Recent Developments and Challenges in Battery Safety with Solid State Technology

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SMTA Pan Pacific

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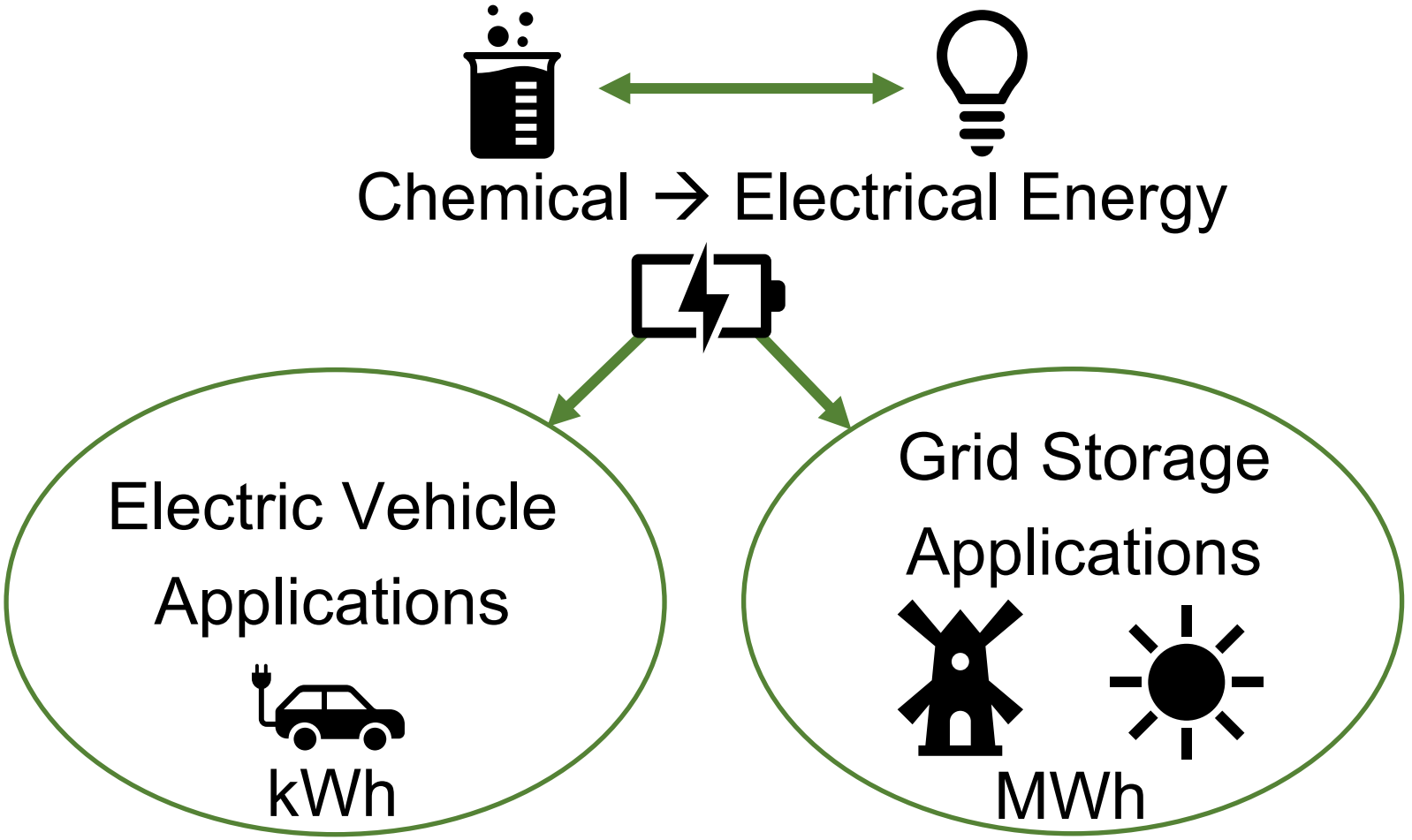
Introduction

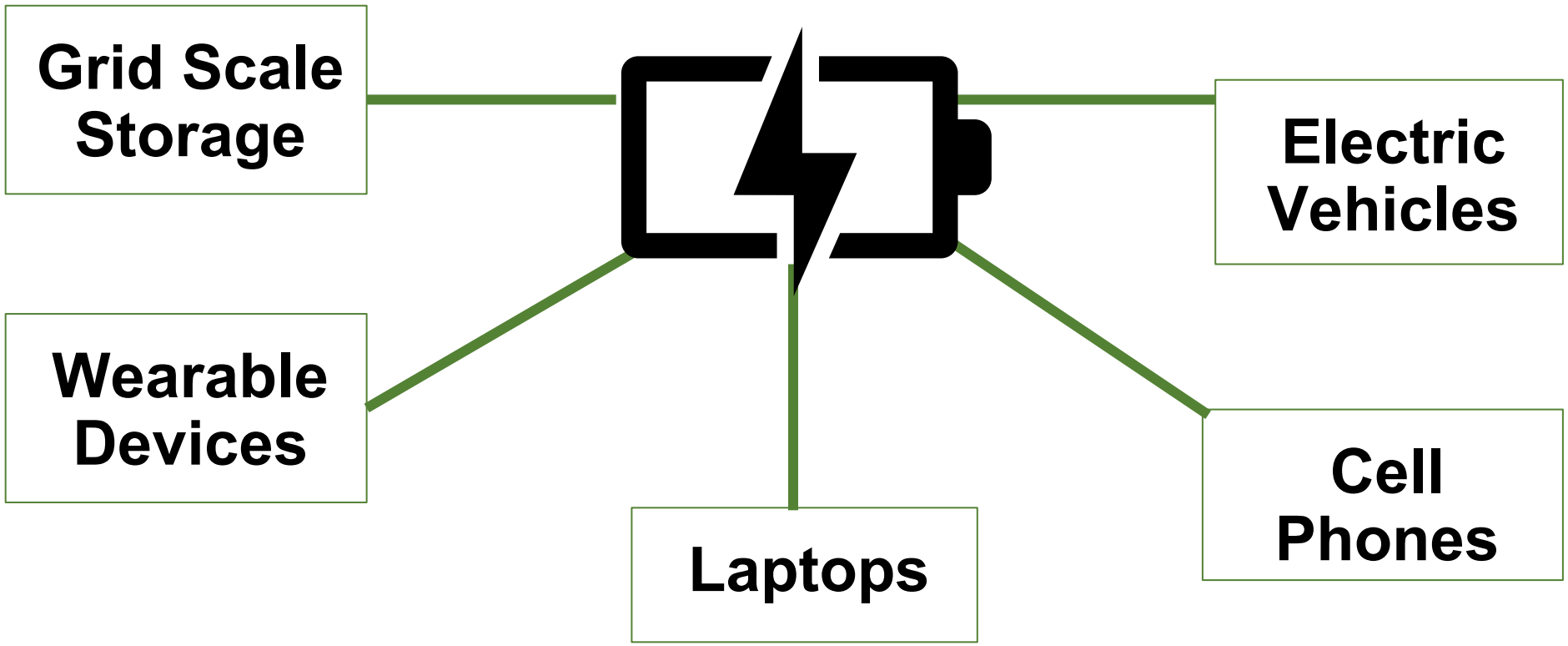
Challenge for the 21st Century: Improved Energy Storage



Agenda

- Overview of the Battery Industry
- Types of Batteries
- Advantages of Solid-State Batteries
- Applications
- Challenges
- Current Research at Dartmouth
- Future Directions
- Conclusion

Overview of the Battery Industry



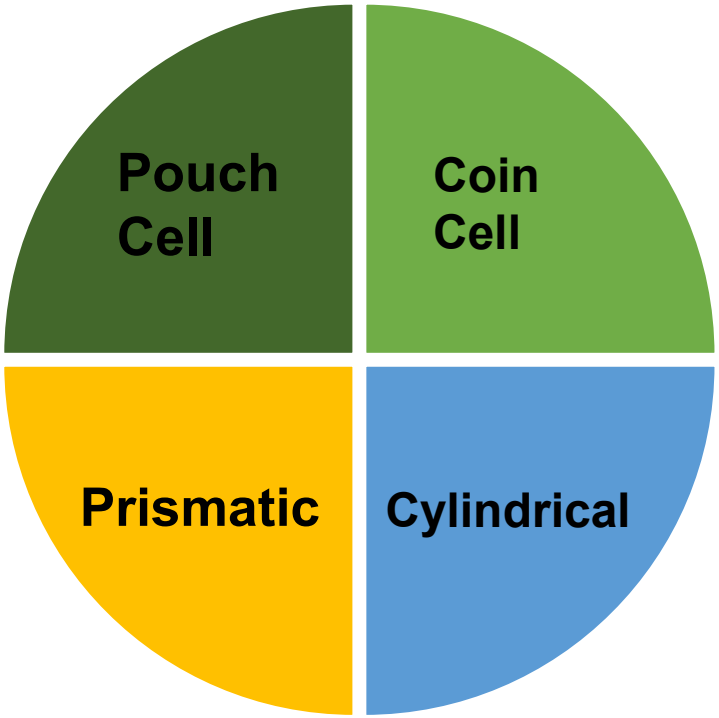
Terminology

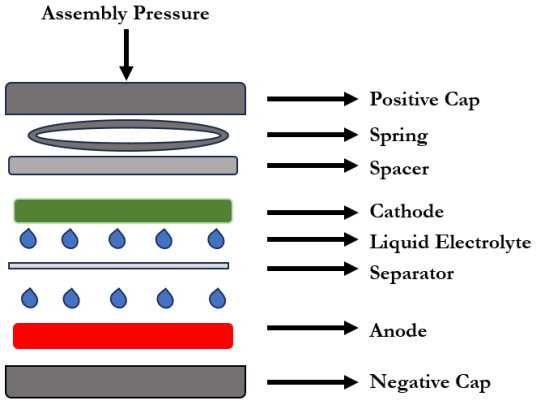
Capacity	Charge stored in the battery. Determined by mass of active material mAh/kg or Ah/g
Energy Density	Energy stored in battery compared to its weight (Wh/kg)
Cycle Life	Measure of expected working lifetime of battery. Defined by number of cycles of a cell before capacity drops to 80% of initial capacity
Self Discharge Rate	How fast a cell loses energy due to unwanted chemical reactions within cell
Coulombic Efficiency	Efficiency which electrons are transferred in the system to create the electrochemical reaction
Power Density	Amount of power per volume (W/m^3) or per weight (W/kg)

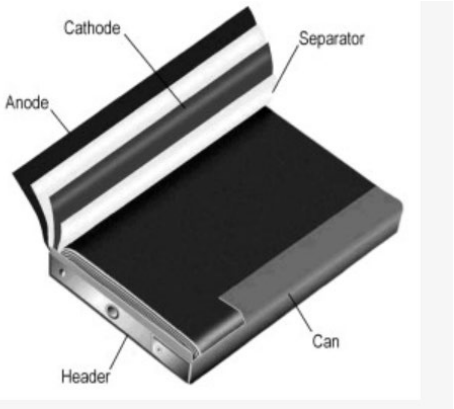
Types of Batteries

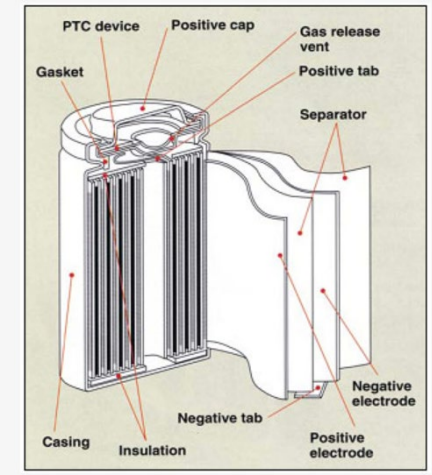
Primary	Secondary
Non-rechargeable	Rechargeable
Non-reversible	Reversible
Ex: Alkaline (AA,AAA), Zinc Carbon	Ex: Lithium-ion, Lead Acid

Basic Structure of Batteries





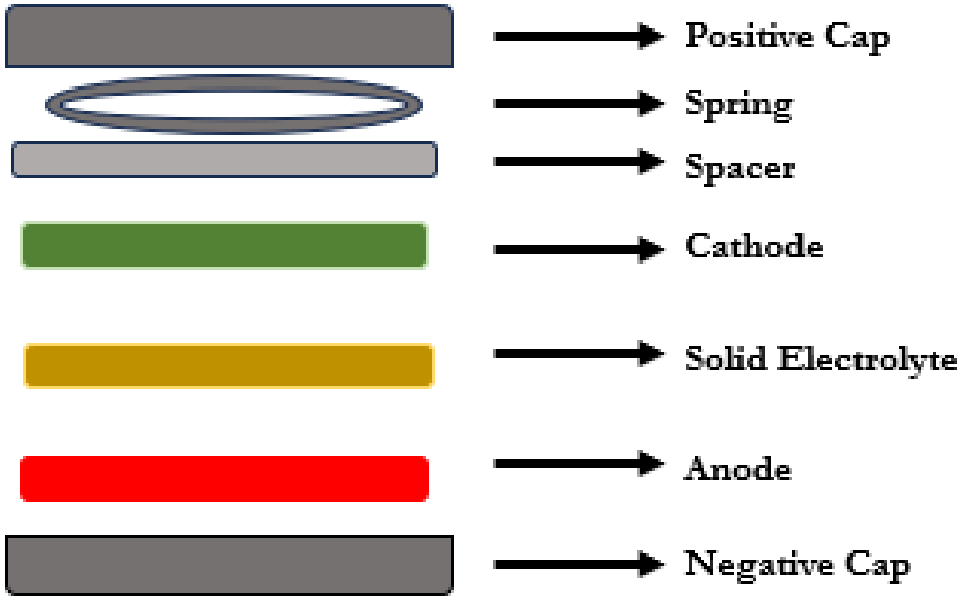




Battery University

Solid-State Batteries

- Solid Electrolyte
- Replaces conventional liquid electrolyte
- No need for a separator



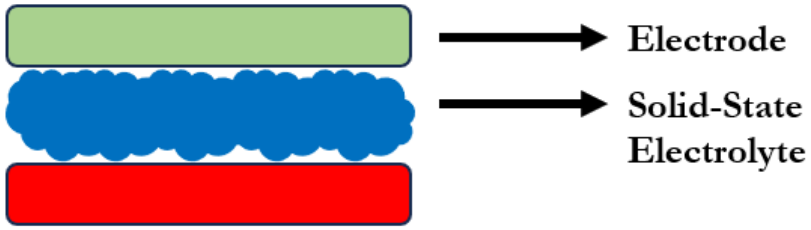
Solid-State vs Liquid Batteries

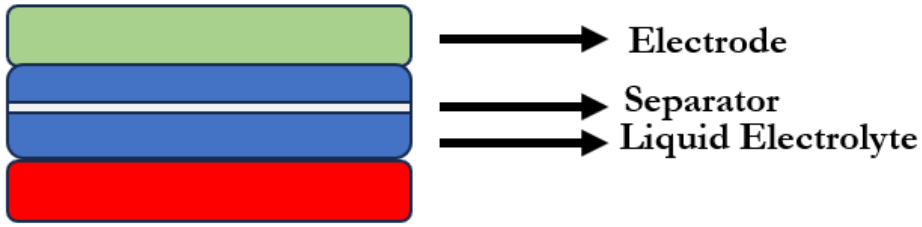
Solid-State Batteries

Solid electrolyte

Conventional Li-ion Batteries

Liquid electrolyte

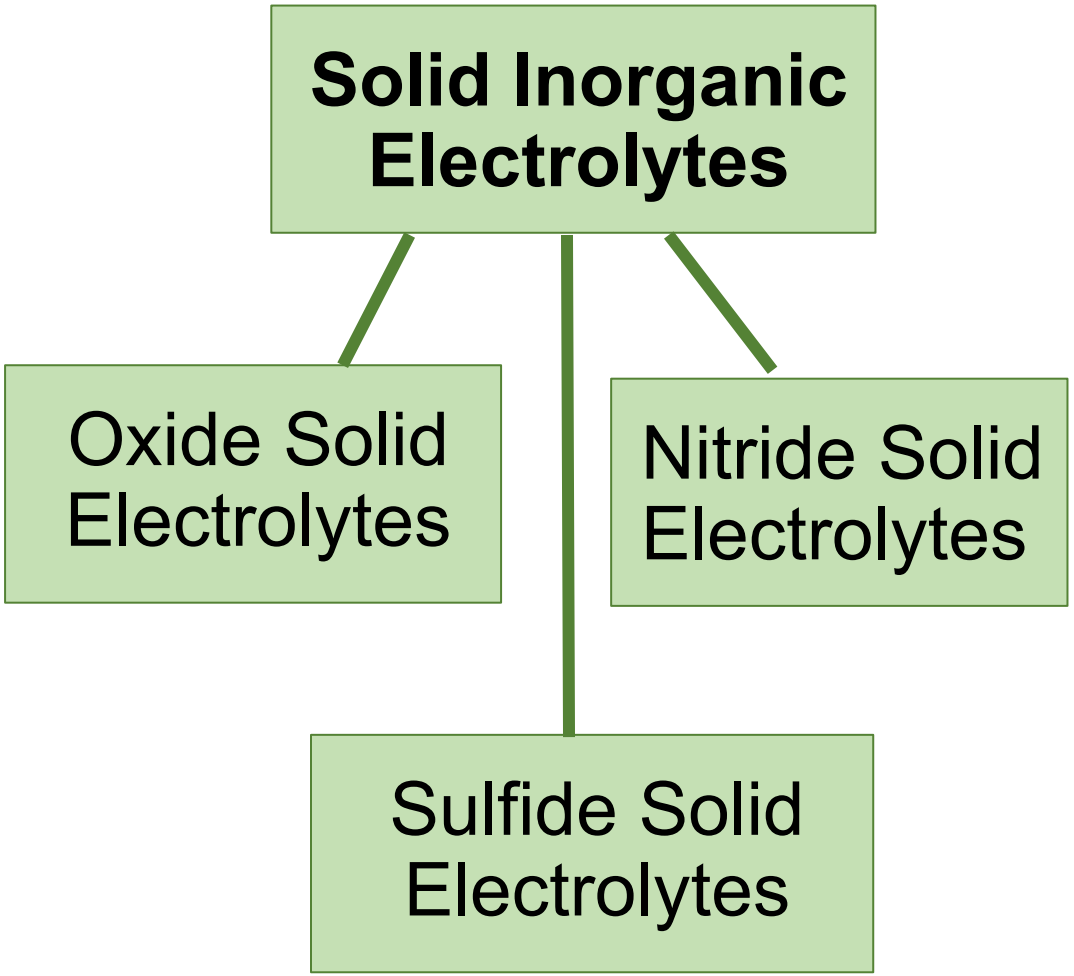


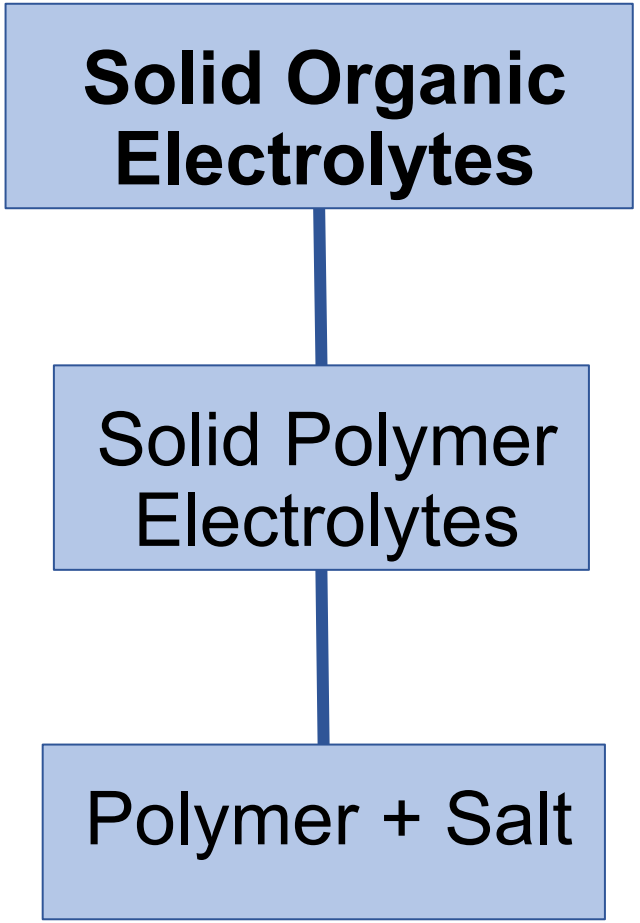


Advantages of Solid-State Batteries

Liquid Electrolytes	Solid Electrolytes
Limited Stability	Better Electrochemical Stability
Safety Concerns (Thermal Runaway)	Safer
Limited Temperature Range -20°C – 75°C	Broader Temperature Range -50°C – 125°C

Types of Solid-State Batteries



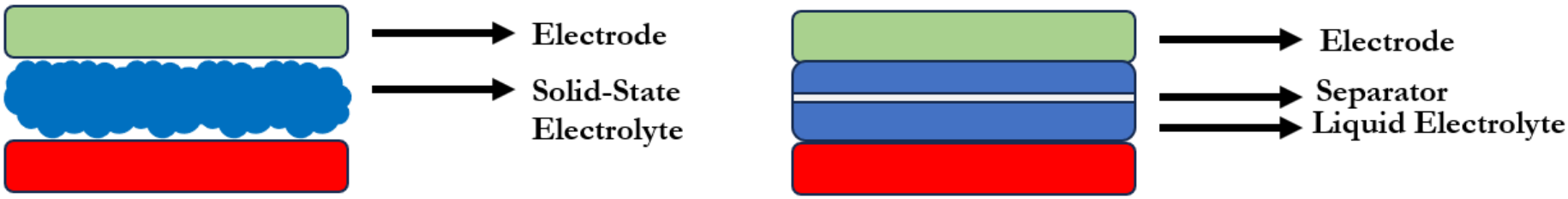


Challenges in Solid-State Battery Development

Liquid Electrolytes	Solid Electrolytes
High Ionic Conductivity	Lower Ionic Conductivity
More Mature Technology	Less Mature Technology
No Interfacial Issues	Interfacial Issues

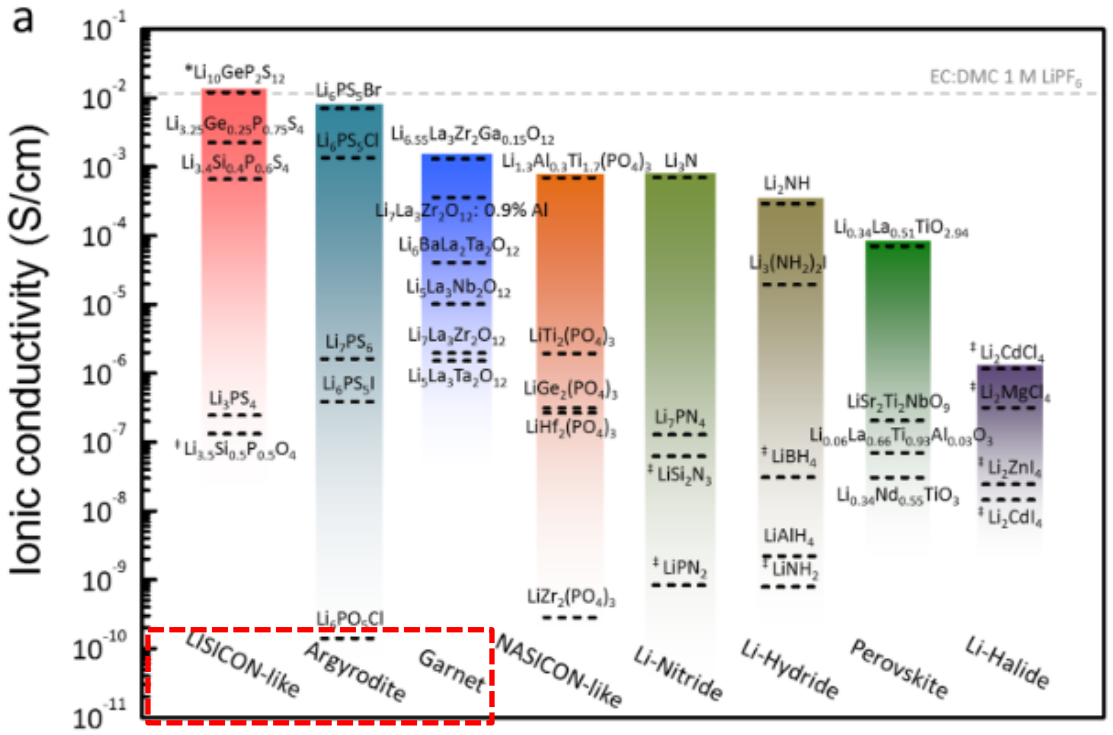
Challenges in Solid-State Battery Development

- Interfacial issues
- Causes poor contact with electrode
- Leads to low ionic conductivity



Current Research and Innovations: Lithium

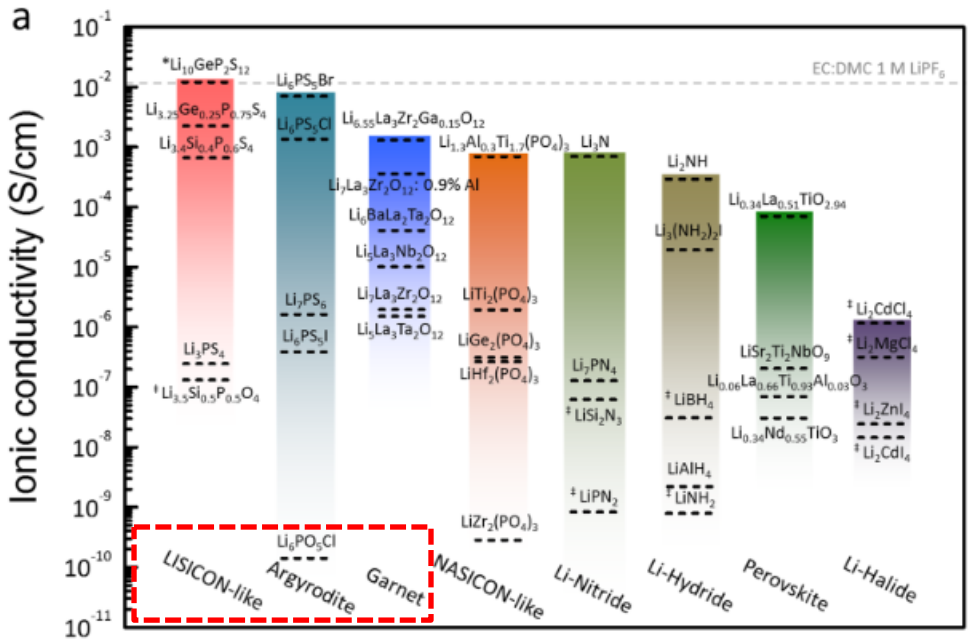
- LISCON
  - **Li**thium **S**uper **I**onic **Con**ductor
- Argyrodite
- LLZO
  - $La_7La_3Zr_2O_{12}$



Chemical Reviews, 2015

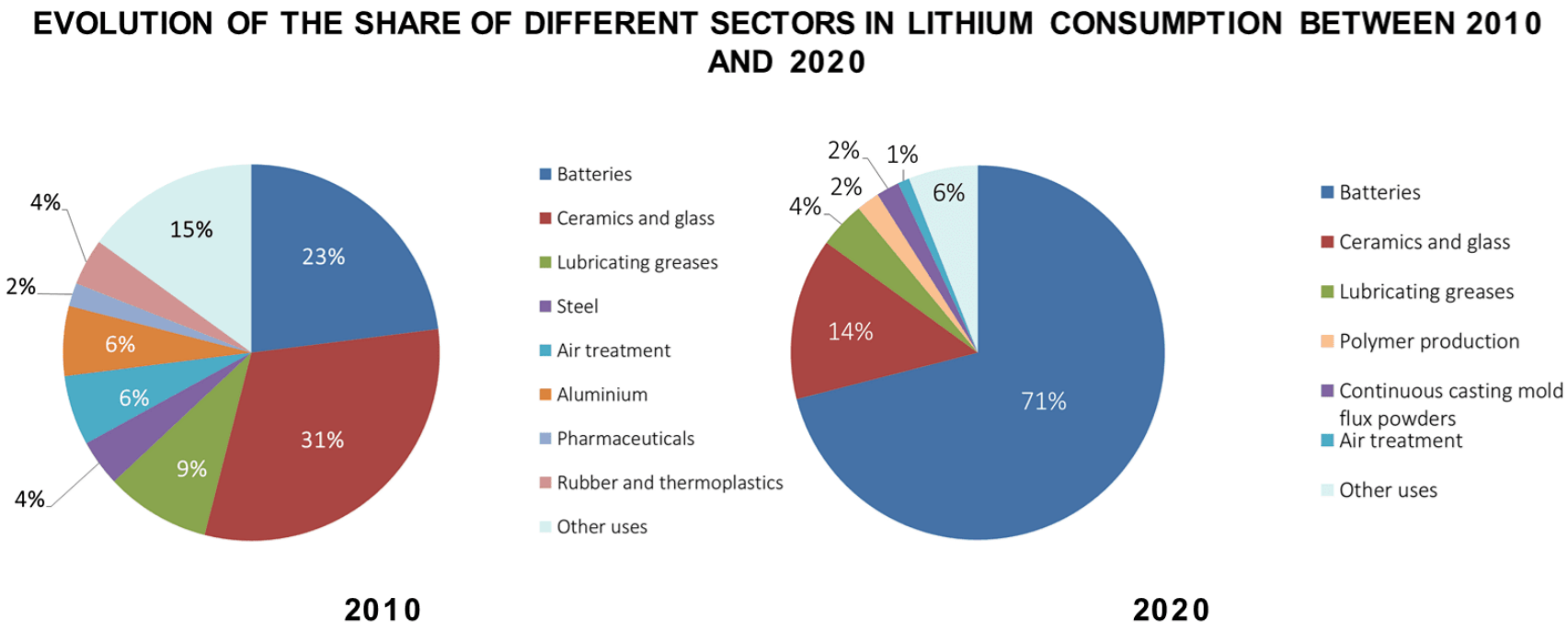
Current Research and Innovations: Lithium

- Difficult to synthesize
- Low reproducibility
- Poor mechanical properties
- High interfacial impedance



Chemical Reviews, 2015

Environmental Impact



Lithium battery is the largest end-user of Li

US Geological Survey

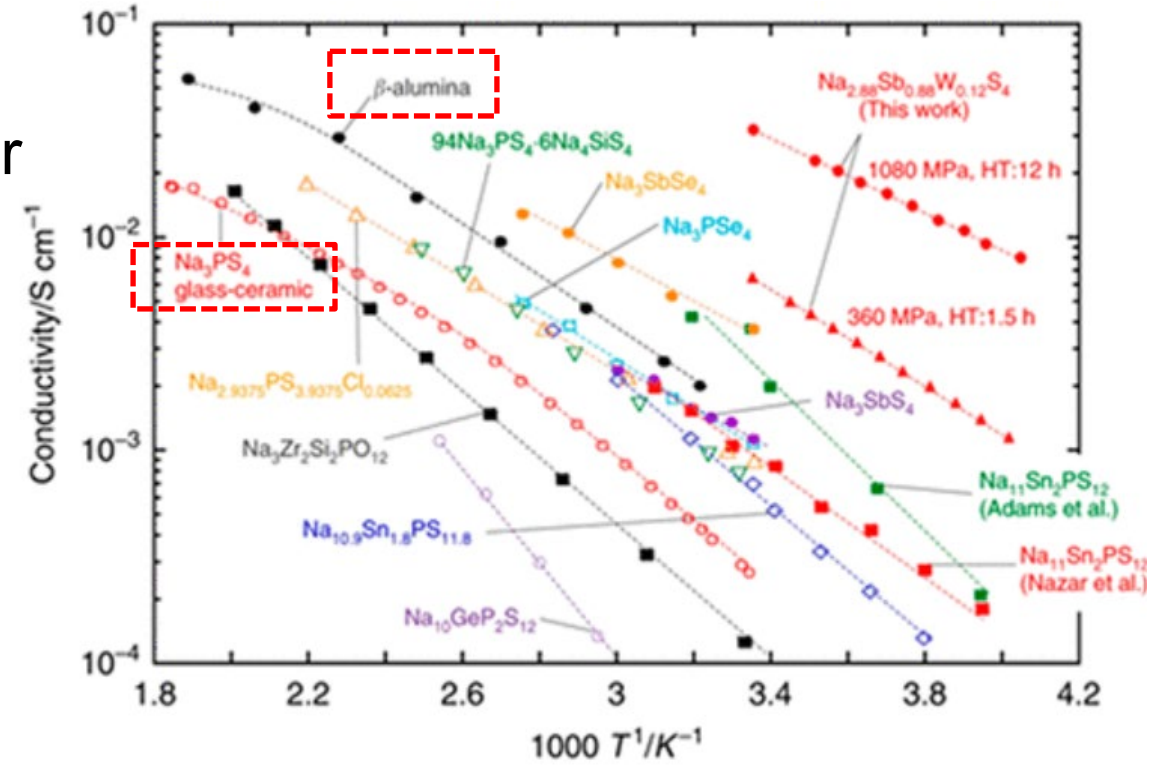
Solid State Batteries: Sodium

"Revolutionize the electric vehicle sector"

IUPAC 2022

Current Research and Innovations: Sodium

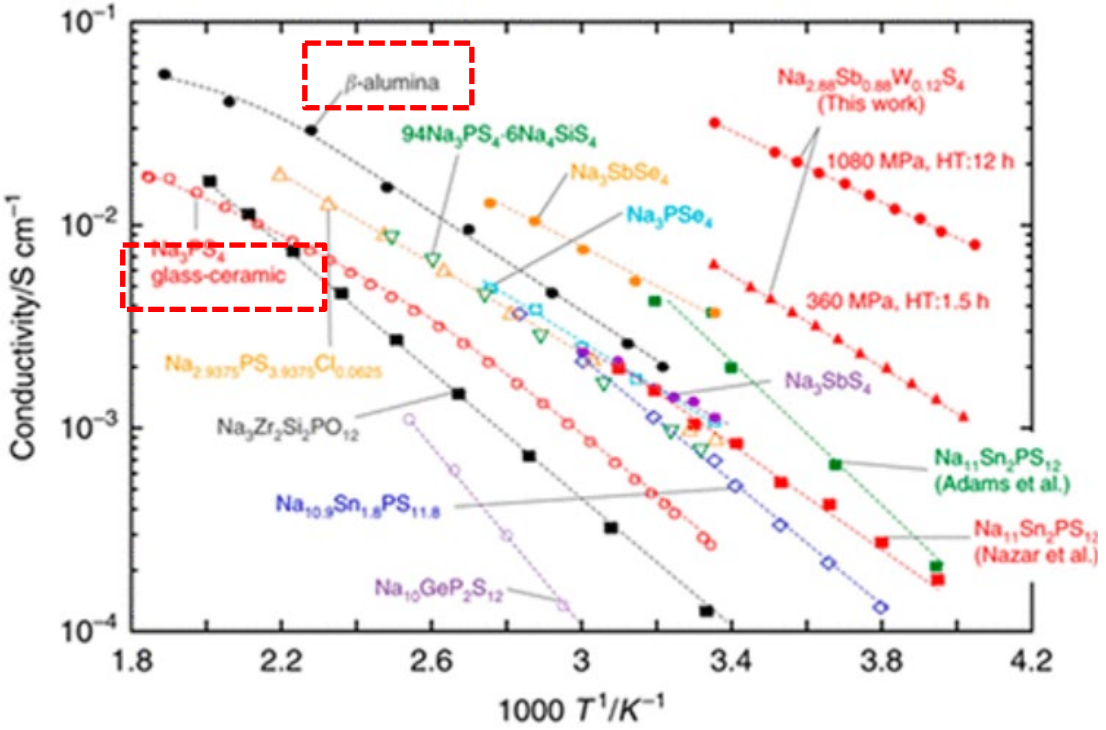
- NASICON
  - Sodium (**Na**) **S**uper **I**onic **Con**ductor
  - 10^{-7} to 10^{-4} S/cm
- Sodium-Sulfur
  - Combat compatibility issues



Chemistry of Materials, 2022

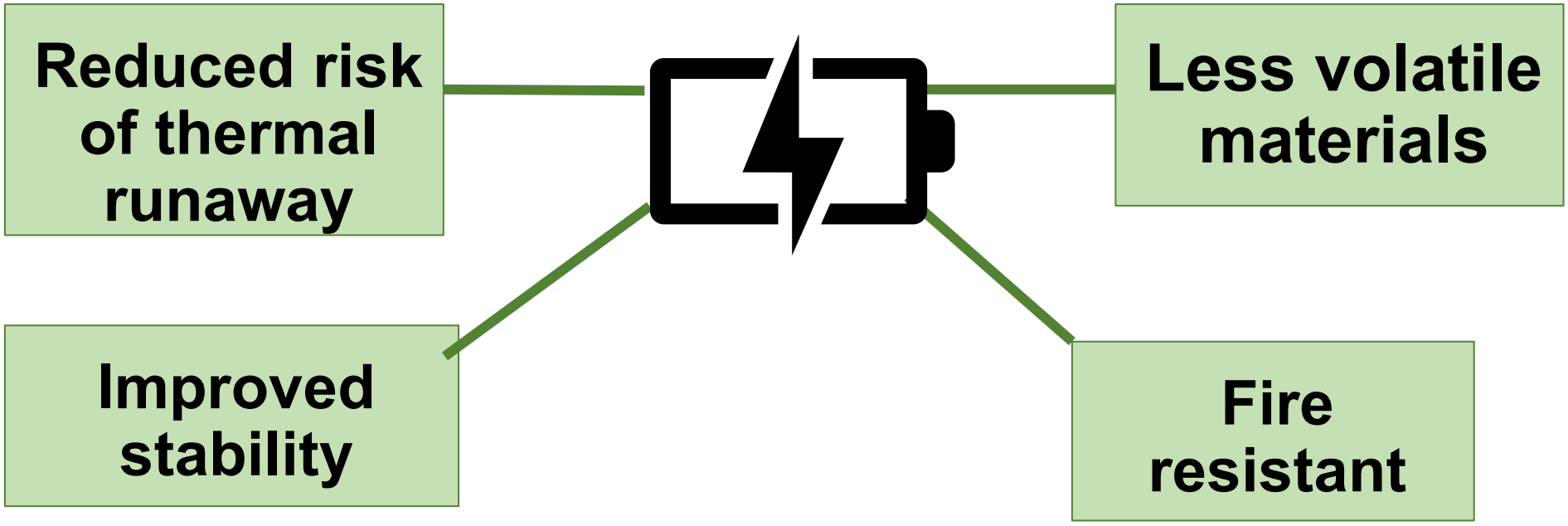
Current Research and Innovations: Sodium

- Unstable solid electrolyte interphase layer
- Poor cycling performance
- Low ionic conductivity
- Poor interfacial contact

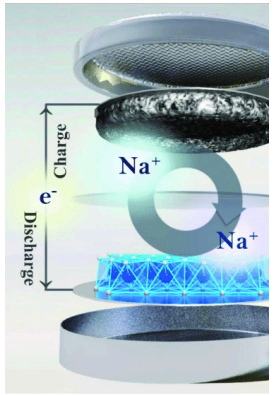


Chemistry of Materials, 2022

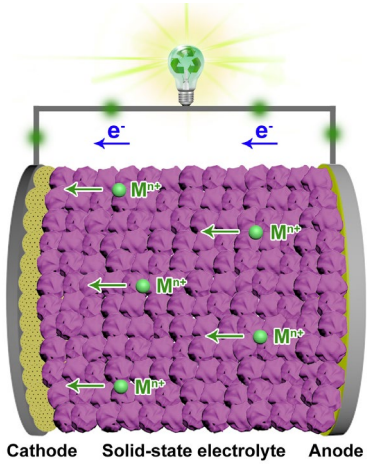
Safety Impact of Solid-State Batteries



Future Outlook in Li Group at Dartmouth



Low-cost & high-energy sodium batteries



Safe batteries with solid electrolytes

Batteries for extreme cold environments

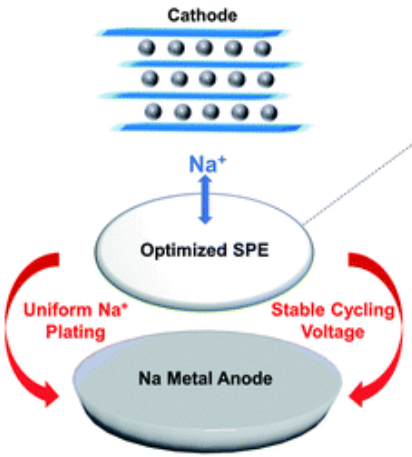
FioNa Li Group www.fionaligroup.com

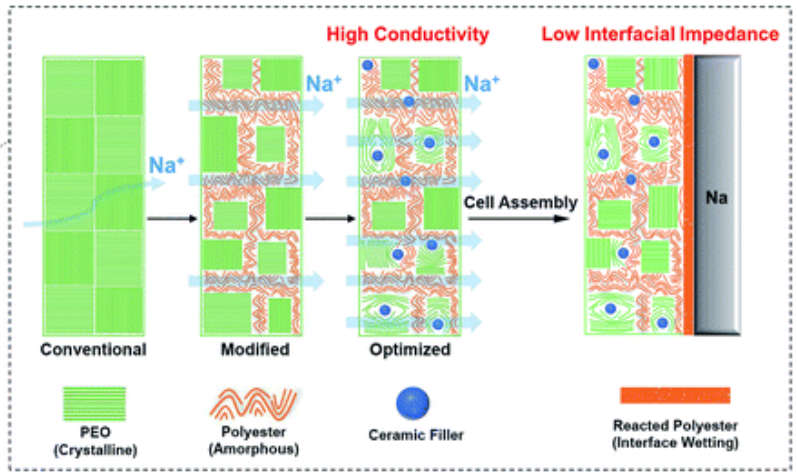
Future Outlook in Li Group at Dartmouth

- Sodium-based batteries
- Sodium solid electrolytes

  (e.g. NASICON or composite polymer electrolyte)

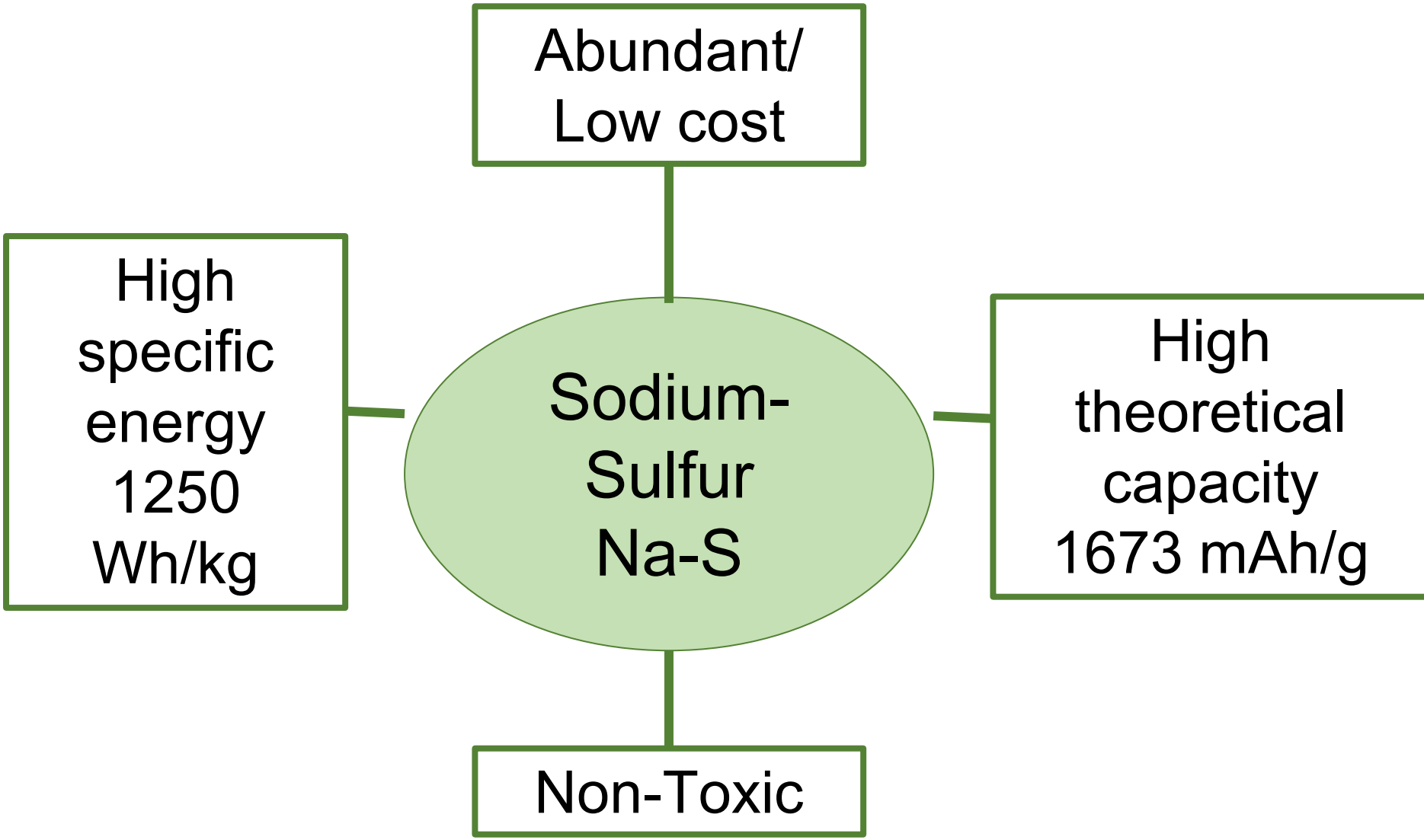
  - Interfacial tuning
  - Improved ionic conductivity, mechanical properties, and stability



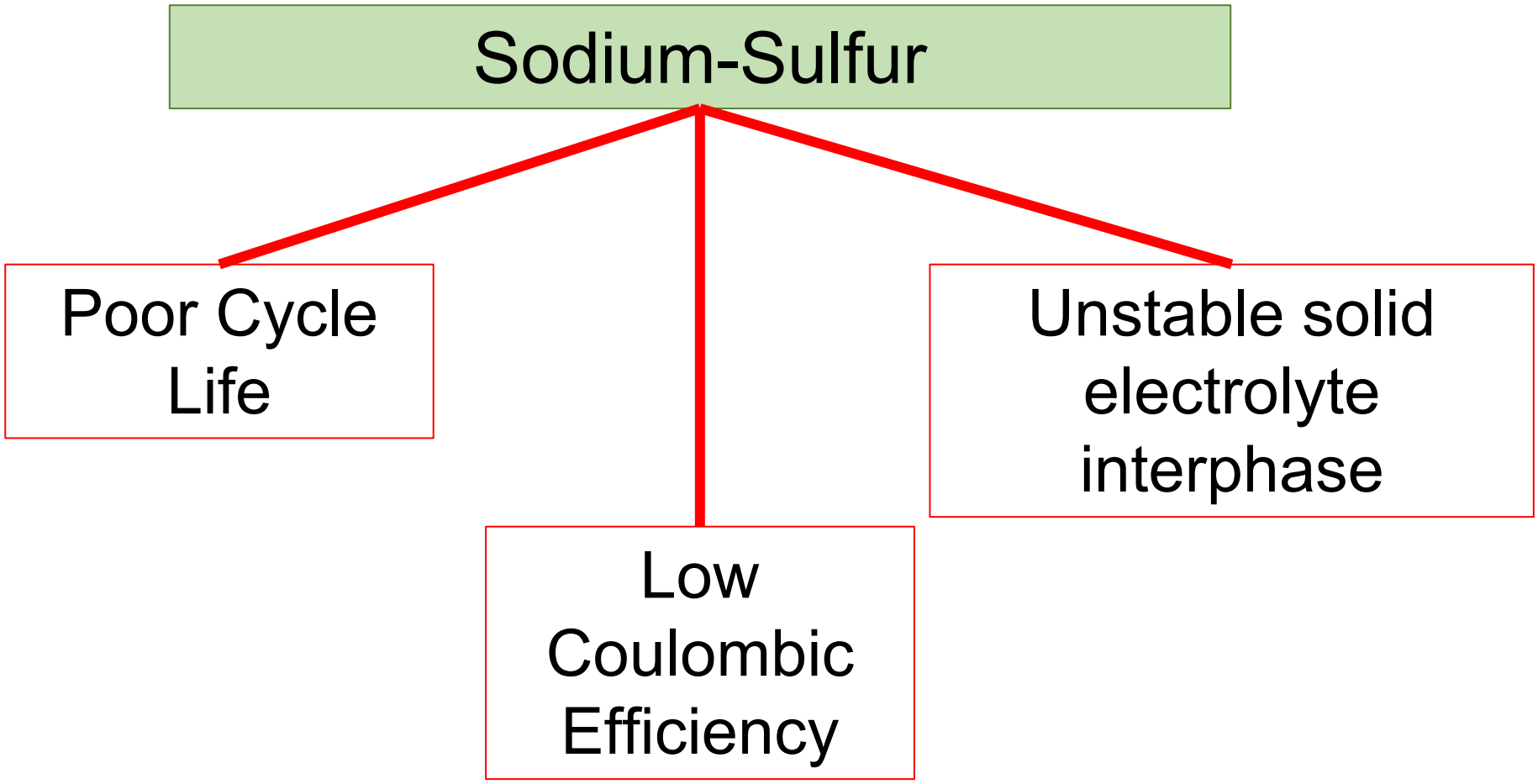


J. Mater. Chem. A, 2021

Future Outlook in Li Group at Dartmouth



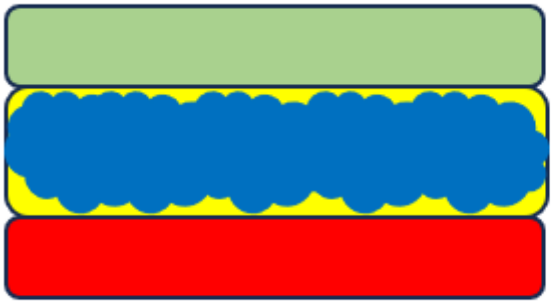
Future Outlook in Li Group at Dartmouth



Future Outlook in Solid-State Batteries (in Li Group)

Composite electrolytes

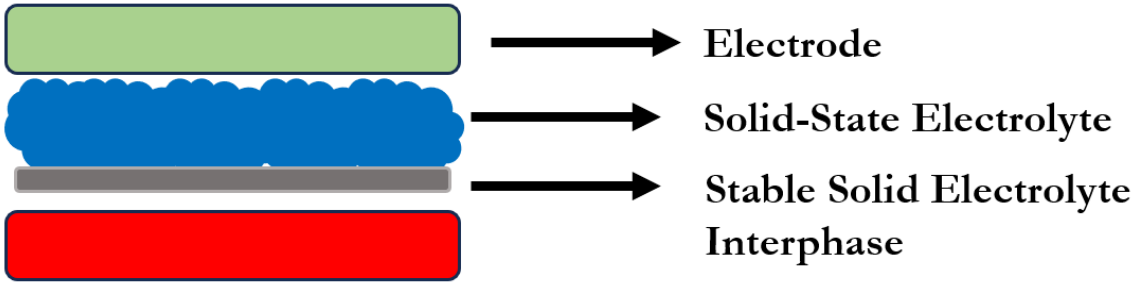
Inorganic +Polymer



Ex: NASICON + Polymer (PEO/PPC)

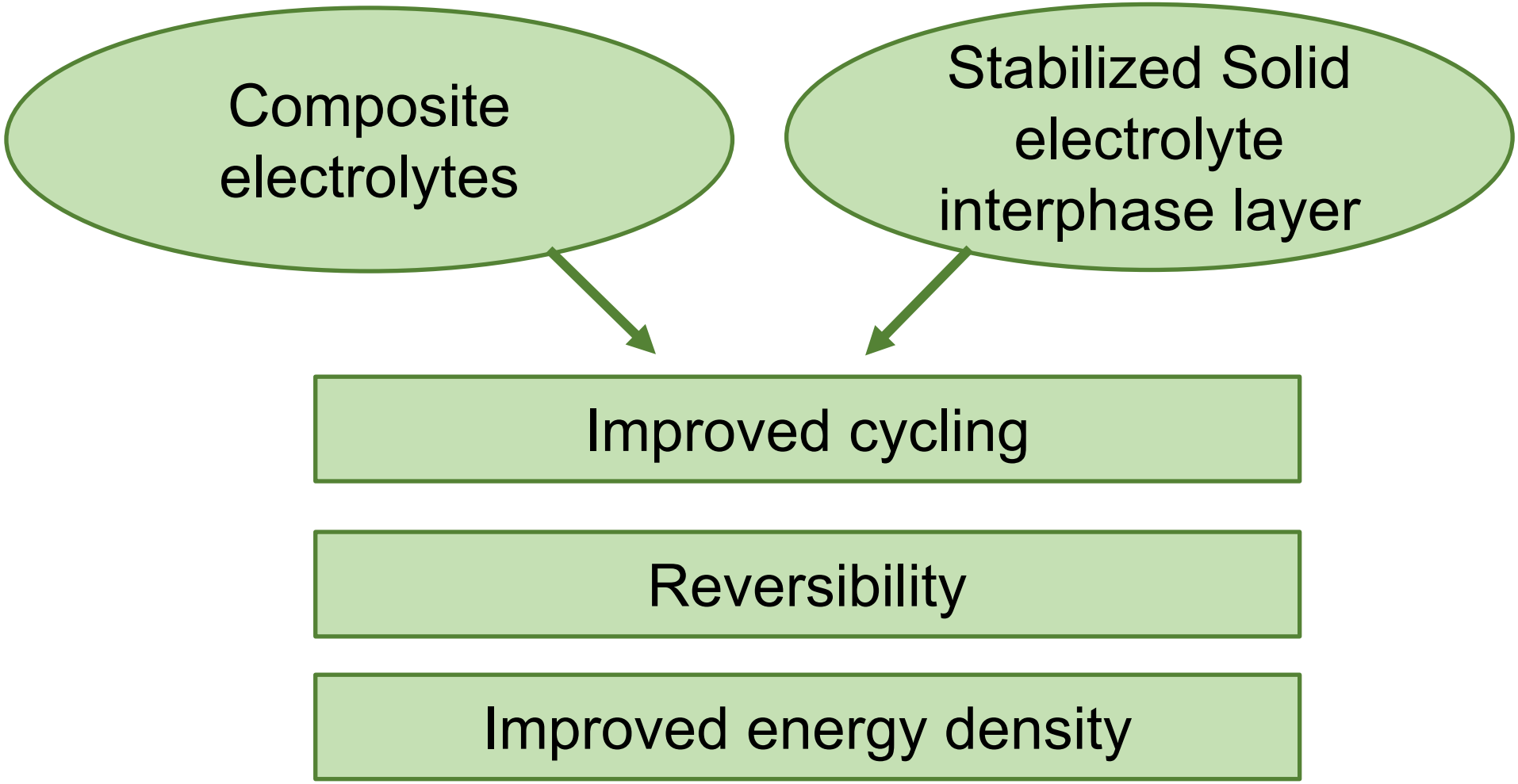
Future Outlook in Solid-State Batteries (in Li Group)

Stabilized solid electrolyte interphase layer



Improves Coulombic efficiency

Future Outlook in Solid-State Batteries (in Li Group)



Conclusion

- Solid-state electrolytes provide a safer alternative to traditional liquid electrolytes
- There are challenges with both inorganic and organic forms of solid electrolytes due to poor interfacial contact and low ionic conductivity
- Engineering composite electrolytes appear to be promising to combat issues of inorganic and polymer-based solid electrolytes
- These electrolytes can be used for a variety of applications including grid-level storage and electric vehicles
- This technology is safer and more environmentally friendly than traditional electrolytes

Acknowledgements

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DARTMOUTH ENGINEERING THAYER SCHOOL

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH UNITED STATES AIR FORCE

NASA

CRREL

NSF

Questions?

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