Military Power Sources Committee:
Information Paper on Li-S Batteries

Lithium Sulfur (Li-S) has been identified as one of the "Beyond Lithium-ion" chemistries. Beyond Lithium-ion is a group of technologies that are viewed as possible replacements for the lithium-ion (Li-ion) technologies currently in use. Li-S is a member of this group since it offers significantly higher capacity, is lighter weight, and inherently safer since the cathode does not contain oxygen. For the consumer this offers a significant increase in safety. For the military, it means less weight required to meet mission requirements. Lastly, sulfur is a cheaper and much more abundant element compared to the metals than are used in standard Li-ion chemistries. The U.S. has an excellent domestic supply chain for sulfur meaning the raw materials need not be sourced from foreign sources who may not be allies of the US.

In spite of the advantages list above, Li-S has some technical challenges to overcome before it can become commercially viable. These issues include short battery life due to polysulfide reactions and inability to suppress lithium dendrite formation. The MPSC hosted a workshop in June 2021 (www.forgenano.com/mpsc) to identify critical roadblocks to commercialization, including the stated issues and others, of Li-S as well as hear from government end users regarding the impact the chemistry would make for their energy storage requirements. The results of this forum served as the basis of this information paper which will be circulated within the NDIA and DoD communities.

The Problem

The U.S. was once a leader in advanced battery technologies, but this has slowly declined to where the U.S. is totally dependent on other countries for the design and production of state-of-the-art technologies. China not only dominates the production of most lithium-ion batteries, but they also control most of the supply chain. Notably, of the few cell producers that are in the U.S., all of them are currently reliant on China for materials, who vastly leads the world in production of battery-grade graphite used for anodes in nearly all Li-ion batteries. Development of a viable, high performance cell chemistry that does not contain graphite would help reduce this imbalance.

Developing a domestic supply chain and production capacity for commercial batteries based on use of standard Li-ion battery chemistries that is competitive with Chinese production capacity is highly unlikely and would be prohibitively expensive due to the overwhelming competitive advantage of China. The alternative is to invest in Beyond Li-ion technologies where new, high-performance chemistries are employed that use materials in which the Chinese are not in control of the supply chain. Li-S chemistry meets these requirements.

In spite of its impressive theoretical performance, Li-S has not yet reached the maturity level where it can be successfully commercialized. Factors limiting the performance of this chemistry include polysulfide solubility, volumetric expansion of the cathode during discharge, Li dendrite formation leading to cell shorting, Li passivation causing capacity reduction during cycle life, and unstable solid electrolyte interphases (SEI) reducing lifetime. The workshop identified that all of these issues can be solved with dedicated R&D funding. Utilizing both academic and commercial expertise, Li-S can be developed such that it provides the U.S. with a "world class" battery chemistry which would restore leadership in advanced energy storage.

The Solution

One of the most practical solutions to overcome the Chinese competitive advantage would be to **not** compete in these technologies but leapfrog to Beyond Li-ion. By investing in Beyond Li-ion, and in particular Li-S, the US would surpass current energy storage leaders. If the US could achieve alignment between policies and resources, regarding energy storage, benefits would include achieving batteries with:

- Lower weight and volume batteries compared to Li-ion, providing a tactical advantage to warfighters
- An abundance of raw materials, removing entirely supply chain risk to the US for energy storage
- Environmentally friendly material having no heavy metals
- An estimated 50% cost reduction
- Significantly improved safety with no oxygen in the cathode

Implementing the Solution

In order to become a commercially relevant chemistry, Li-S must achieve at least 350 Wh/kg and 500 cycles. To achieve the required performance, advances in the following areas must be made:

- Increased electrical conductivity of the cathode to improve rate capability
- Cathodes with a structure that retains polysulfide species
- Improved material interfaces to prevent polysulfide poisoning of the anode and keep cell resistance low
- Reducing the electrolyte to sulfur ratio while maintaining high capacity and cycle life
- Improved reversibility of Li-metal anodes
- Development of high-performance solid-state electrolytes

To accelerate the R&D timelines and achieve faster commercial implementation a higher degree of nation-wide participation must be achieved. Instead of the leading groups working individually a consortium of private companies, academia, government representatives and/potential funding sources (e.g. venture capitalists) must be formed and incentivize with the mandate to:

- Share information
- Establish a unified strategy with quantifiable success metrics
- Recommend funding levels and where/how the funding should be invested so as to establish multiple domestic sources of supply development with a clear path from R&D to production without going overseas

We believe that some of the funding being proposed to develop advanced batteries to meet the Administration's goal of 100% clean electricity by 2035 should be dedicated to R&D on Li-S technologies. We also recommend that a Li-S subgroup be part of the Federal Consortium on Advanced Batteries (FCAB), to assure that all relevant information is shared among those companies developing this technology and their input can be used towards the commercialization of the technology.

About the MPSC

The Military Power Sources Committee (MPSC) is comprised of companies, academia and government organizations who do R&D, advanced design and production to provide the DoD and other government agencies state of the art energy storage and generation devices. The Military Power Sources Committee (MPSC), is chartered by the National Defense Industrial Association and has close ties with which consists of organizations that design, develop, and manufacture power sources, for the Department of NATTBatt and the Battery Materials Technology Coalition (BMTC). The mission of the MPSC is to provide an open forum by which the membership can exchange information, challenges and issues and provide a collective voice on issues of concern to its members.

The MPSC, believes strongly that the U.S. requires a robust, domestic energy supply chain, especially as it pertains to Beyond Li Ion batteries, and that the U.S. must invest in domestic materials and manufacturing technologies to ensure continued, uninterrupted prosperity.

For more information about the committee and our activities, please contact James Trevey at jtrevey@forgenano.com. or Marc Gietter at sagelyconsultant@gmail.com. Whether you agree or disagree, provide us feedback so we continue to refine our goals as we pursue them since future U.S. dominance in advanced battery technologies benefits all of us.