Redox Flow Batteries for Long-Duration Energy Storage: Toward Scalable and Sustainable Grid Solutions

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The transition toward carbon-neutral energy systems demands not only large-scale deployment of renewables but also robust solutions to manage their intermittency. In this scenario, long-duration energy storage (LDES) technologies are critical for enabling the integration of renewables and for supporting the decarbonization of power systems. While lithium-ion batteries dominate the market for portable and short-duration storage, their high maintenance costs, safety concerns and the limited availability of lithium make them less competitive for long-duration applications. Redox flow batteries (RFBs) are emerging as leading candidates for low-cost, long term energy storage due to their unique ability to decouple power and energy. Among RFBs, vanadium-based systems are the most commercially mature; however, the high cost of vanadium and associated supply chain risks significantly limit their widespread diffusion.

To overcome these barriers, significant research efforts have focused on alternative redox chemistries and materials that offer lower costs and improved sustainability. As a result, significant research efforts have focused on developing alternative chemistries based on more abundant, low-cost materials. Notable examples include iron–chromium, all-iron, zinc–bromine, organic and metal hybrid systems.

These emerging chemistries, however, bring their own technical hurdles, including side reactions, solubility limits and electrode degradation which must be addressed through careful electrolyte formulation and innovative cell design.

Recent developments have shown the potential of zinc-based RFBs, which benefit from zinc's high volumetric capacity, low cost and global availability. Our work contributes to this landscape through the exploration of low-cost, high-energy-density alternatives, accompanied by a techno-economic assessment to evaluate commercial viability. As an example, a novel Zn–Mn RFB was investigated for its favorable material cost and operational metrics, offering insights into how emerging chemistries can bridge performance with economic feasibility.

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