US ARMY RDECOM

U.S. Army Research, Development and Engineering Command

Electrolytes in Support of 5V Li-ion Batteries

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Inventors: Drs. Kang Xu and Arthur von Wald Cresce

This ground breaking invention enables Li-ion batteries to operate at high voltage (5V), which is impossible with current state-of-art electrolytes.

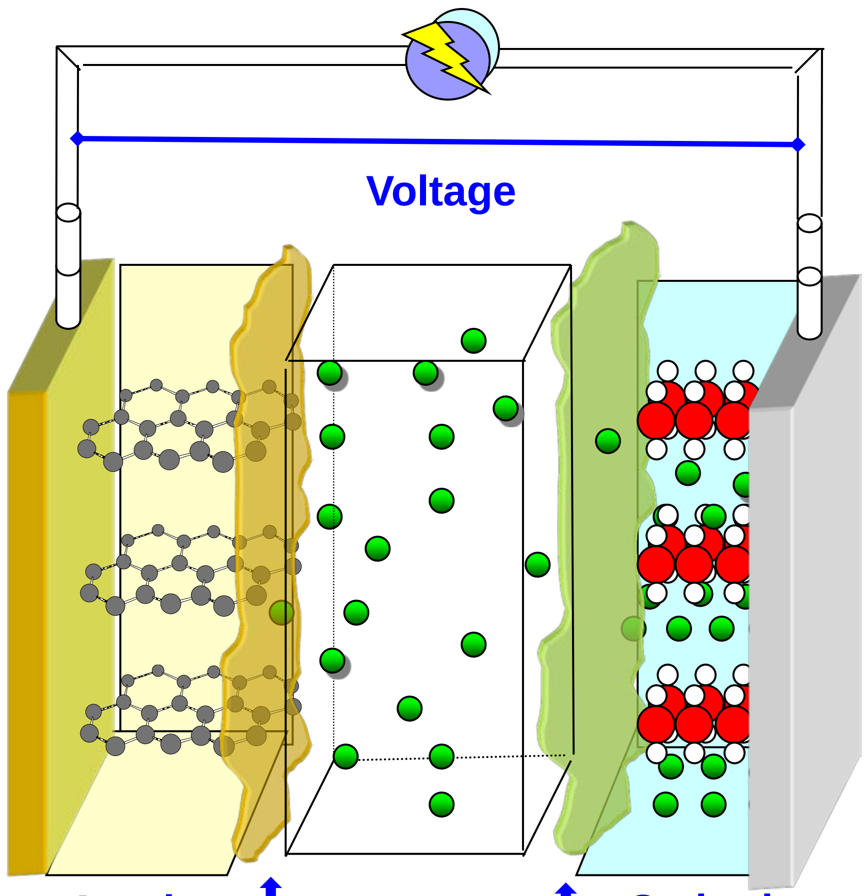
- There is a strong commercial interest in high voltage, or “5V” Li ion batteries
- Various candidates $LiCoPO_4$, $LiNi_{0.5}Mn_{1.5}O_4$, $Li_2FeCoPO_4$ etc, projected to deliver 15~40% more energy than state-of-art $LiFePO_4$

The additive invented by SEDD is easy to prepare, low in cost and causes minimum impact on the existing battery manufacturing processing

The electrolyte formulated is an open and flexible system that is compatible with multiple cathode chemistries

- Demo’ed on $LiCoPO_4$ in a previous presentation
- Now on spinel systems

Energy = Voltage X Capacity (Wh)



Why 5 V is important

Answer: (1) Energy Density

- Energy is proportional to voltage and capacity

(2) Energy quality (voltage quality)

- Higher quality when energy delivered at higher voltage

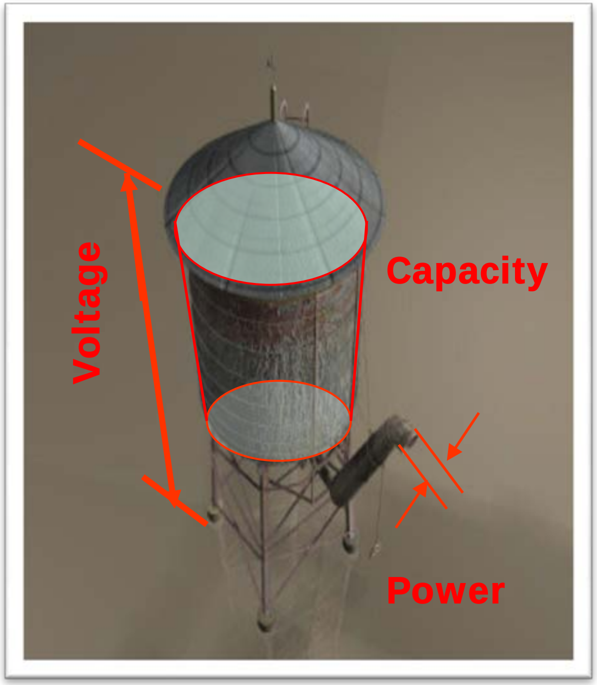
The current SOA Li Ion battery chemistries runs on 4 V class cathodes

"5 V" chemistry is coveted because of two factors:

- Energy density: proportional to voltage
- Energy quality: higher quality when delivered at higher voltage

Take a battery pack for HEV as example: 300 V hybrid electric system

- requires at least 100 $LiFePO_4$ Li ion cells in series
  - power electronics, protection circuits etc adds to parasitic weight
  - safety concerns about probability of "imbalanced" cells
- only ~60$LiNi_{0.5}Mn_{1.5}O_4$ cells needed to be in series



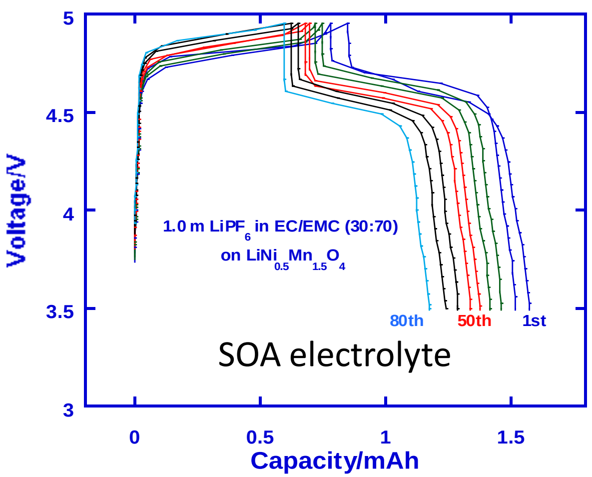
Energy = Voltage X Capacity (Wh)

Technology Overview

This innovation includes a series of new additive compounds based on phosphate ester with highly fluorinated alkyl side arms

SOA electrolyte cannot support "5V" chemistry
- Cell impedance increasing with cycling
- Rapidly fading capacity

SOA electrolyte with 1% HFiP presence dramatically improved stability
- Flexible with different cathode chemistry
- As demo'ed with $LiCoPO_4$ (4.8 V) in previous presentation
- Here with $LiNi_{0.5}Mn_{1.5}O_4$ (4.6 V)
- Cell impedance stabilized over long cycling
- Capacity retention > 90% at 300th cycle



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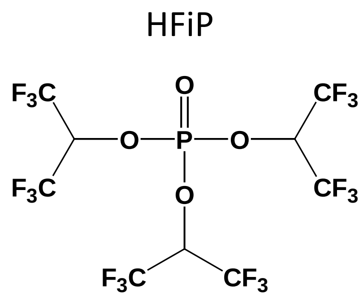

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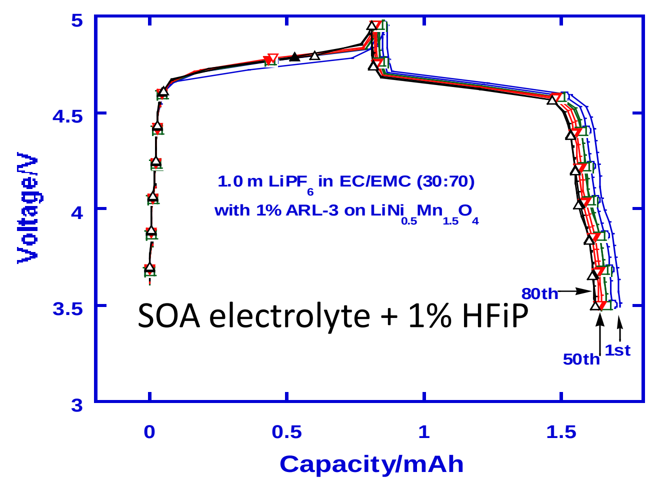

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Technology Advantages

The "5V" Li ion cathode needs a "5V" electrolyte

- Potentially up to 40% greater energy density than $LiFePO_4$
- Higher voltage at cell level may reduce number of cells required for application

This additive provides a simple but effective way for such a "5V" electrolyte

- Dramatically improves capacity retention
- Significantly reduces cell impedance
- Effectively stabilizes electrolyte against high voltage (5V) and high temperature (55 ^{o}C)

Easy and inexpensive method to prepare

- Two-step synthesis, high yield
- Easy purification

Potential flame-retardant serves as safety advantage over state-of-art electrolytes

- It was well-established that phosphate-esters are effective flame-retardants

Technology Differentiation

A BB2590, the current Soldier rechargeable battery, constructed with this cathode material has a projected energy density of about 170 Wh/kg relative to current specifications of about 120 Wh/kg.

What problem will it solve?

- A Soldier currently is required to carry 50 lbs of batteries. This technology could reduce the overall weight by about 20 lbs allowing to soldier to carry other essential equipment.
- Current military vehicles consume immense quantities of fossil fuels. Cost to bring fuel forward to the battlefield is enormous in terms of dollars. Hybrid electric vehicles based on this technology will consume less fuel.

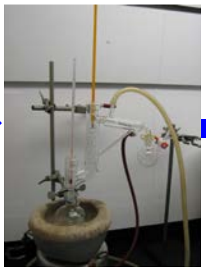
Military Battery BB2590

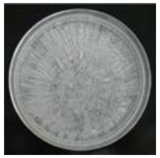
Charge Station for BB2590 Li Ion Batteries

Technology Proof of Concept

Method of preparation of these novel additives

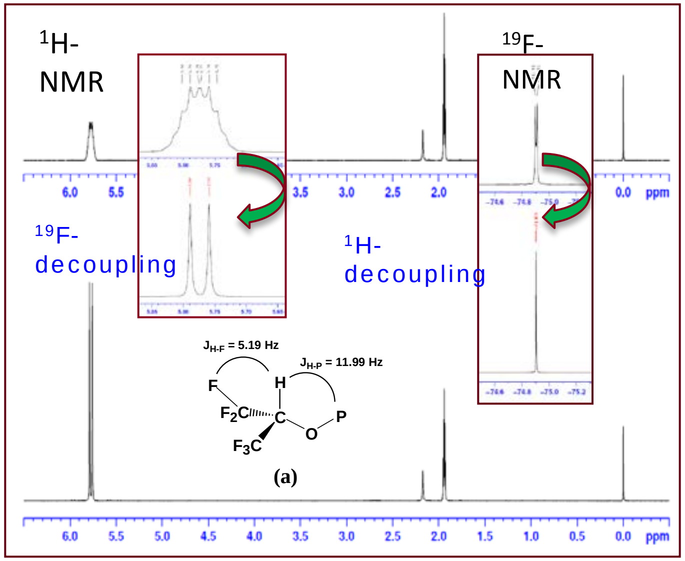
Reaction in organic media





Purification

Coin cells assembled using cathode materials provided by partners



Structural characterization

Current TRL: 5

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Military Applications

Battery is the most expensive logistic component second only to ammunitions

– In 2009 ~$263 millionmarket
– Lessen the burden of Soldier: power-hungry electronics
  - Soldier power for a longer life rechargeable Li-ion, e.g., BB-2590
  - 50 lbs reduced by 20 lbs.
– Lessen the logistic burden: vulnerable transport convoy
  - Military hybrid electric vehicle applications to reduce fuel consumption and reduce the need for dangerous logistical refueling operations

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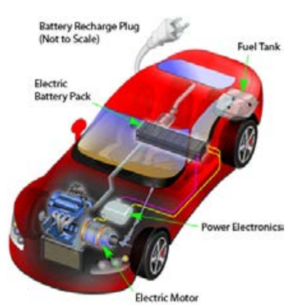
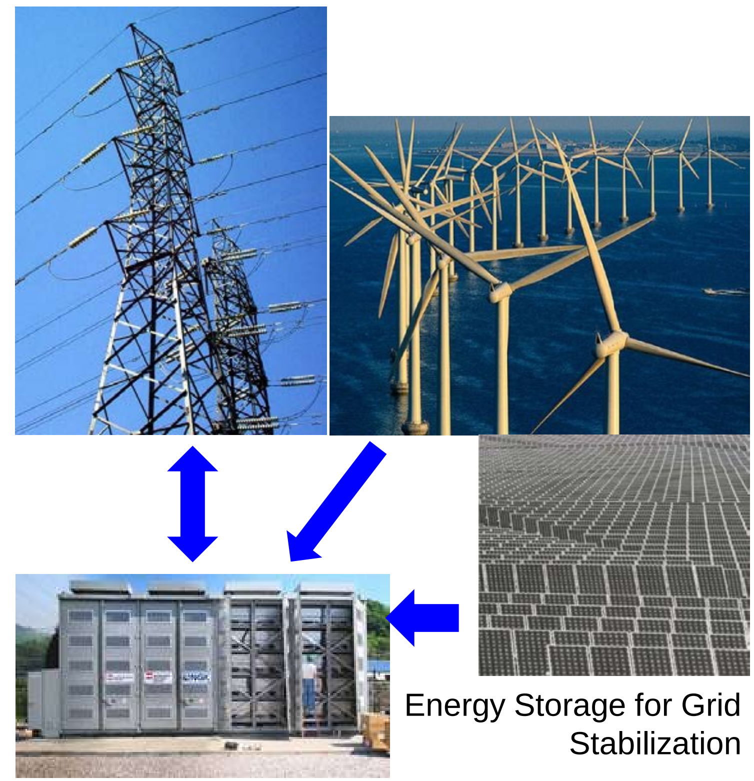
Commercial Applications

- Three major markets
  - Electric Vehicle, Hybrid Electric Vehicle
  - Consumer Electronics
  - Large scale stationary energy storage
- Projected By 2015 (Sanyo estimate)*:
  - $18 Billion in Automotive applications
  - $18 Billion in Consumer electronics
  - $24 Billion in Large scale stationary energy storage

Consumer Electronics



Electrified Vehicular Power Systems



Energy Storage for Grid Stabilization

Technology Agreements

A patent license and CRADA is sought.

The current technology is TRL 5 and will benefit from a collaboration between the inventor team and the commercialization partner in order to speed the development to the market.

– This would most readily be done through a license agreement/CRADA.

• A patent application has been filed.