

NOHMs Update on Advanced Safety Ionic Liquid Electrolytes

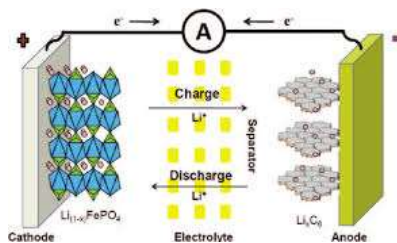
NAATBatt International Annual Meeting & Conference
March 2019

Paul Homburger, VP Business Development

Battery Technology Drivers: EV Customers

Safety (**Essential**): Prevent/Contain Fires

- Rugged battery module, pack, and car design (increases cost)
- Cell that does not undergo thermal runaway in a crash (**impossible** with today's electrolyte)



Affordable Price: Reduced Costs & Advanced Chemistries

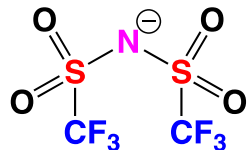
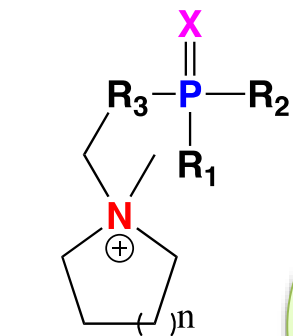
- Improve energy density with high capacity anode materials (Silicon or Lithium)
- Reduce Cobalt in cathode materials (high nickel or high voltage cathodes)
- Simplify battery design (heavily influenced by safety)

Convenience: Fast Charging

- Reduce electrolyte internal resistance
- Reduce/control amount of heat generation in fast charging

Significant alignment in the industry how to address these issues in just the past 18 months, but competitive electrolyte solutions remain elusive!

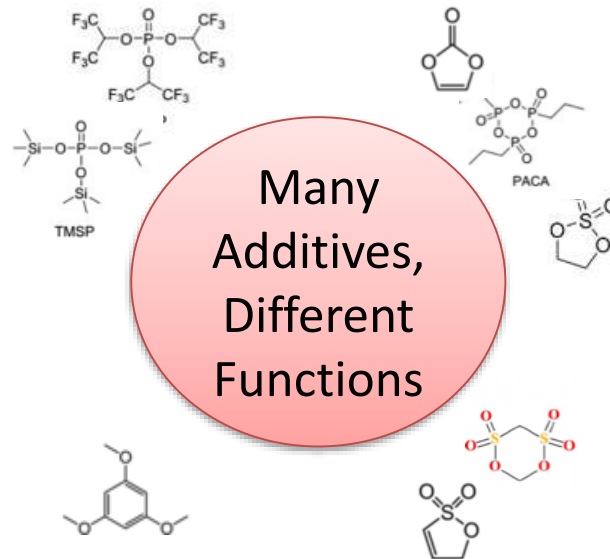
Unique Approach to Advanced Electrolyte Formulation



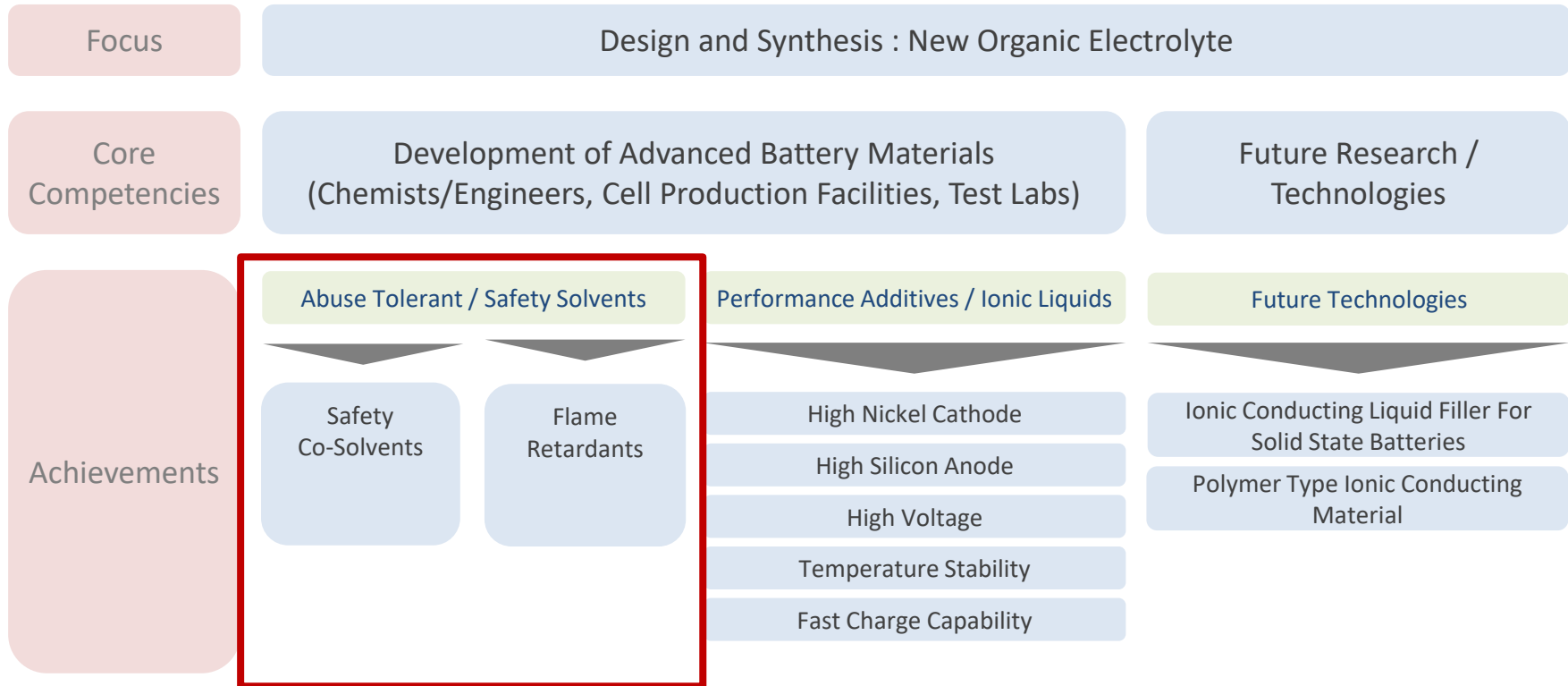
One Ionic
Liquid,
Many
Functions

Replacing

Many
Additives,
Different
Functions



NOHMs' Next Generation Liquid Electrolyte



Let's Look At Safety Aspects

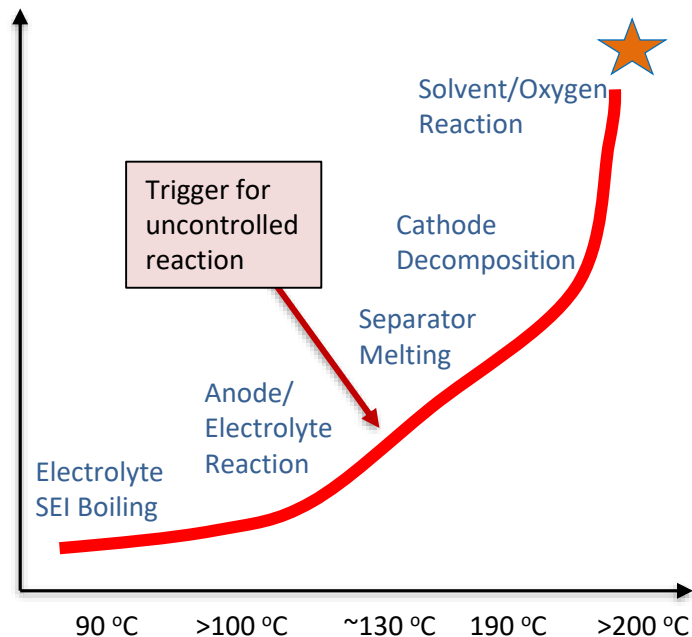
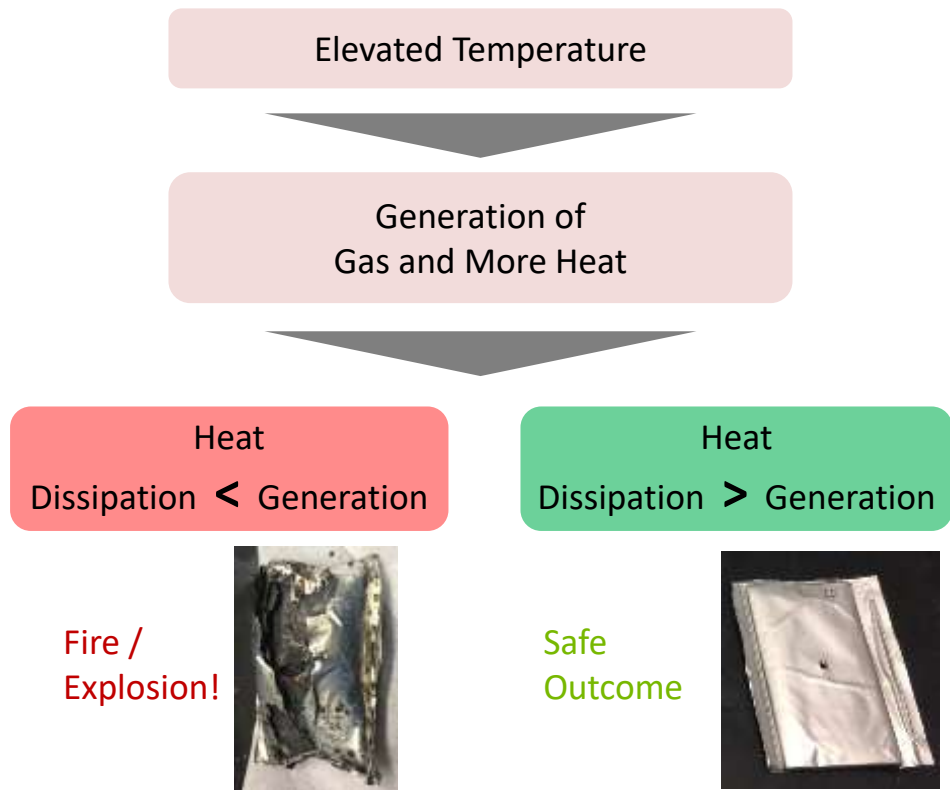
Safety

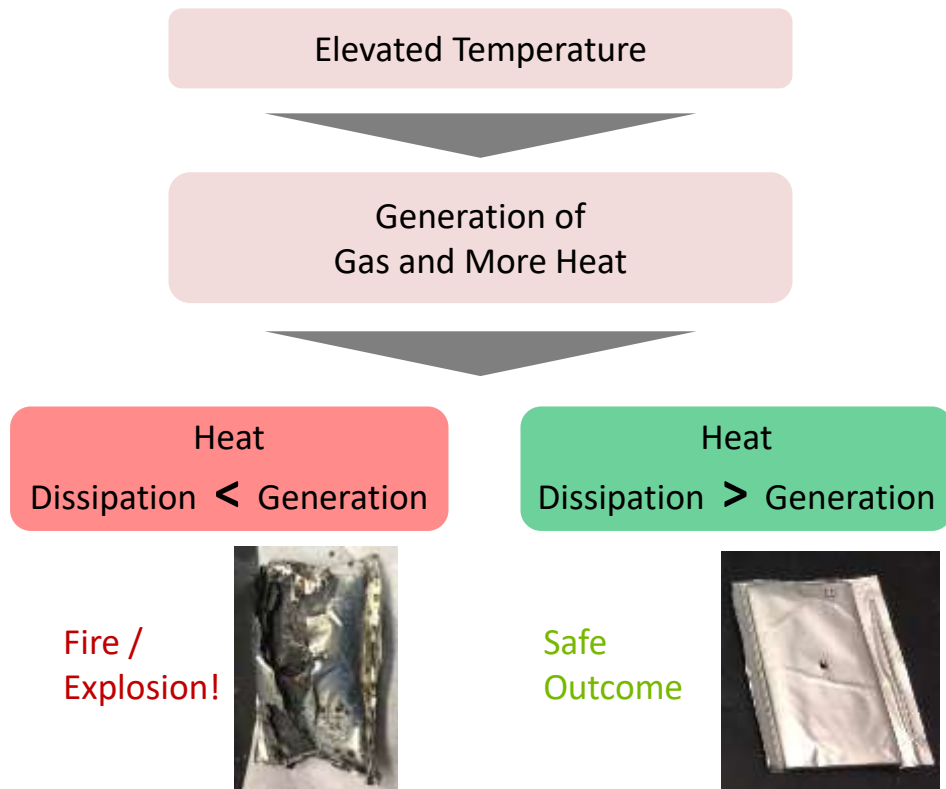
- Liquid Electrolyte is Explosive
- Higher Energy Density Requirements Imply More Energy to Dissipate in an “Event”

- NMC811 Represents Next Generation For the Automotive Industry
- NMC811 Safety Is Critical to Solve
 - OEM **Liability** Reduction
 - OEM **Reputation** Protection
 - **Consumer Perception** Of EVs
 - 1 Tesla Burning is Big News
 - 470 ICE's that burn / day in the US is “simply a traffic jam” (FEMA 2016 data)



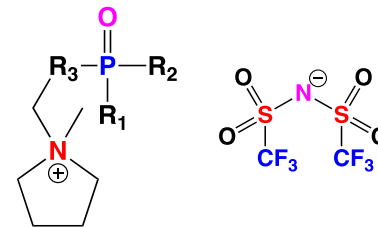
Preventing Thermal Runaway





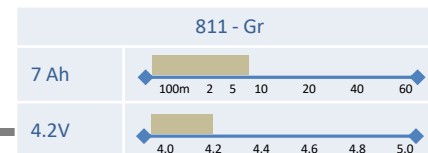
Molecular engineering of molecules that absorb heat during thermal runaway reactions:

- **Slow down** the self heating rate
- **Delay** thermal runaway onset
- **Reduce** the heat release from the cathode

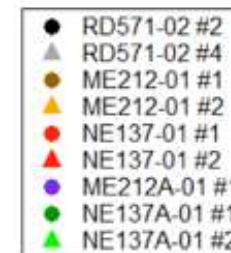
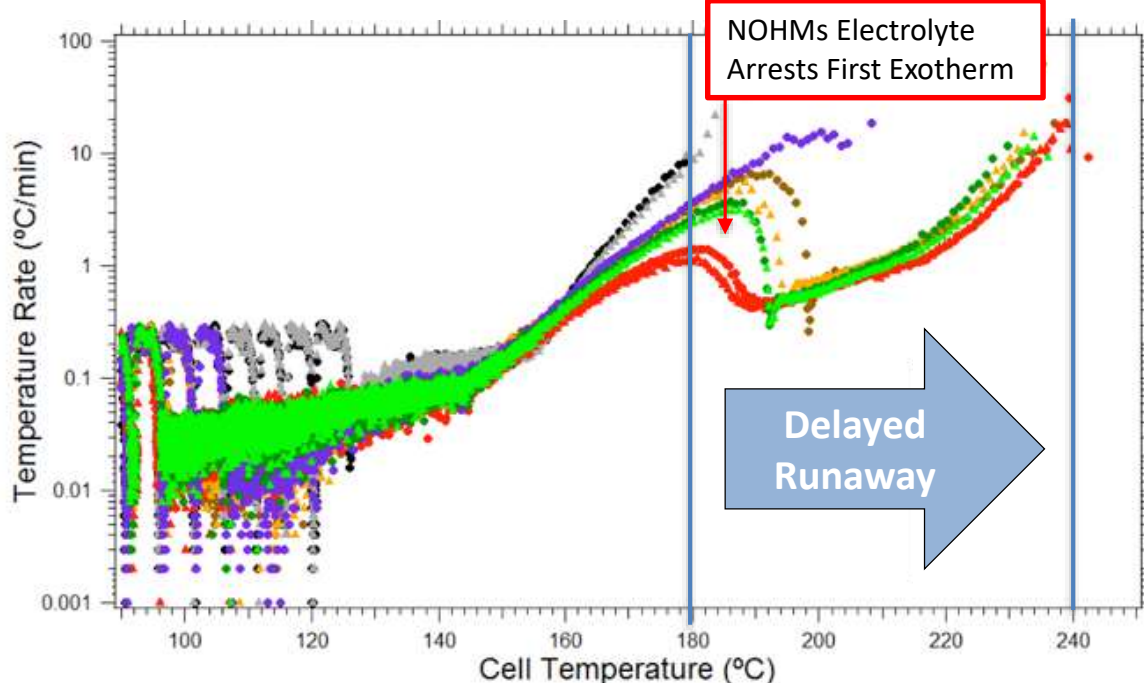


Phosphorus - Key Element for Safety

NOHMs Achievement: Safe Solvent

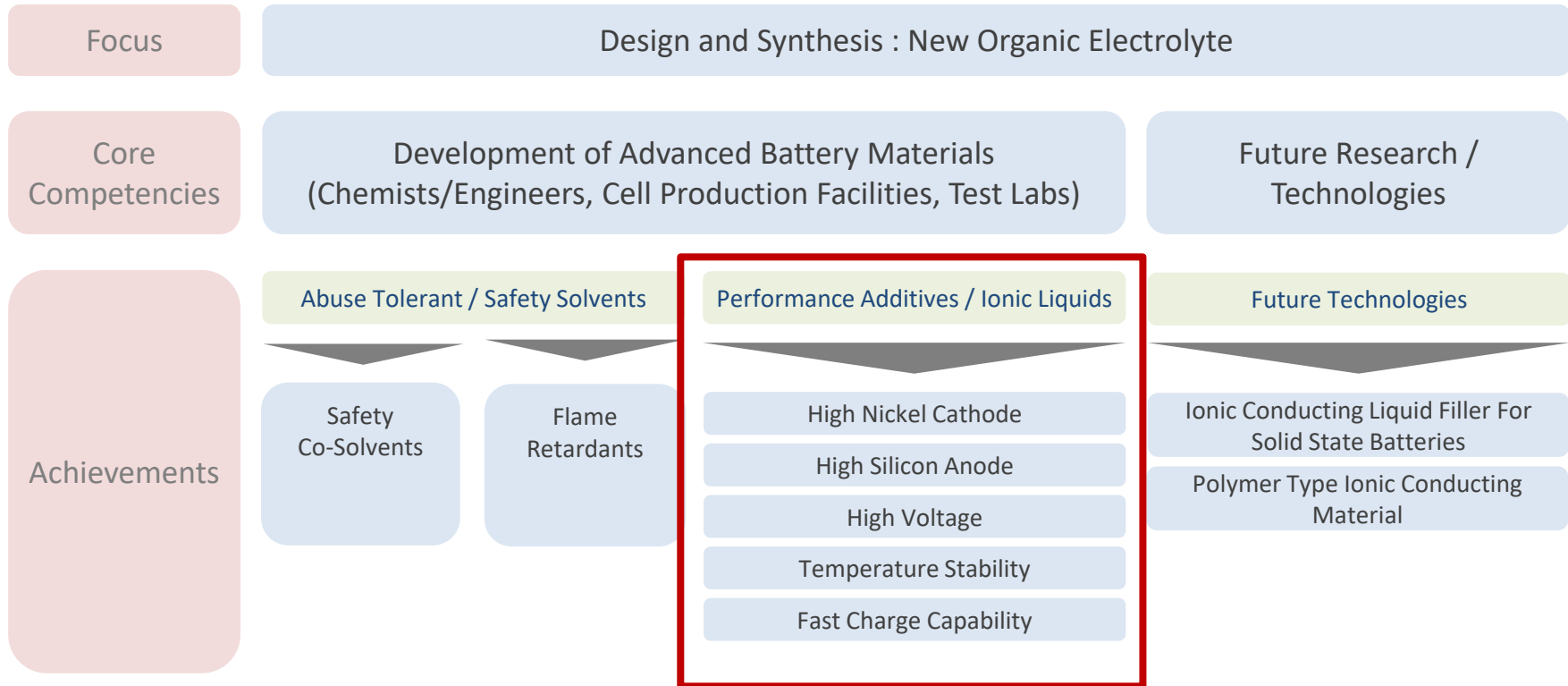


7 Ah NMC811-Gr: ARC Results- "HWS test"



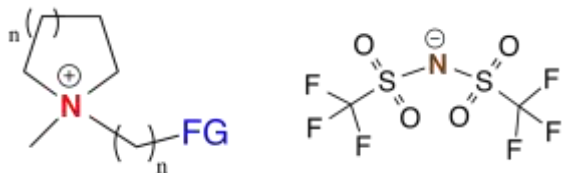
Electrolyte Name	Formulation
Baseline/RD571	EC/EMC 1MLiPF ₆ 2%VC
ME212	EC/EMC (15% IL)
ME212 (A)	EC/EMC (10% IL)
ME212 (B)	EC/EMC (7.5% IL)
NE137 (A)	EC/PP (10% IL)
NE137 (B)	EC/PP (7.5% IL)

NOHMs' Next Generation Liquid Electrolyte

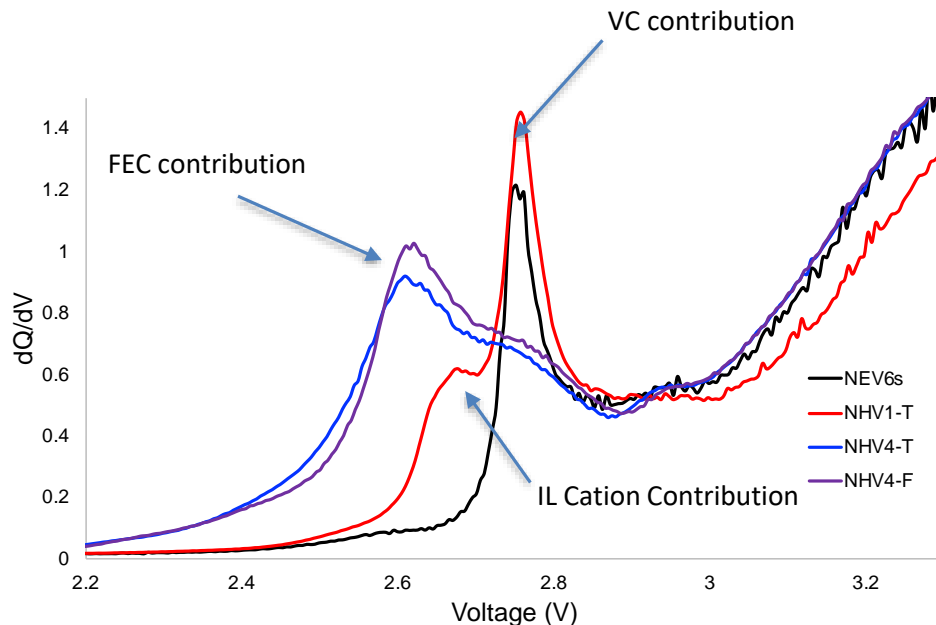


NOHMs Additive for “High Nickel” Electrolyte

Performance Additive™ Ionic Liquid

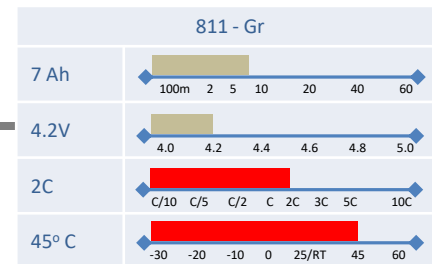


- SEI forming additive (1% in electrolyte)
- Improve Cycle Life at High Temperature Extremes
- Improves Fast Charging at Low Temperatures
- Solves FEC High Temp Challenge

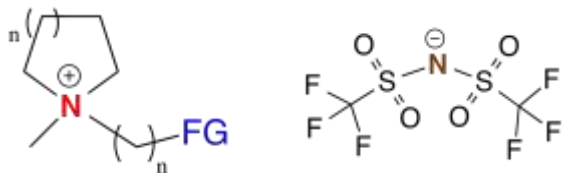


- dQ/dV plots show how different additives interact during formation
- In general multiple peaks indicate complex SEI
- Lower voltage peaks may provide insights into differences of reaction products

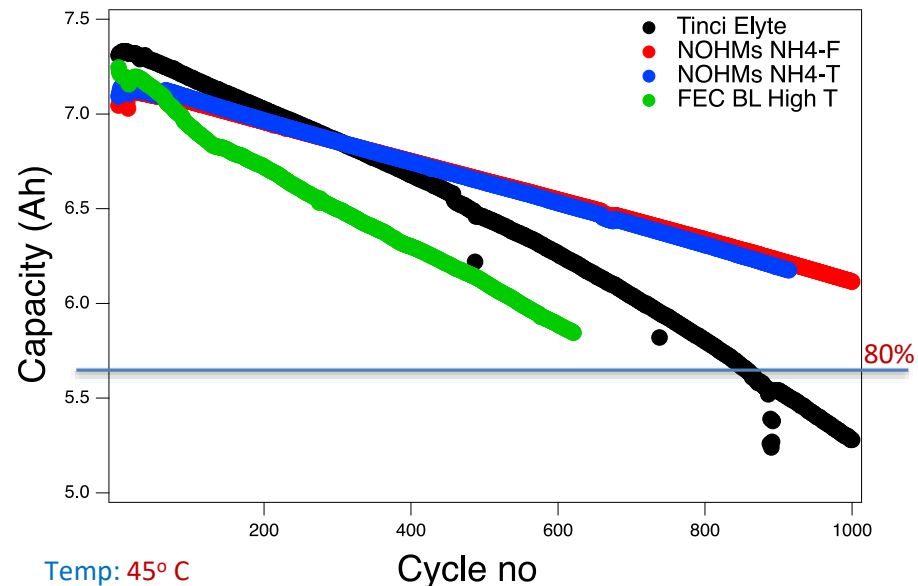
NOHMs “High Nickel” Electrolyte



Performance Additive™ Ionic Liquid

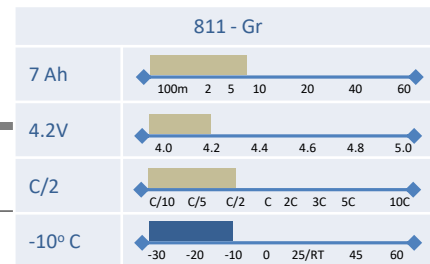


- SEI forming additive (1% in electrolyte)
- **Improve Cycle Life at High Temperature Extremes**
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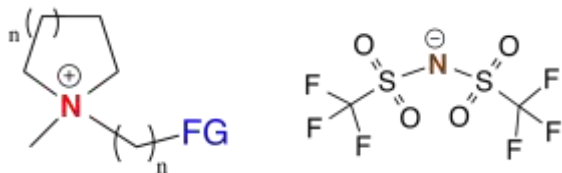


Temp: 45° C
C-Rate: 2C
4.2 to 2.7V

NOHMs “High Nickel” Electrolyte Additive

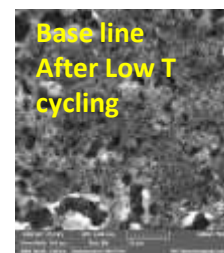
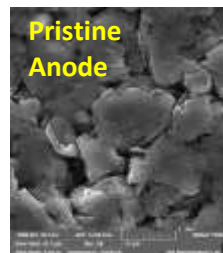
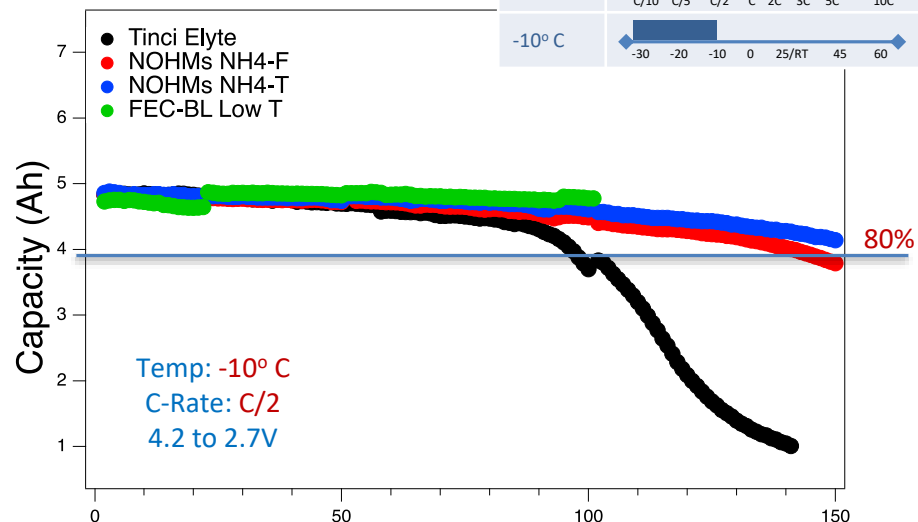


Performance Additive™ Ionic Liquid



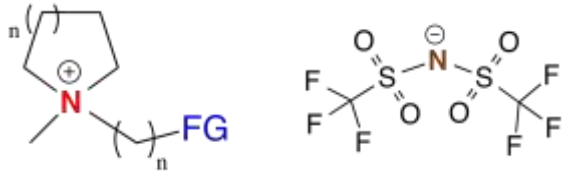
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- Improve Cycle Life at High Temperature Extremes
- **Improves Fast Charging at Low Temperatures**
- Solves FEC High Temp Challenge

- Base line electrolyte showed Li dendrites at -10 °C cycling
- Addition of NOHMs IL increased low temp cycle life to 5x
- Robust NOHMs SEI is Responsible for Low T Performance



NOHMs Additive for “High Nickel” Electrolyte

Performance Additive™ Ionic Liquid

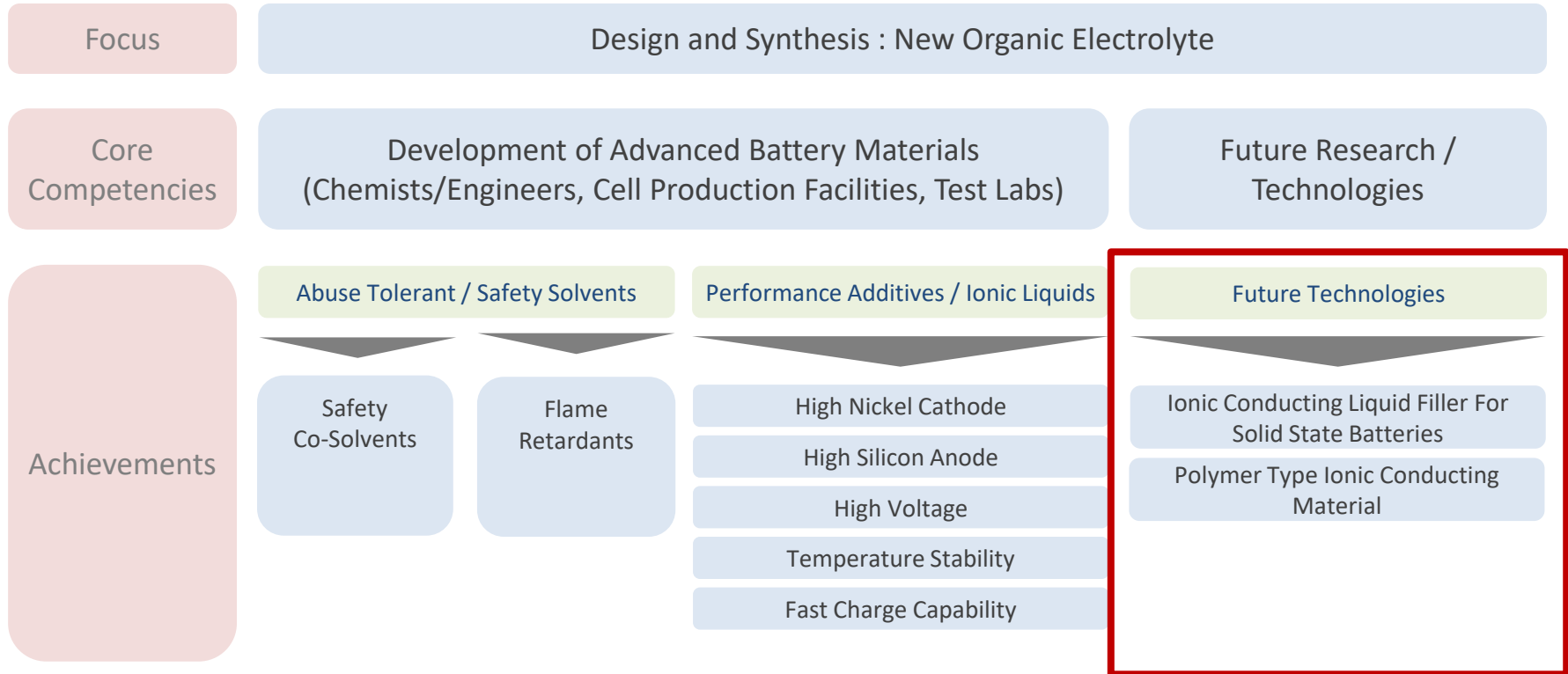


- SEI forming additive (1% in electrolyte)
- Improve Cycle Life at High Temperature Extremes
- Improves Fast Charging at Low Temperatures
- **Solves FEC High Temp Challenge**

High Temperature Storage:
FEC Alone Expands > 50%



NOHMs' Next Generation Liquid Electrolyte



Bridging To Future Technology

2020



2030+

Cathode	High Cobalt (111, 532, 622)
Anode	Graphite
Electrolyte	Carbonates

Cathode	High Nickel > 80%
Anode	Graphite-Silicon
Electrolyte	Next Generation Liquid

Cathode	No Cobalt (NMO, Sulfur, Etc.)
Anode	Lithium-Metal
Electrolyte	"Solid"

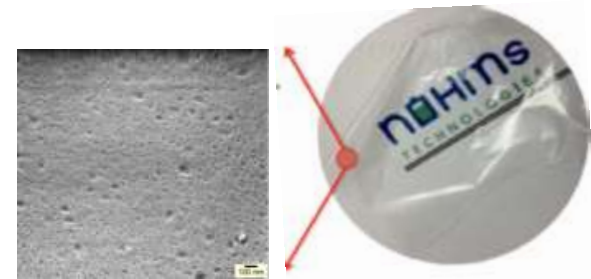
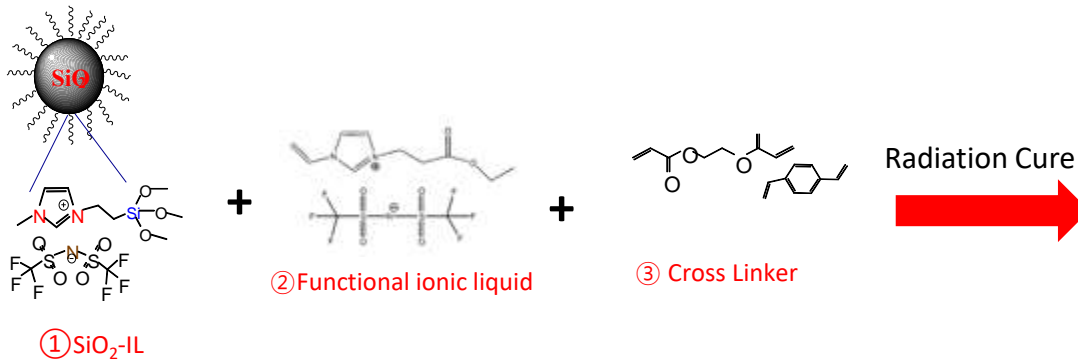
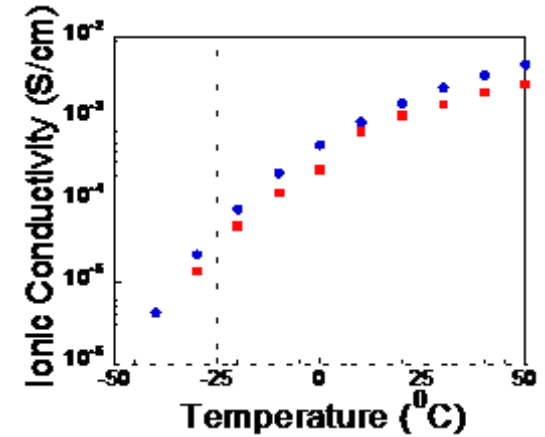
NOHMs' Ionic Liquids Provide All Advantages
Expected from Solid State in the Future – TODAY!

Solid State Cells May Not Need Solid
Electrolyte, Given That Safety and
Other Requirements Can Be Met
With NOHMs Gel/Polymers.

NOHMs' Ionic Liquid Gel Polymer Electrolyte

NOHMs alternative vision for nanofilm + ionic liquid

- Polymer nanoparticle composite for mechanical stability
- Ionic liquid gives good ionic conductivity (10^{-3} S/cm)
- Ionic liquid is non-flammable, giving similar safety to SSB
- IL-composite stabilizes Li metal dendrites
- Flexible, durable film = manufacturability



(4) Flexible stand-alone film

NOHMs Solutions For Next-Generation Cells

Safety

- NOHMs' Abuse-Tolerant Safety Solvents

Higher Energy Density

- NOHMs' Ionic Liquid Performance Additives

Cost Reduction

- Reduction in Overall System Costs
 - Safety Improvements Lessen Other Costs

Fast Charging

- Ionic Liquids Protect Electrodes
- Safety Solvents Absorb Heat Due to Charging

Manufacturability

- Polymer Versions of NOHMs' Electrolytes Are In Lab Testing Phase Today

Material Expansion

- Not An Issue With Polymer Versions of NOHMs' Materials

Global Partners

