To: Carbon Mitigation Task Force
From: iCons 3E Energy Storage Team (Jack Moody, Shawn Small, Kenneth Eva, Tristen Heck)
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Re: Implementation of Redox Flow Batteries to the UMass Amherst Campus Energy Infrastructure

Summary
To assist UMass Amherst in meeting the carbon mitigation goals, while providing a safer alternative to lithium-ion batteries that requires no burning of fossil fuels, we propose a large-scale redox (reduction-oxidation) flow battery, as the next renewable energy technology for implementation on campus as an energy storage device. Redox flow batteries, invented by NASA in 1976 [1], store energy in liquid chemical form, which is later converted to electrical energy when the liquid is pumped through the battery cell during discharge. Charging occurs when the liquids capture energy from an energy generation system. Ideally, the redox flow battery will be charged with an existing renewable energy system (e.g. solar panels) on campus. This will enable the battery to operate independently of fossil fuels and without requiring new infrastructure to be used specifically for charging the battery.

Background
The University purchases approximately 30% of the electricity it consumes from the grid because the energy supplied by campus infrastructure alone cannot meet the entire campus electricity demand.[2] The electricity is purchased from Berkshire Gas, which burns fossil fuels to generate power.[2] To reach carbon neutrality, the University must stop purchasing electricity from that company. Storing energy for later use when demands are high is one strategy for reducing purchases from the grid. The clear alternative is to use renewable energy generation techniques. Unfortunately, the amount of energy captured by renewable energy systems generally varies throughout the year, according to weather patterns. This poses the question: How can UMass store energy produced from renewable sources during peak production to distribute whenever needed?

Currently, the UMass operates one 4MWh Borrego lithium-ion battery. Plans are already set for implementing a second lithium-ion battery into the campus energy infrastructure within the next ten years.[2] However, several major drawbacks to using large-scale lithium-ion batteries for energy storage have been identified. These drawbacks include a lack of scalability, limited energy storage capacity, limited lifespan, severe safety risks, and the high societal cost through inhume mining practices. [3, 4, 5, 6]

Recommendations

Redox flow batteries are the best energy storage solution for the UMass campus needs due to its scalability, storage capacity, lifespan, and safety when compared to other solutions like the continued use of lithium-ion batteries.[3, 7, 8, 9, 10, 11] A specific example of the superior technology of a redox flow battery over a lithium-ion battery can be seen in its storage capacity capability. A vanadium redox flow battery has a theoretical energy density of 332 WhL^{-1}, whereas a lithium-ion battery only has a theoretical energy density of up to 223 WhL^{-1}.[8] This means that a vanadium redox flow battery can store more energy than a lithium-ion battery of the same size.

There are different liquid electrolytes used in redox flow batteries that are used to store energy. Two of the most common are iron-chromium and vanadium. The battery storage team is specifically recommending a vanadium redox flow battery because of larger commercialization and easier purchase accessibility over iron-chromium.

Alternative Technology

The battery storage team believes that if a vanadium redox flow battery is unable to be installed, another lithium-ion battery could be used. However, there must be major safety majors put in place in order to ensure the safety of the campus. There would also be significant drawbacks for how much energy the university could store and the university would have to buy another lithium-ion battery much sooner than if a redox flow battery is purchased.

Battery Limitations

The primary limitation of a redox flow battery in comparison to a lithium-ion battery is the material cost. [12] Vanadium is an expensive metal, and special containers and pumps are necessary to contain the fluids used in the redox flow battery. However, iron and chromium are more abundant and cheaper than vanadium, which could be a more competitive option than vanadium, when comparing costs with lithium-ion technology. It is also important to remember the storage capacity of a redox flow battery is higher than a lithium-ion battery, so a redox flow battery of comparable size would hold more charge than a lithium-ion battery. [8]

Conclusion

Overall, regardless of how UMass chooses to generate energy over the next ten years to power our campus, there is a clear need for a safe and large scale energy storage system that can quickly store and distribute its energy across campus during normal and peak demand times. The iCons 3E energy storage team believes that vanadium redox flow batteries are the best technology to fulfill this large demand. It is a clear alternative to current energy storage techniques that offers far greater scalability, energy storage capacity, lifespan, and safety measures. The only current drawbacks to the technology are cost due to high membrane costs and the mining of vanadium.

References

1) Thaller, L. (1976, December 7). Electrically rechargeable REDOX flow cell. Retrieved April 20, 2020, from https://ntrs.nasa.gov/search.jsp?R=19770007638
2) 'UMass Amherst Campus Master Plan' (2012): Available at: https://www.umass.edu/cp/master-plan
3) 'The Hazards of Lithium Batteries' In Case You Haven't 'HERD' About: A Newsletter of Tufts EHS Available at: https://viceprovost.tufts.edu//ehs/files/The-Hazards-of-Lithium-Batteries.pdf
4) "Lithium-Ion Battery." Clean Energy Institute, (2020), Available at: www.cei.washington.edu/education/science-of-solar/battery-technology/.
5) Notman, Nina. 'A Battery Technology Worth Its Salt.' Chemistry World, Chemistry World, 28 Oct. 2019 Available at: https://www.chemistryworld.com/features/a-battery-technology-worth-its-salt/3010966.article
6) Yang, Z. Gary. "Full Page Reload." *IEEE Spectrum: Technology, Engineering, and Science News*, 26 Oct. 2017, spectrum.ieee.org/green-tech/fuel-cells/its-big-and-longlived-and-it-wont-catch-fire-the-vanadium-redoxflow-battery.
7) Konig, Sebastian. *Model-Based Design and Optimization of Vanadium Redox Flow Batteries*. 19 July 2017, publikationen.bibliothek.kit.edu/1000070670/4285008.
8) Chen, Ruiyong, et al. "Redox Flow Batteries: Fundamentals and Applications." *IntechOpen*, IntechOpen, 6 Sept. 2017, www.intechopen.com/books/redox-principles-and-advanced-applications/redox-flow-batteries-fundamentals-and-applications.
9) Gantenbein, S.; Schönleber, M.; Weiss, M.; Ivers-Tiffée, E. Capacity Fade in Lithium-Ion Batteries and Cyclic Aging over Various State-of-Charge Ranges. *Sustainability* **2019**, *11*, 6697.
10) Conca, James. "Can Vanadium Flow Batteries Beat Li-Ion for Utility-Scale Storage?" *Energy Post*, 3 Sept. 2019, energypost.eu/can-vanadium-flow-batteries-beat-li-ion-for-utility-scale-storage/.
11) Skyllas-Kazacos, Maria, et al. "Off Campus Log in: UMass Amherst Libraries." *Off Campus Log in | UMass Amherst Libraries*, 13 June 2016, onlinelibrary-wiley-com.silk.library.umass.edu/doi/full/10.1002/cssc.201600102.
12) K Mongird, et al. "Energy Storage Technology and Cost Characterization Report" (2019) Available at: https://www.energy.gov/sites/prod/files/2019/07/f65/Storage%20Cost%20and%20Performance%20Characterization%20Report_Final.pdf