Review of: "Flow Batteries From 1879 To 2022 And Beyond"

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The author has prepared an excellent article tracing the historical development of redox flow batteries (RFBs) and has compared it to state-of-the-art lithium-ion batteries (LIBs) to draw conclusions on their respective strengths and weaknesses. I would strongly recommend splitting this manuscript into two papers, one being a review of RFB development (and the related patent/publication trends) and another being a paper on the efficiency model. The model is quite comprehensive, and I consider it a disservice to relegate most of it to the appendices.

The initial discussion around the patent/publication ratios was quite interesting and using the patent to publication ratio as an indicator of commercial interest and investment is an excellent metric (given the orders of magnitude higher cost and time involved in getting a patent). While the author has looked at historic events such as the oil crisis and the introduction of the LIB by Sony as inflection points in research and patenting, I think the Bayh-Dole Act of 1980 (which incentivized patenting from federally funded research) should not be overlooked. I would make an educated guess that the proportion of academic/non-profit patent applicants to for-profit patent applicants changed after this point.

The non-vanadium RFB chemistries selected for discussion appears very arbitrary. The historic arguments for considering Zn-halogen RFBs is reasonable but the review would be strengthened by also discussing other RFB systems that were commercialized (or piloted) at one point or another (the eventual success of the commercial venture notwithstanding). For example, Plurion Inc piloted a MW scale stack of the Zn-Ce system while EnerVault brought a 250kW Fe-Cr system to market. This can serve to show that investment appetite does exist for RFB systems despite the developmental lead enjoyed by LIBs.

The modeling effort clearly illustrates the effect of the carbon felt fiber structure on the flow characteristics and losses in the all-V RFB cell. The mismatch demonstrated between the operating current density that will result in peak energy efficiency as opposed to peak power density (thus the smallest stack size and lowest capital cost) was very illuminating. This clearly shows that there is a disconnect between the energy component costs and power component costs in the system. But the author does not appear to have considered the impact of catalysts. The introduction of catalysts can lower the charge-discharge overpotentials and increase the voltage efficiency. Given that catalyst loading on electrodes is in the order of a few micrograms per square centimeter, the cost increase due catalyst incorporation is quite negligible given the costs of the bipolar plates and other components. The low loading will also mean that the power component prices are quite insensitive to catalyst cost increases. Another factor discussed is the cross-over of the V ions. I agree that the Donnan effect starts to taper off at higher concentrations. But it is possible to obtain separators with “beyond-Donnan” exclusion and permselectivity in the order of <0.2% crossover per month in some new separator configurations where metal oxide fillers enhance charge-based exclusion due to their surface charge (developed upon electrolyte immersion). This can be seen in US patent application # 17/264,016 (DISCLOSURE - I am an inventor on this application). I am optimistic that further technical developments that can boost the coulombic and voltage efficiencies of RFBs can help them further increase their energy efficiency. This possibility is also evident from reference 254 in the pre-print which demonstrates an all-V RFB with energy efficiencies comparable to LIBs (albeit in small, lab-scale cells).

But beyond optimistic predictions of future research success (which may or may not pan out), business model innovations may also help the all-V RFB and other RFBs compete with LIBs. One such innovation is the concept of electrolyte leasing. The LIB could leverage its high energy efficiency to achieve a cost advantage in high energy price markets. But this assumes that the customer has to account for the payback period for the electrolyte (the key energy component cost). In case of electrolyte leasing, the energy components capital costs drastically reduces as the most expensive component (the electrolyte) is no longer owned by the end-user but is leased from a vanadium supplier. The vanadium supplier can in turn select their market (RFBs vs others) for vanadium sales based on spot market prices of vanadium. The RFBs can thus serve as a vanadium warehouse, insulting the supplier from vanadium market downturns.

In conclusion, several avenues can enable the energy storage end user to take advantage of the energy and power decoupled scaling characteristics of RFBs and the incumbency of LIBs (in my opinion) is likely a function of its first-to-market and scale of production advantages rather than a function of inherent techno-economic superiority.