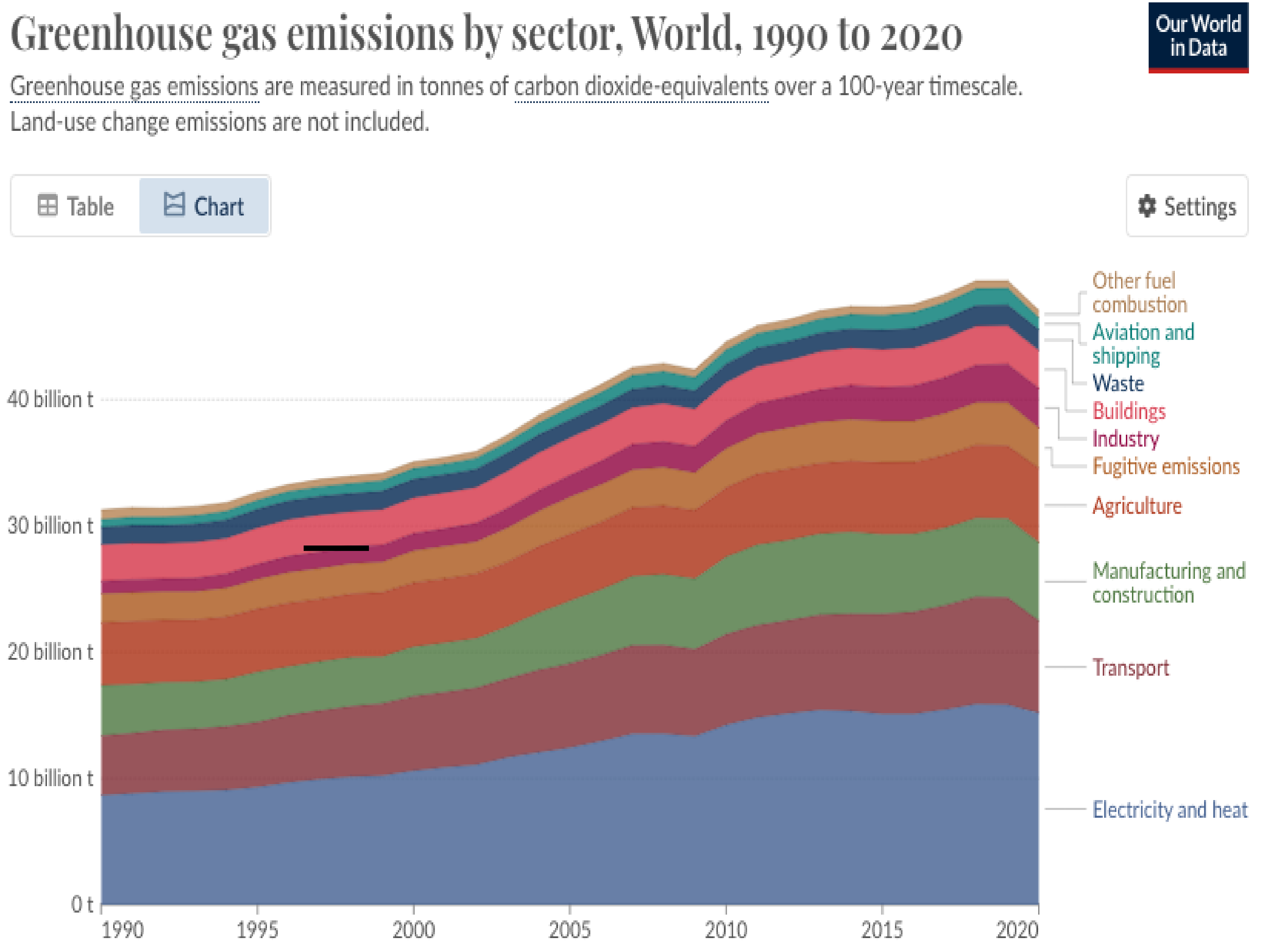
Solid State Batteries

Chris Hendrick

Nate Reynolds

Two Major Use Cases for Batteries: Transportation and Storage for RE

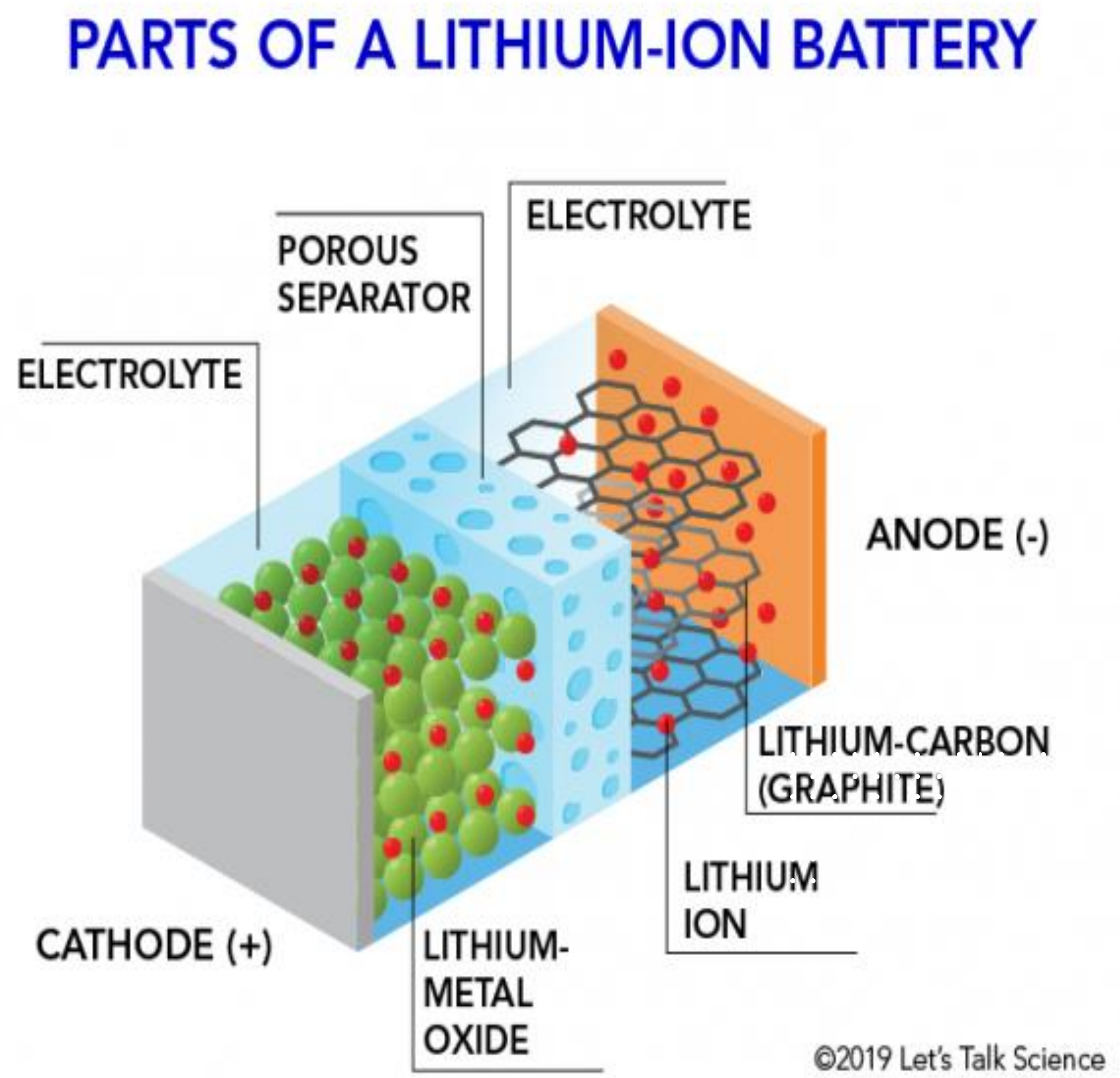
- Road transport responsible for 11.9% global emissions
- Electricity and Heat responsible for 32.3% of global emissions
- Storage will be a crucial part of electrification efforts
- Lithium Ion with liquid electrolyte is the current standard



Our World in Data, 2024. GHG emissions by sector, 1999 to 2020. https://ourworldindata.org/emissions-by-sector

Traditional LiB

- Liquid (usually gel) electrolyte
  - Lithium hexafluorophosphate ($LiPF_6$) salt dissolved in organic carbonates: (FLAMABLE)
- Separator made of polyethylene or polypropylene material (several layers)
- Cathode made of metal oxide
  - (e.g. NMC, $LiMn_2O_4$, etc)
- Anode made of graphite or silicon

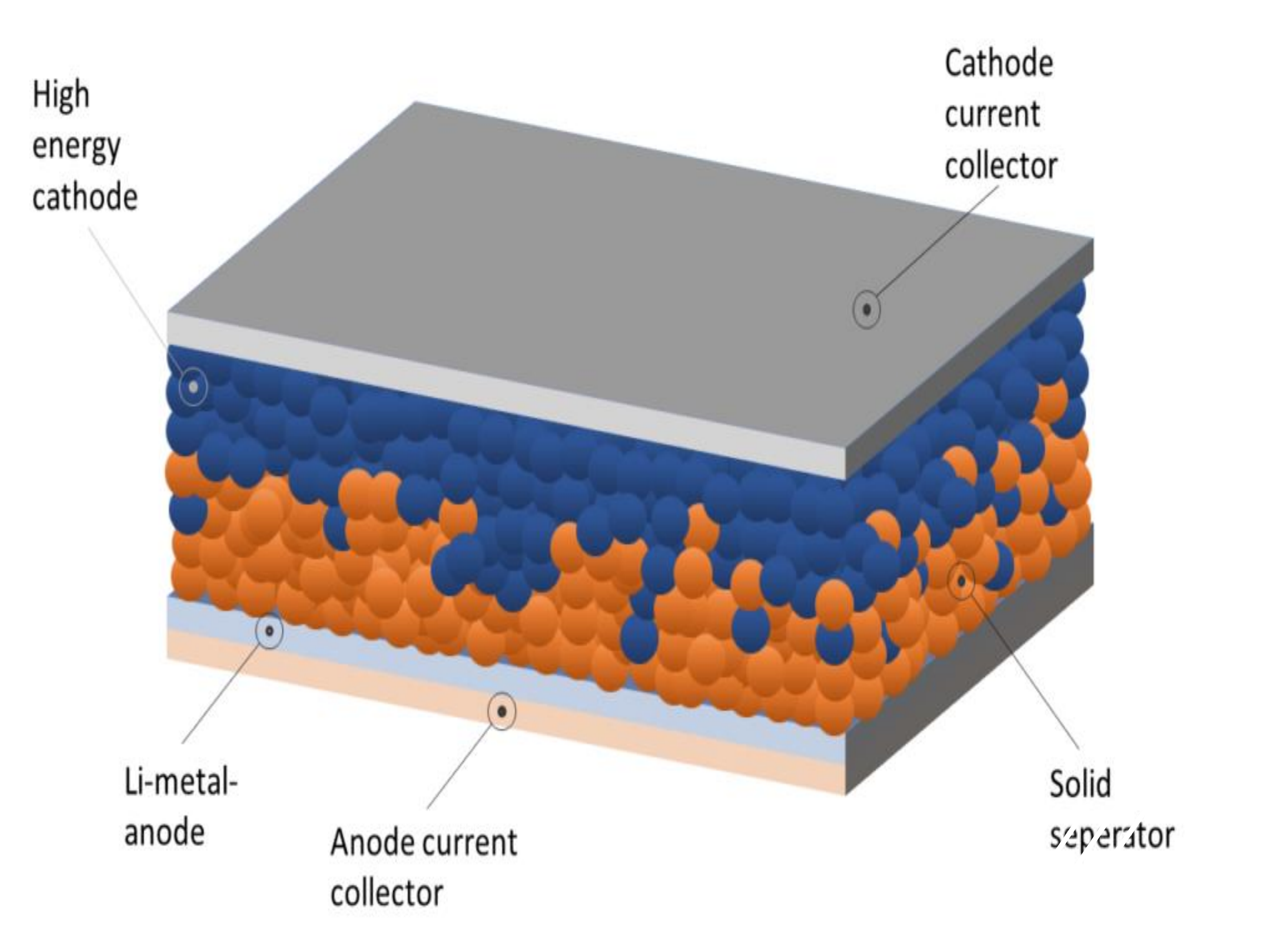


Future Battery Lab. https://futurebatterylab.com/solid-state-batteries-at-a-glance/

Components of Solid State Battery

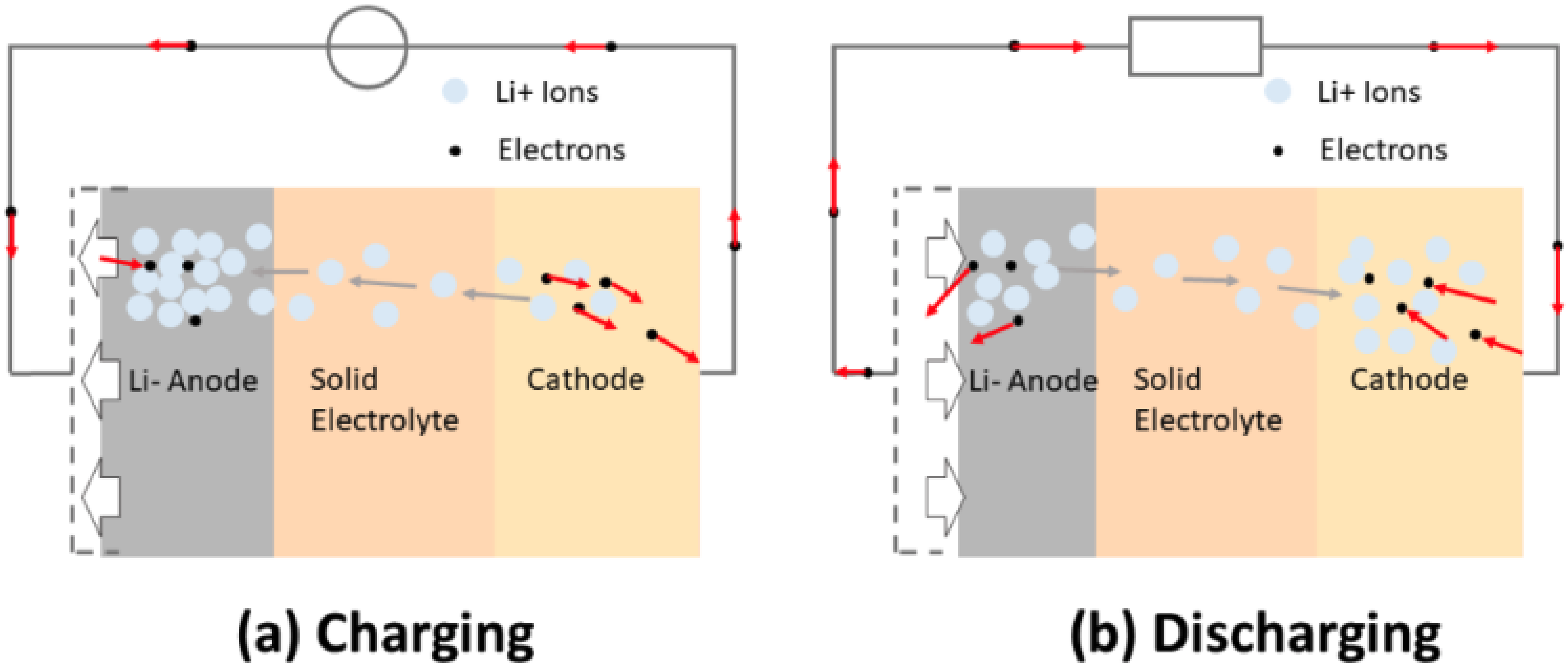
What are the differences?

- Solid Electrolyte
    - Ceramic (Higher conductivity and thermal stability but brittle)
        - Sulfides
        - Oxides
        - Phosphates
    - Polymers (Flexible, “soft”, easier to fabricate)
- NO SEPERATOR
- Cathode also made from metal oxide
    - (Similar to LiB battery)
- Anode made of Li metal
    - Different than LiB)



Future Battery Lab. https://futurebatterylab.com/solid-state-batteries-at-a-glance/

Charging Discharging SSB



Future Battery Lab. https://futurebatterylab.com/solid-state-batteries-at-a-glance/

Comparison Between SSB and Li+ Storage

	SSB	LiB
Weight/Size	Lighter/Smaller due to greater energy density	Heavier due to liquid electrolyte and separator
Energy Density	>500 Wh/kg	250-300 Wh/kg
Capacity/Range	• Can increase capacity or range of EV by 30-50% • 400-700 miles on full charge	110-400 miles on full charge
Thermal Stability and Safety	• High thermal stability in hot environments (higher ionic conductivity in hotter temps) • Can operate up to 120° F • Poor ionic conductivity in temps below 32° F • Dendrite formation through SE can short battery	• Thermal runaway can occur in at temps >120° C • Dendrite growth more common • Flammable liquid electrolyte
Recharge and Lifecycle	• Up to 20 minutes • 8,000-10,000 charges	• Can take up to 12 hours to recharge • 1,500-2,000 charges
Carbon Footprint	• Higher energy density • Significant Li metal and other elements required in SE as well as more energy to manufacture material	• Less energy dense • Still significant resource depletion including non-lithium metals used in electrodes

Challenges

	Electrolyte needs heat	More conductive when hot, making cold applications challenging
	Size changing: while charging and discharging, lithium metal builds up. Needs to "breath"	Hard to engineer for constant volume change
	Solid Electrolyte Looses Contact vs liquid	Some trying compressing, or semi-solid electrolyte
	Dendrites	Although Solid Seperator reduces short circuit risk, dendrites can still form

Pros/Cons (SS perspective)

Pros:

- More Energy Dense*
  - Dependent on chemistry
- Lower fire risk
  - No reactive liquid means no Thermal Runaway
- Fewer critical minerals needed
  - Cheaper (once scaled)
  - Smaller/energy unit

Cons:

- More resistance unless very hot (50 degrees C)
- Volume changes with charge/discharge
- Hard to dissipate heat in some applications
  - EV might require cooling unit, negating some advantages from size/weight
- More sever electrolyte degradation leads to shorter lifespan
- Higher precision needed during manufacturing
  - Costly, hard to scale

Domestic Manufacturing

- Increase domestic manufacturing for quality control and "domestic content" investment incentive from IRA
- Strates with SS manufacturing:
  - Maryland
  - Massachusetts
  - California

EV Application- Nate

Factorial: Solstice Battery

- 1st 100+ Ah Automotive sized Solid State cell
- Manufactured in the US
- Partners (20% of market)
  - Mercedese
  - Hyundai
  - Stallantis
  - LG Chem

Tech

- If enough weight reduction, can use aluminum instead of steel in car increasing weight savings
- Mercedese has $200 Million dollar investment in Factorial
- Mercedese also investing in ProLogium, high silicon anode tech
- Solstice (SS) at Scale by end of decade
- Factorial also producing Semi-Solid-state option

Grid Scale Energy Storage

EV SSB market is helping to accelerate grid storage

Stationary energy storage systems to represent $385 Billion global market by 2030

QuantumScape partnership with Fluence Energy Inc to develop SSB Li metal for stationary energy storage

As of 2021, has 3.6 GW of LiB Storage across 30 markets world wide

QuantumScape 2022, https://www.quantumscape.com/press-release/quantumscape-and-fluence-to-collaborate-on-stationary-storage-with-solid-state-lithium-metal-technology/#:~:text=As%20a%20leader%20in%20stationary,Perez%20Dubuc%2C%20CEO%20of%20Fluence.

The Future

SAFER, CHEAPER, MORE ENERGY DENSE ENERGY STORAGE FOR MANY APPLICATIONS

STILL NEED TO ION-OUT SOME FEASIBILITY CHALLENGES

SEMI-SOLID STATE IN DEVELOPMENT AS WELL