Physics and data driven exploration of flow battery commerciality for grid-scale energy storage

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In an electrifying world, power needs are ever growing, as is the share of power sourced from renewables. Wind and solar photovoltaics continue to lead capacity additions to the grid, though the variability in their supply does check further grid penetration. There is then urgent need for complementary energy storage. In keeping with expectations that electricity costs remain low, grid storage must be, above all, cost-effective.

The redox flow battery (RFB) promises to meet such demands, thanks to its high durability and notably flexible design. Unlike a conventional solid-state battery, the RFB sees separable power and energy capacities. It is also well served by the repertoire of studied redox reactions and small number of moving parts. As novel chemistries and engineering improvements are realized in the laboratory, the design space only grows larger. Scale-up and commercial demonstrations comparatively lag. Thus, for imminent questions of feasibility and cost, modeling is a vital asset.

We hereby detail methods to model the physics, costs, and value of RFBs. We develop a fully general analytical formulation for performance, with validation from cell testing and independent experiments. We then define consistent, quantitative bases for optimality and scale-up. This enables comparisons across different designs, as well as optimization of operations for better practice. We also draw from the volume of current grid data to inform a peak shaving application.

As demonstrated, RFBs can now be meaningfully evaluated even in early stages of technological maturity. Screening can begin sooner and smarter, so that we orient research in directions of probable cost-effectiveness. To ultimately clear the path to market, theory, numerics, and data are best integrated.