Safe, Inexpensive and Very High-Power Batteries for Use to Reduce Short-Term Transients on the Electric Grid

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Objective
The goal is to develop new materials for fast, safe, long-life and inexpensive batteries that address energy storage problems resulting from the integration of intermittent wind and solar systems on the electrical grid. The research will focus on a new family of electrode materials and hybrid-ion aqueous electrolytes.

Background
Utility-scale storage technologies are too expensive for high-energy, cost-sensitive applications. Small lithium-ion cells have many costly components, including separators, electrode materials, and electrolyte solvents and salts. The same holds true for larger Li-ion devices and systems. While the cycle life of Li-ion batteries may be sufficient for consumer devices, the technology is inadequate for the large-scale integration of alternate energy sources, such as solar and wind power, to the electrical grid. Batteries produced for cell phones, digital cameras and laptop computers are generally designed to undergo 500 discharge cycles and to last for three to five years. Those intended for vehicle use are expected to undergo one discharge per day for 10 years, approximately 3,600 cycles. For solar and wind applications, battery systems must perform at least 10,000 cycles. Moreover, the output from solar and wind sources can be especially sporadic.

It has been found from evaluating the deterioration of the capacity of lithium-ion cells under cycling conditions (at relatively low rates) that calendar life is just as important as the number of charge/discharge cycles. This result is due to 1) parasitic reactions, 2) the loss of oxygen from the positive electrode which causes oxidation of the electrolyte, and 3) the formation of the solid electrolyte interphase layer which consumes lithium on the negative electrode. Conversely, high rate charging is especially deleterious because it causes a loss of useful lithium by local lithium metal plating on the graphite negative electrode surface. Safety is a particular problem when using high voltage cathodes in organic electrolytes. They tend to give off oxygen, which can react with the adjacent highly reducing organic electrolyte to cause overheating, and in extreme cases, thermal runaway.

Approach
The research approach proposed addresses the safety issues, involves significantly less expensive components, and will result in cells that operate at higher power and have much greater cycle life than is possible with other current alternatives.

This program will involve three major activities:
1. The use of a new family of electrode materials with truly remarkable properties; one example has already shown that it can be charged and discharged at unusually high rates, and that it has much better capacity retention and cycle life than any other known battery electrode material.
2. The use of modified aqueous electrolytes with extended voltage stability ranges.
3. Use of hybrid-ion electrolytes to enable the use of a wider range of possible electrode materials than is possible in other electrochemical cells.
One particular electrode material will be closely evaluated whose crystal structure has the general formula $A_xPR(CN)_6$. These are stiff metal-organic framework structures through which a number of different hydrated alkali metal cations ($Na^+$, $K^+$, and $NH_4^+$) can readily move in and out of the $A$-type sites (Figure 1). The well-known, safe and widely used dyestuff commonly called Prussian Blue, nominally $KFe^{3+}Fe^{2+}(CN)_6$, which also contains zeolitic water, is the prototype material for this crystal structure, and its physical and thermodynamic properties are also well established. This material alone has shown small voltages and modest cycle life, however analogous materials such as $K_xCuFe(CN)_6$ have shown much more favorable and promising results.

Figure 1