



Global Climate & Energy Project STANFORD UNIVERSITY

Novel Electrolyte Energy Storage Systems

Investigators

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Objective

The objective of this work is to develop efficient, cost-effective energy storage systems using redox flow batteries (RFB). The investigators seek transformative changes in the construction and composition of RFBs using an integrated approach to identify new electrolyte systems and cell designs that drastically reduce costs while maintaining high efficiency and performance.

Background

An RFB system (Figure 1) offers some key advantages for grid-scale electrical energy storage relative to conventional batteries. In flow battery systems, the electrochemical reactor and the storage tanks of the free-flowing electrolyte streams can be sized independently of one another, which means that power capacity and energy capacity can be optimized individually. The ability to deliver the active material to the electrode surface by convection ensures that one can bypass mass-transport limitations that curtail the energy density of conventional batteries with solid-phase active materials. The cycle life of RFB cells is not dependent on depth of discharge, because the electrodes are not required to undergo physical changes during cycles, and the utilization of the active materials can be very high without impacting cycle life. Additionally, flow batteries can have extremely large energy capacities without the use of thick electrodes, which limit the power density of conventional batteries.



Figure 1: A disassembled laboratory-scale redox flow battery (RFB) cell for evaluation of new electrolyte chemistry and comparison with the all vanadium system. The cell uses flow-through porous electrodes and an ionomer membrane.

In the design of an RFB system, there is a distinction between rated power capability, which specifies the size of the cell stack, and the total stored energy, which dictates the quantity of electrolyte. While the cost breakdown of an RFB system depends on the application, cost modeling of today's vanadium redox flow batteries indicates that the most expensive components

are the cell stack and the electrolyte. The thermodynamic potential difference between the two redox couples, the ohmic losses and the mass-transport losses are the primary limitations on the power density that a given cell can deliver.

Approach

The research team will systematically identify new candidate materials and carry out a thorough examination of their underlying chemistry, thermodynamics, physics and kinetics. The project seeks to accomplish the following:

1. Synthesize new ligands and complexes as electrolytes with tailored thermodynamic potentials.
2. Screen these candidate materials under a variety of conditions on carbon electrodes.
3. Characterize the most promising materials in larger electrochemical cells.
4. Quantify the transport properties of ionomeric membranes in the presence of redox couples and the supporting electrolyte.
5. Test and simulate candidate systems as a means of down-selecting lab-scale tests to understand performance issues.
6. Develop transient models based on conservation principles, incorporating the fundamental modes of transport for the charged species and solvent, including transport and reaction kinetics to simulate the performance of various RFB systems.
7. Facilitate the design of large-scale (>10 MW, and on the order of 1 GWh) RFB systems.

The researchers will develop a robust and flexible model to describe the uptake and transport of ions with vastly different mobilities across the separator in the flow battery system. By developing experimental procedures to measure ion uptake in these membranes, and understanding the interactions of participating ions with supporting electrolyte and with one another in the polymer, the research team will obtain a detailed understanding of how cell potentials vary with composition and potential. These results will help guide the development of materials with specific selectivities or mobilities to render better performance. Models will also be deployed to describe the nonlinear and highly coupled phenomena that occur in the porous electrodes, and to provide means for evaluating the tradeoffs between the various ohmic and solution-phase mass transport resistances.

The electrochemical behavior of promising metal ion complexes of manganese, titanium and tin with a variety of ligands will also be investigated. Measurements will be made of the formal potential, electrode kinetics, stability of reactants and products (the chemical reversibility) and the ionic mass transport rates of the complexes in solution and in standard ion-exchange membranes. Rapid screening will be based on techniques developed earlier with scanning electrochemical microscopy. Desirable properties sought in the screening include high solubility, excellent stability, rapid electron transfer kinetics, high current efficiencies for oxidation and reduction, low crossover rates through any membrane separator, and low cost.