AVAILABLE FOR LICENSING

HIGH ENERGY- HIGH VOLTAGE BATTERY MATERIALS

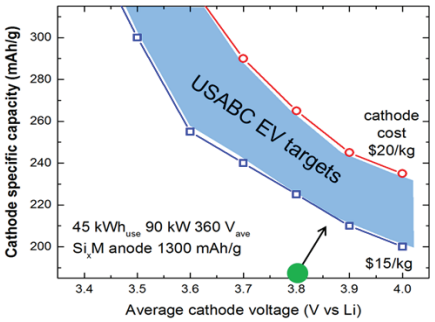
This IP bundle combines the expertise in battery technology research from Argonne, Lawrence Berkeley, and Oak Ridge National Laboratories. The emphasis is on novel materials that will yield high voltage, high energy batteries.

TECHNICAL ADVANCES Current cathodes perform at approximately 150–180 mAh/g at 3.5–3.8 V (Li) giving <700 Wh/kg oxide energy. Some of the USABC targets for 2020 are a sales price of $125/kWh (system) or $100/kWh (cell) with a cycle life of 1000 cycles and calendar life of 15 years.

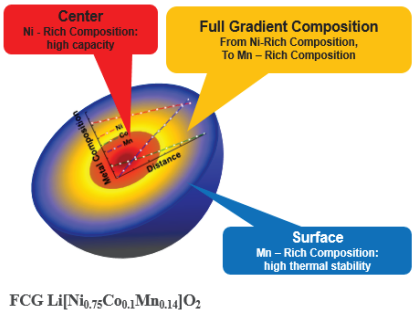
Two classes of cathode materials show promise to achieve these targets:

1. Ni-rich NMC — if paired with advanced anode (e.g., Si based). Higher voltages need to be pushed to increase capacity. However, this causes surface reactions between Ni and the electrolyte. This technology can be expensive — relies on the use of LiOH. Advanced anodes have challenges — 1st cycle irreversible capacity loss
2. LiMn-rich composite cathode — high enough energy to meet the targets, operating at a reasonable voltage range. These cathodes can use existing electrolytes, they are safe, and Mn is cheaper than Ni. However, LiMn-rich structures face challenges such as voltage fade
   - Advanced cathode — Cathode material having an alkaline source for improved specific capacity, energy density, cycle life and stability for rechargeable batteries.
   - Continuous Gradient Cathode Materials achieve a high energy density of 250 Wh/kg by protecting a Ni-rich center with a Mn-rich surface which provides thermal stability. Argonne holds a patented process to enable this technology for higher energy cathodes for Li- ion batteries.
   - Advanced additives — Lithium ion battery incorporating heat-treated carbon black that limits the reactivity of the carbon black and electrolyte.
   - High voltage electrolytes — High voltage lithium ion battery with fluorinated electrolytes and lithium additive have improved performance at high temperature and voltage.

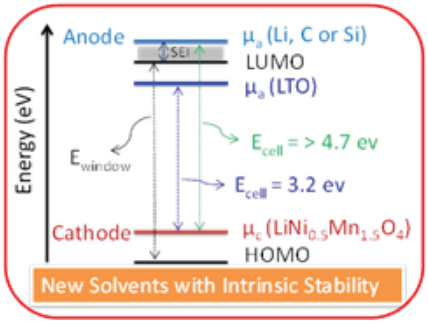
REFERENCES Frost & Sullivan. *"Analysis of the Global Lithium-ion Battery Market."* Accessed February 24, 2017. http://www.frost .com.



Current state of the art performance of Li-ion batteries and USABC targets



Full concentration gradient particle- one approach to solving the instability problems of Ni-rich cathodes



High voltage batteries require high voltage stable electrolytes

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MOTIVATION, CHALLENGE, AND OPPORTUNITY Demand for Li-ion batteries continues to grow in different applications. This IP bundle includes valuable strategies and novel materials for improved battery technologies. In addition, industry leaders will have the opportunity to leverage the expertise from three National Labs, through one standard and convenient agreement.

INTELLECTUAL PROPERTY INCLUDED IN THIS BUNDLE

TECHNOLOGY	NUMBER
Electroactive materials for rechargeable batteries	US20140212755
Lithium ion battery incorporating heat-treated carbon black that limits the reactivity of the carbon black and electrolyte	US9368798
Cathode material having an alkaline source for improved specific capacity, energy density, cycle life and stability for rechargeable batteries including, but not limited to Li-S	US9012091
Lithium phosphorus oxynitride protective layer of coating between the cathode and electrolyte to allow Li-ion operation at high temperature and high voltage	US20140106186
Electrolyte solvent enabling high temperature operation of Li-ion battery	US9005822
Non- aqueous electrolyte solution preventing solid electrolyte interface films on carbonaceous electrodes for improved performance	US9246187
High voltage lithium ion battery with fluorinated electrolytes and lithium additive for improved performance at high temperature and voltage	US20150050561
Electrolyte comprising of lithium hexafluorophosphate for high voltage applications providing longer life stability and better cycling performance	US20160099484