [4, 5] and industry [6, 7].

Taking advantage of these wider electrochemical windows requires the development of appropriate electrochemically-active materials and the application of these materials in a high capacity flowable format. Of particular promise are redox-active organic molecules, as key electrochemical and physical properties (e.g., redox potential, reversibility, solubility) can be modulated via tailoring of the redox-active moiety or the surrounding molecular structure [8, 9]. Moreover, previous work in organic materials for lithium (Li)-ion batteries has led to the identification of a number of promising material classes and to the establishment of some key design principles. Here, I will describe our research efforts on the development of suitable electrochemical couples and electrolytes for non-aqueous Li-ion redox flow batteries with a focus on alkoxybenzene and quinoxaline derivatives as electroactive materials [9].

References

[1] Z. Yang *et al*., *Chem. Rev.*, **2011**, *111*, 3577
[2] D. Rastler, EPRI Technical Update 1020676, December **2010**
[3] US Department of Energy Funding Opportunity Announcement, *Energy Innovation Hub – Batteries and Energy Storage*, DE-FOA-0000559, February **2012**
[4] Q. Liu, A.E.S. Sleightholme, A.A. Shinkle, Y. Li, L.T. Thompson, *Electrochem. Commun.*, **2009**, 11, 2312.
[5] D. Zhang, Q. Liu, X. Shi, Y. Li, *J. Power Sources*, **2012**, 203, 201-205.
[6] H.Y. Sun, J.W. Park, D.Y. Lee, S.U. Son, US Patent Application 0195283 A1, **2011**.
[7] P.G. Rasmussen, US Patent 8080327 B1, **2011**
[8] F.R. Brushett *et al*., Exploratory Research of Non-aqueous Flow Batteries for Renewable Energy Storage, *220th ECS Conference*, Boston, MA, October **2011**
[9] F.R. Brushett et al., *Adv. Energy Mater.*, **2012**, 2, 1390