Safe, High-Energy-Density, Solid-State Li-Batteries

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Overcoming the performance limitations to enable a new generation of safe, high-energy-density, solid-state Li-batteries

Total project cost: $4.7M
Length: 48 mo.
**Concept - Overcome Solid State Battery Limitations**

Utilize non-flammable, high-conductivity, high-voltage-stability, ceramic electrolytes to achieve safer, higher energy-density, Li-metal solid-state batteries.

Surface modification overcame interfacial impedance.

Novel 3D architecture supports thin dense central separator layer with low ASR that blocks Li dendrites.

Porous outer layers infiltrated with electrodes provide large electrolyte/electrode interfacial area, and pore filling mechanism removes external cell dimensional changes upon cycling.
Team

Eric D. Wachsman & Liangbing Hu
Expertise: Solid ion conducting materials, electrochemistry, and ceramics
Role: project management and materials, structures, and cell development

Eric D. Wachsman, Greg Hitz, Alireza Pesaran, Patrick Stanley
Expertise: Solid ion conducting ceramics
Role: Ceramic and cell scale-up and commercialization

Venkataraman Thangadurai
Expertise: Solid ion conducting ceramics - inventor of garnet electrolytes
Role: Research garnet properties and stability

Mike Hill
Expertise: Ceramic synthesis and fabrication
Role: Scale-up commercial ceramic fabrication processes
Results - High Rate Li-Metal Cycling

Adapted from:

Status and challenges in enabling the lithium metal electrode for high-energy and low-cost rechargeable batteries

Achieved IONICS and DOE VTO Fast-Charge goals for current density

Achieved area specific resistance far below conventional batteries
Results - High Energy Density Batteries

Li$_{metal}$/garnet structure provides transformative battery solution for wide range of cathode chemistries with high efficiency & stable cycle life

High Voltage Spinel Cathode

- ~99% Coulombic efficiency and no capacity fade for 480 cycles

Li-NMC Battery

- ~300 Wh/kg and ~99% Coulombic efficiency with no capacity fade for 30 cycles

Li-S Battery

- ~300 Wh/kg and ~99% Coulombic efficiency with no capacity fade for 300 cycles
Results - High Temperature Capability and Safety

Wide operating temperature range with low activation energy

• Energy Density based on **Total Cell Mass**
• Significant increase in energy density with increasing temperature
• $350\text{Wh/kg}_{\text{total cell}}$ achieved at 90°C
• Dramatically reduces cost, complexity, mass & volume requirements of current battery technology

Even higher temperature capability demonstrated with certain cathode chemistries

Safe operation even after cutting open and exposing to air

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**Figure:**

- **Before Heating**
- **Flame Heating**
- **After Heating**

**Graph:**

- Energy Density (Wh/kg) vs. Temperature (°C)
- Data points at -10°C, 25°C, 60°C, 90°C

**Images:**

- All-in-one Li-S Cell
- Cut-open Pouch Cell
- After 48 Hours
Challenges - Scale-up and QC

Tape casting is a highly scaleable, low-cost, conventional ceramic fabrication technique without dry room.

Challenge is scaling from small coin cells to reproducible, flat, 30 cm² full format garnets.

With desired trilayer microstructure and no pinholes.

Achieved by extensive process characterization and development.
Cells are stacked in series with metal current collectors to achieve desired battery pack voltage depending on market needs.

Defense/Aerospace - Early adopter multiple formats
Consumer Electronics - 4V Rigid pack ~1 mm thick
Electric Vehicle - 100V Rigid pack ~1 cm thick

Markets

Finalized initial investment round, in discussion with strategic partners in each of these markets
Setting up pilot-line and developing 1st product