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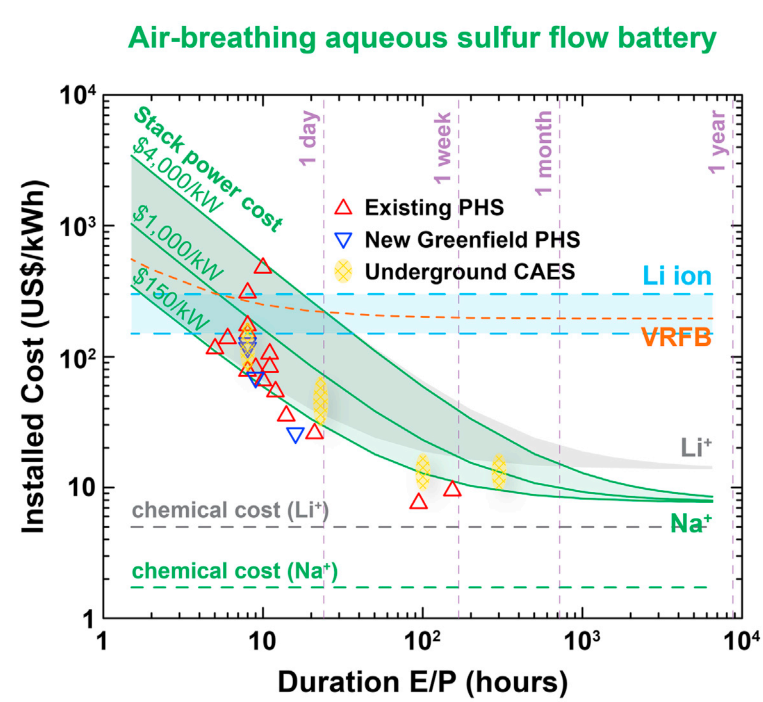
Air-Breathing Aqueous Sulfur Flow Battery for Ultralow-Cost Long-Duration Electrical Storage



The dropping cost of wind and solar power intensifies the need for low-cost, efficient energy storage, which together with renewables can displace fossil fuels. While batteries for transportation and portable devices emphasize energy density as a primary consideration, here, low-cost, ultra-abundant reactants deployable at massive (TWh) scale are essential. An air-breathing aqueous sulfur flow battery approach with ultralow energy cost is demonstrated at laboratory scale and shown to have economics similar to pumped hydroelectric storage without its geographical and environmental limitations.

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HIGHLIGHTS

Chemical cost analyzed for 40 rechargeable couples developed over the past 60 years

Aqueous sulfur/sodium/air system identified with ultralow chemical cost of ~US$1/kWh

Air-breathing flow battery architecture demonstrated at laboratory scale

Techno-economic analysis shows installed cost is comparable with PHS and CAES

Li et al., Joule *1*, 306–327
October 11, 2017

https://doi.org/10.1016/j.joule.2017.08.007

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Air-Breathing Aqueous Sulfur Flow Battery for Ultralow-Cost Long-Duration Electrical Storage

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SUMMARY

The intermittency of renewable electricity generation has created a pressing global need for low-cost, highly scalable energy storage. Although pumped hydroelectric storage (PHS) and underground compressed air energy storage (CAES) have the lowest costs today (~US$100/kWh installed cost), each faces geographical and environmental constraints that may limit further deployment. Here, we demonstrate an ambient-temperature aqueous rechargeable flow battery that uses low-cost polysulfide anolytes in conjunction with lithium or sodium counter-ions, and an air- or oxygen-breathing cathode. The solution energy density, at 30–145 Wh/L depending on concentration and sulfur speciation range, exceeds current solution-based flow batteries, and the cost of active materials per stored energy is exceptionally low, ~US$1/kWh when using sodium polysulfide. The projected storage economics parallel those for PHS and CAES but can be realized at higher energy density and with minimal locational constraints.

Context & Scale

Wind and solar generation can displace carbon-intensive electricity if their intermittent output is cost-effectively reshaped using electrical storage to meet user demand. Reductions in the cost of storage have lagged those for generation, with pumped hydroelectric storage (PHS) remaining today the lowest-cost and only form of electrical storage deployed at multi-gigawatt hour scale. Here, we propose and demonstrate an inherently scalable storage approach that uses sulfur, a virtually unlimited byproduct of fossil fuel production, and air, as the reactive components. Combined with sodium as an intermediary working species, the chemical cost of storage is the lowest of known batteries. While the electrical stacks extracting power can and should be improved, even at current performance, techno-economic analysis shows projected costs that are competitive with PHS, and of special interest for the long-duration storage that will be increasingly important as renewables penetration grows.

INTRODUCTION

The rapidly dropping cost of wind and solar electricity generation, as illustrated by levelized costs of electricity (LCOE) that are now competitive, or nearly so, with fossil fuel generation,[1] highlights the need for low-cost electrical storage that can transform intermittent renewable power into predictable and dispatchable electricity generation, and potentially even baseload power. Such a revolutionary outcome will require energy storage with costs well below the trajectory of current technology, while also being safe, scalable, long-lived, and sufficiently energy dense for widespread deployment, including in space-constrained environments. Emerging use-case studies suggest that installed costs of <$50/kWh, operating over multi-day or longer durations, will be required for renewable-based generation to compete economically with existing fossil plants on a drop-in basis. It is unclear whether electrochemical storage can meet these challenges.

Here, we first review the underlying chemical cost of energy storage for about 40 electrochemical couples representing all major classes of rechargeable batteries developed over the past 60 years. From this analysis, it is clear that the best opportunities for overcoming the above challenges reside with electrochemical couples that use ultralow-cost, highly abundant raw materials. Among these, sulfur has the 14th highest crustal abundance and is widely available as a byproduct of natural gas and petroleum refining.[2] Sulfur also has the lowest cost per stored charge of known redox active materials, next to water and air (see Table S1; in US$/kAh, sulfur