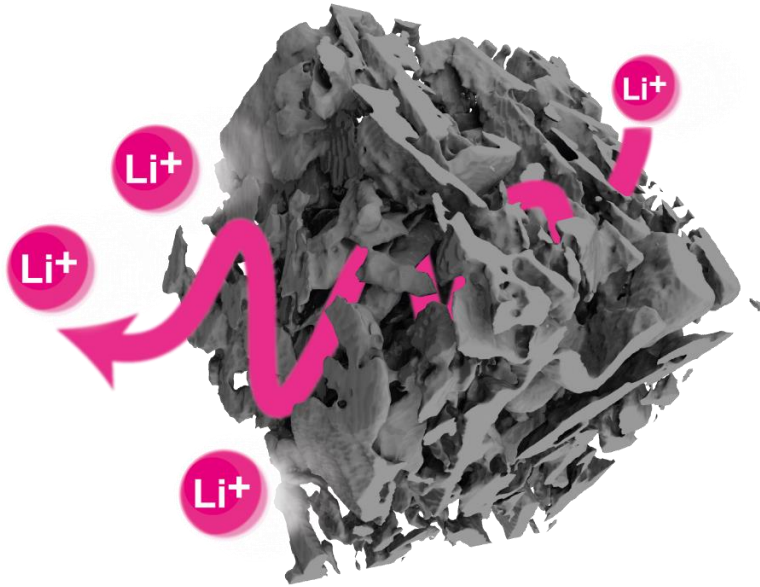




State of Lithium Ion Battery Research

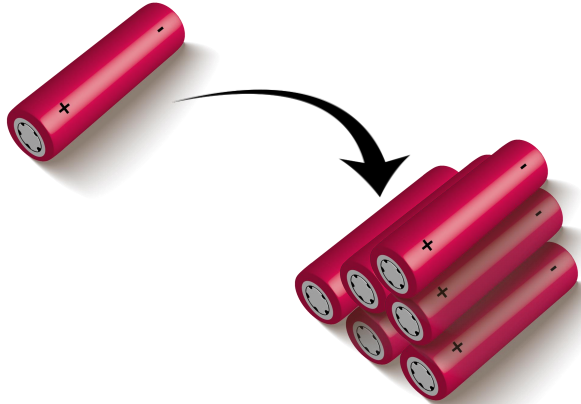
Professor Vanessa Wood

Department of Information Technology and Electrical Engineering

ETH Zürich

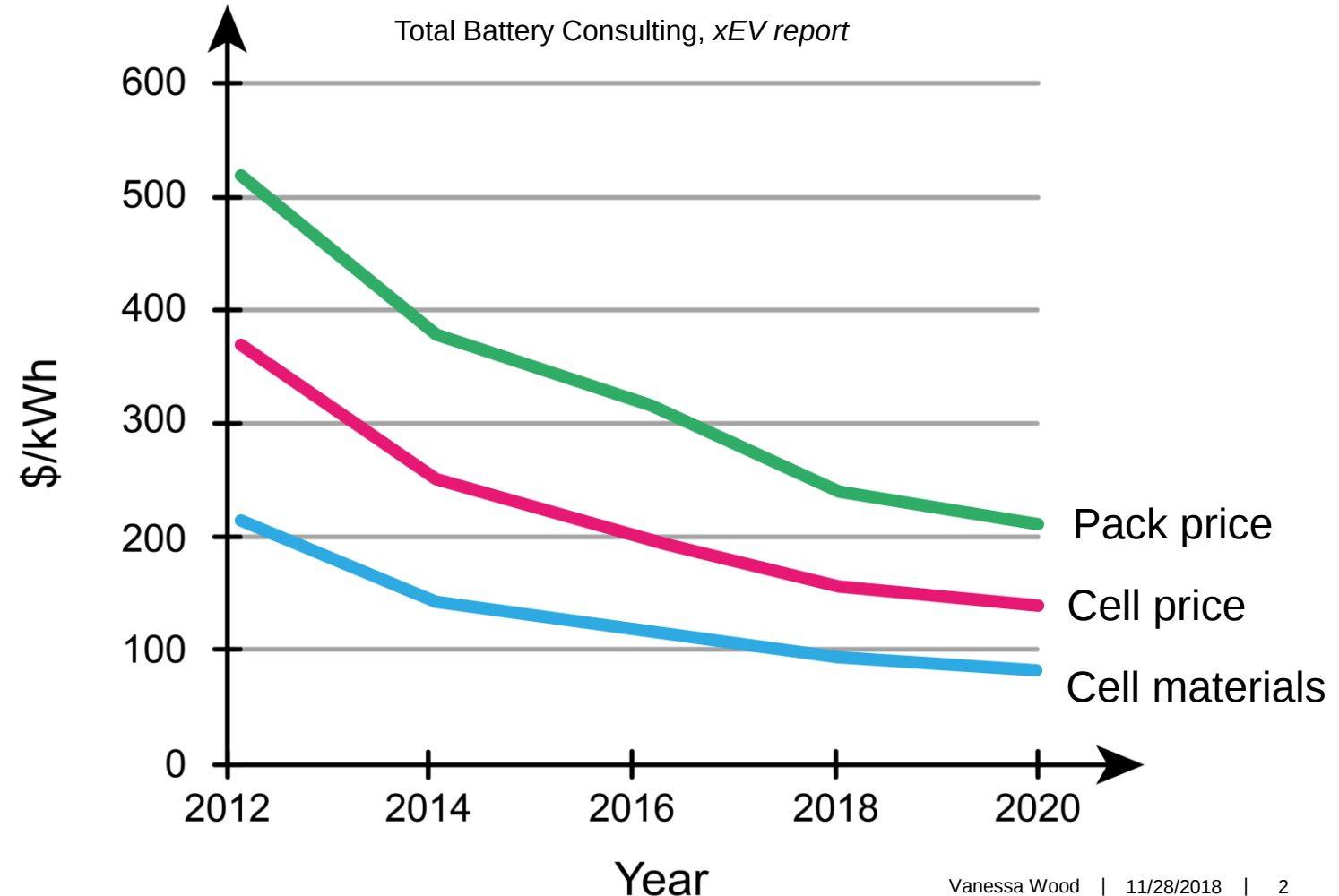
High volume production has decreased costs

2.5 Billion cell phones, tablets, laptops sold in 2017

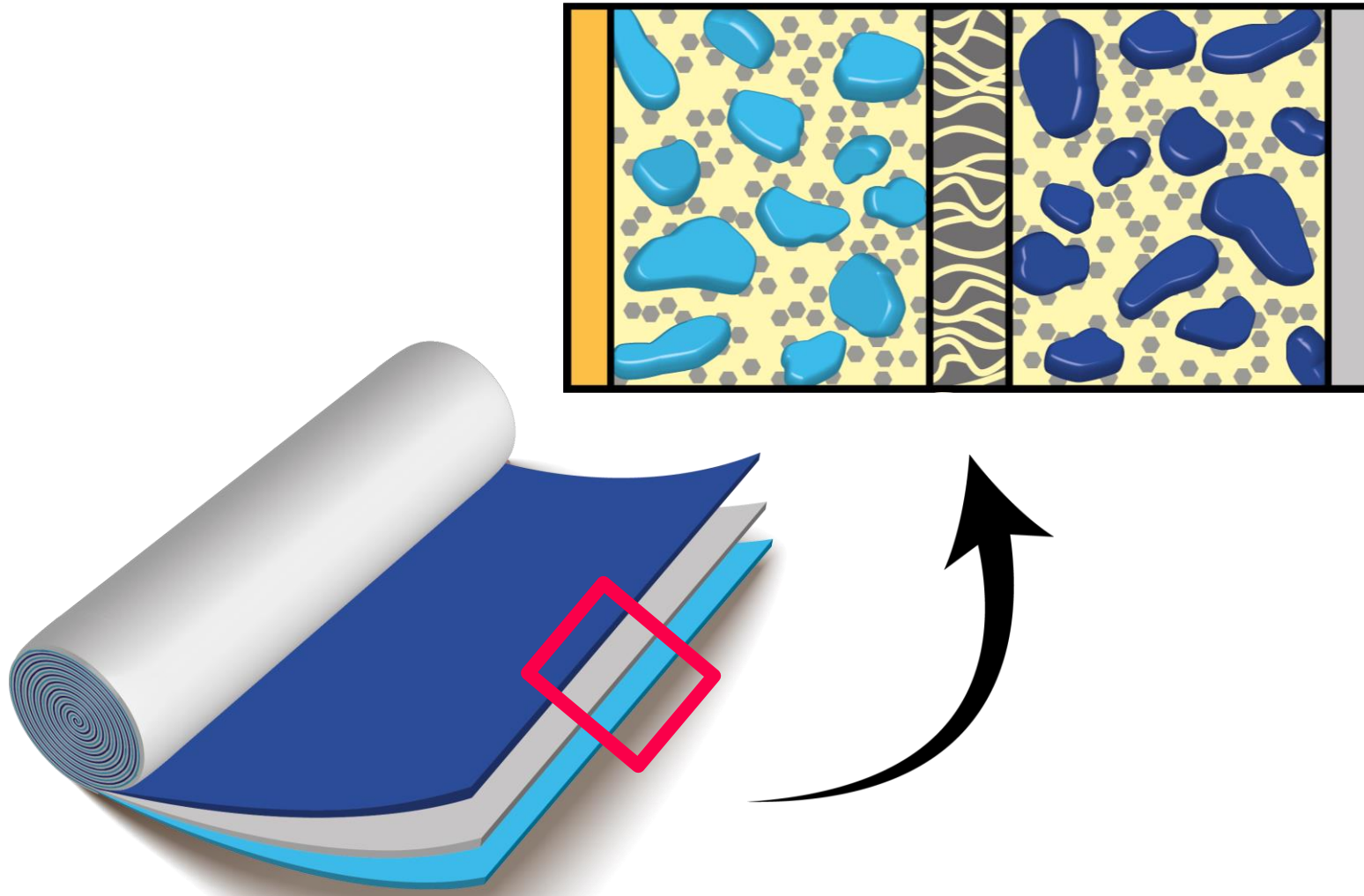


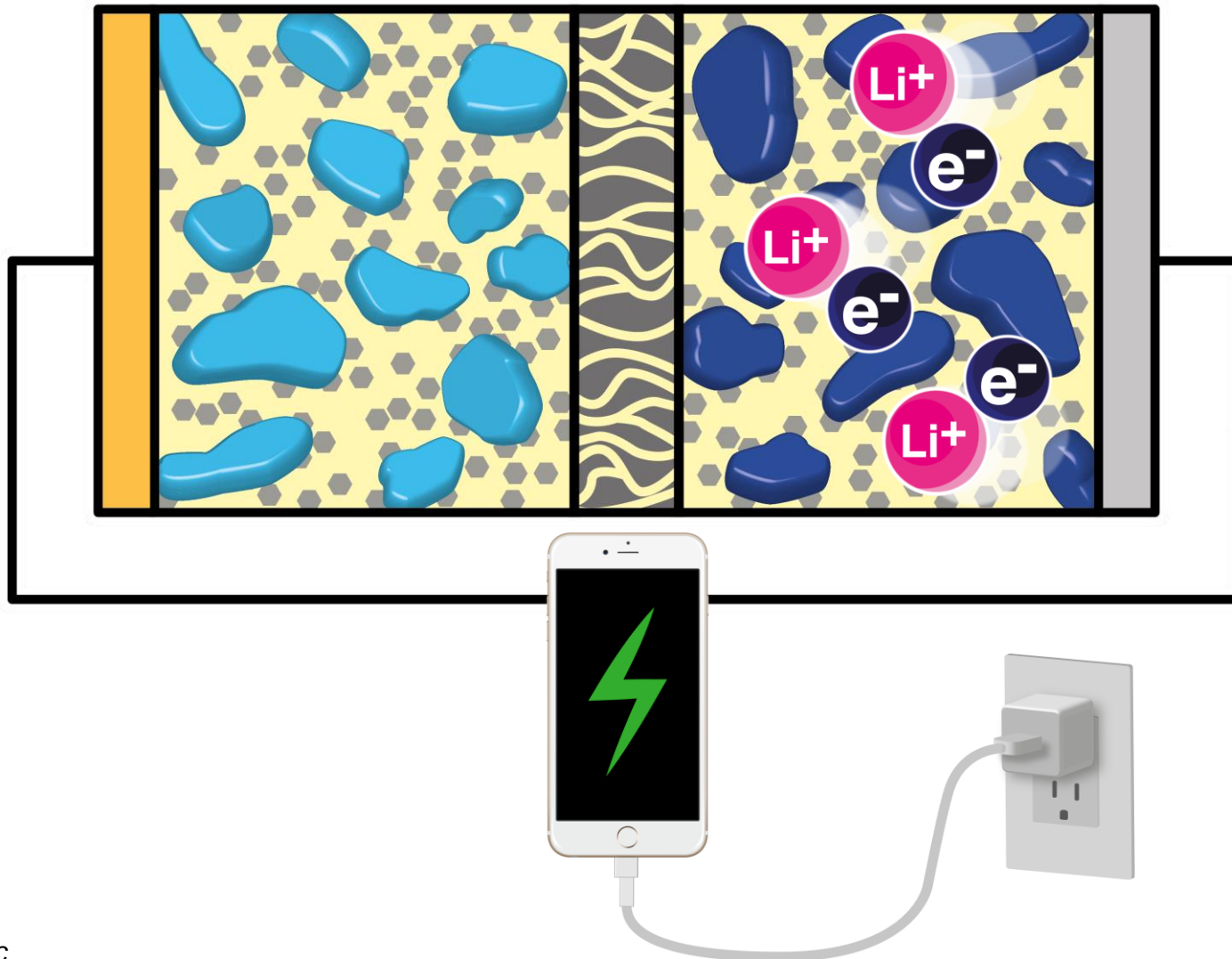
By 2020, materials projected to be > 70% of cell cost.

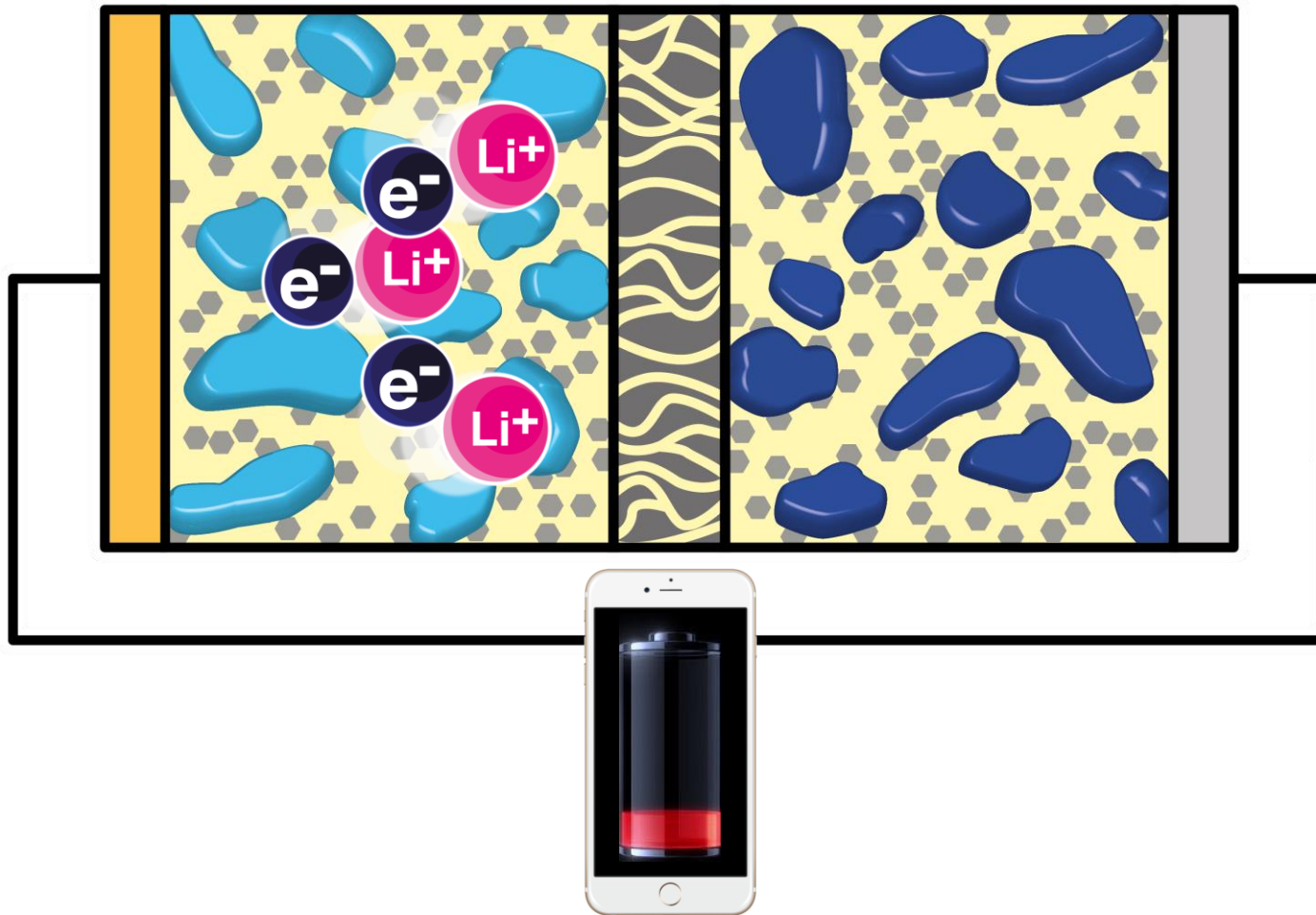
Price trends for electric vehicle batteries



Inside a lithium ion battery





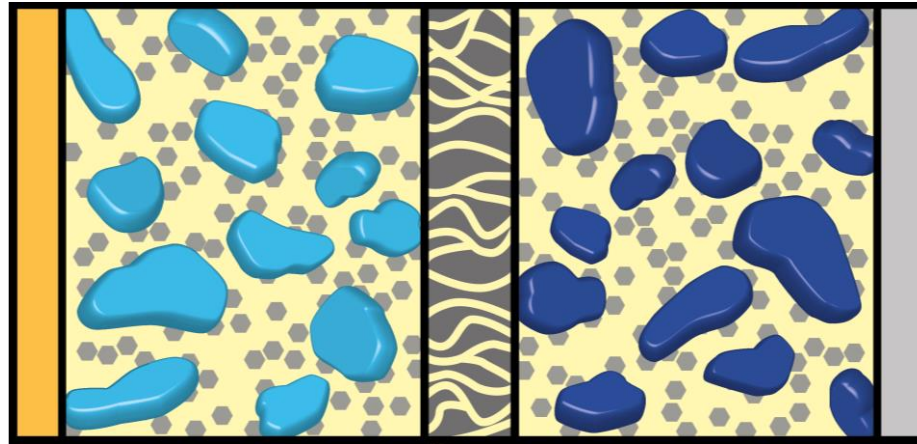


How can we improve a lithium ion battery?

Energy density

Charge / discharge speed

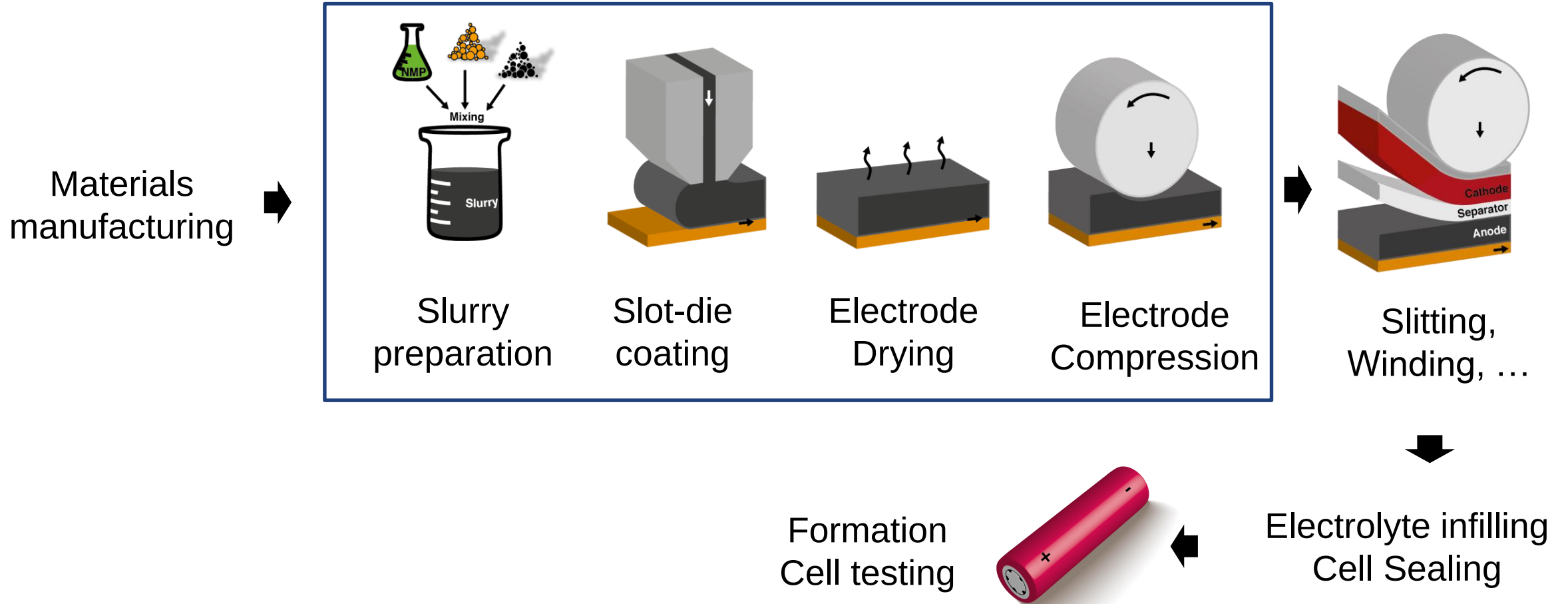
Cycle Life



Materials/Chemistry

Structure

Cell Manufacturing



“Incremental” Innovation

**Sony's
commercial LIB
1991**



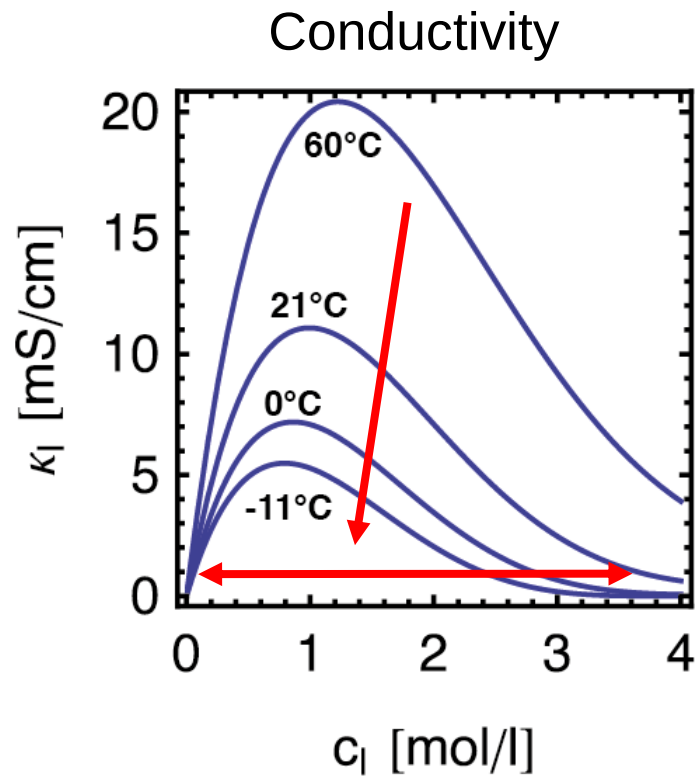
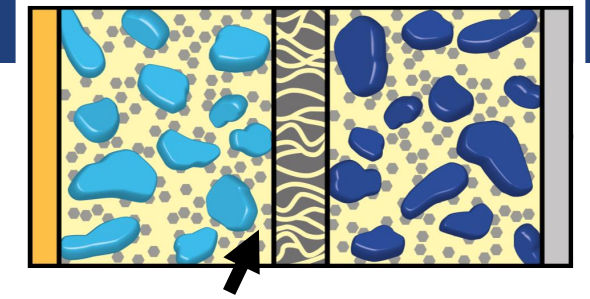
2018

Cathode: lithium cobalt oxide
Anode: soft coke carbon
Separator: polymer membrane
Electrolyte: organic solvent + salt

Cathode: lithium nickel manganese cobalt oxide
Anode: graphitic carbon
Separator: thinner, more wettable membrane
Electrolyte: complex solvent mixtures, salt & additives

~3x higher energy density

Electrolytes: The future is additives



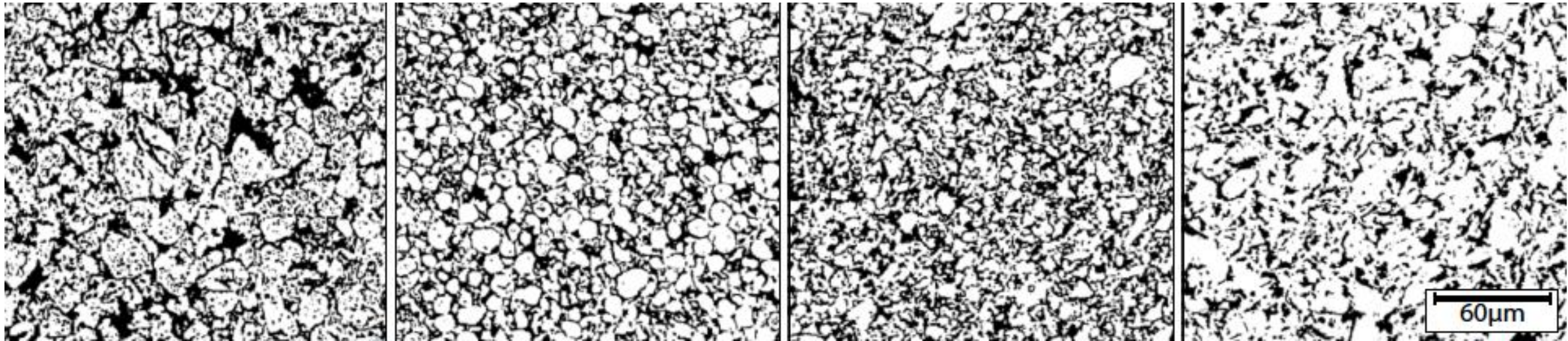
- Solvent (typically carbonates) + salt (e.g., LiPF_6)
- Low conductivity, means high resistance and, for a given current, a high voltage loss
 - Low temperatures
 - Non-uniformity
- Additives (e.g. addition of methyl acetate leads to 10 mS/cm at 0°C and 14 mS/cm at 20°C) ^[1]
- Active materials size and shape will influence homogeneity of salt concentrations in pore space during fast operation ^[2]

[1] E. R. Logan et al. *J. Electrochem. Soc.* (2018).

[2] S. Müller et al. *J. Electrochem. Soc.* (2018).

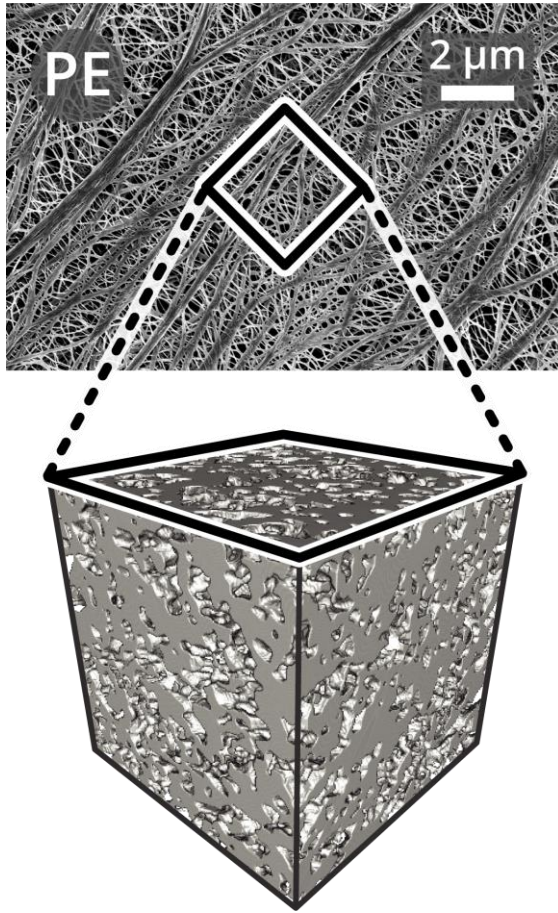
Heterogeneity

Images of 4 different commercial anodes from cells with similar power/energy ratings ^[1]

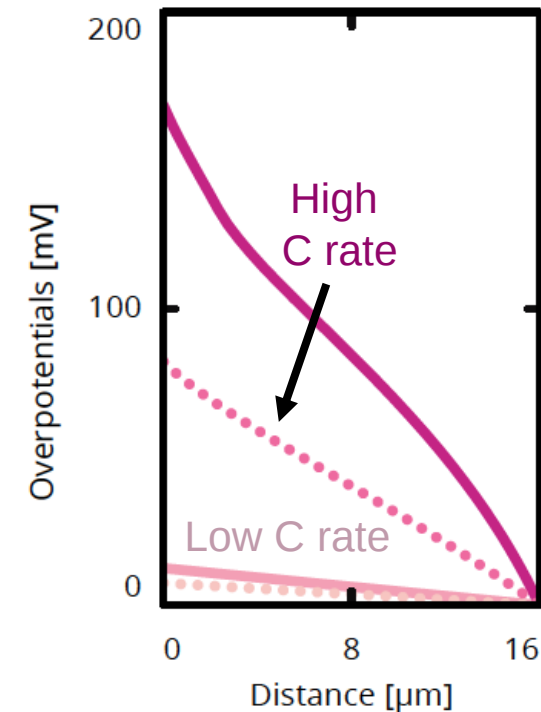
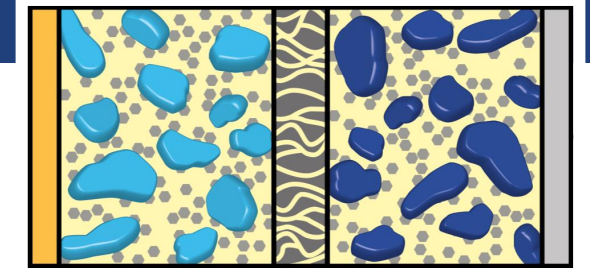


- We now have the tools to quantify heterogeneity in cells and understand how to control it

Separators: Optimizing structure & chemistry

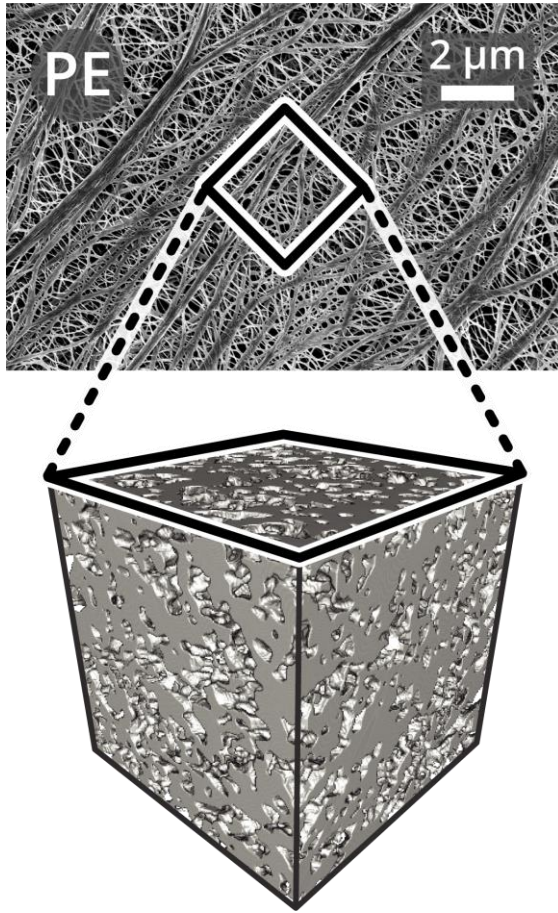
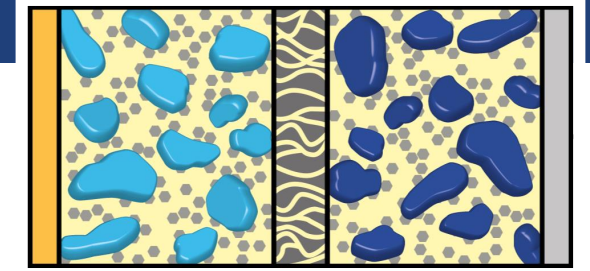


- Polyolefin member (12-20 microns thick w/ 40% porosity)
- ***Inactive component?***
 - Surface chemistry (wettability & interaction with Li-ions) ^[1]

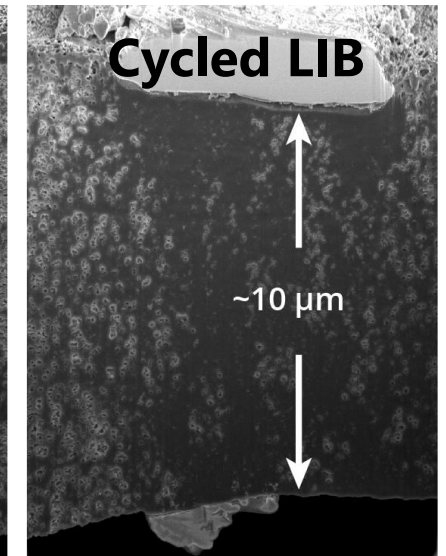
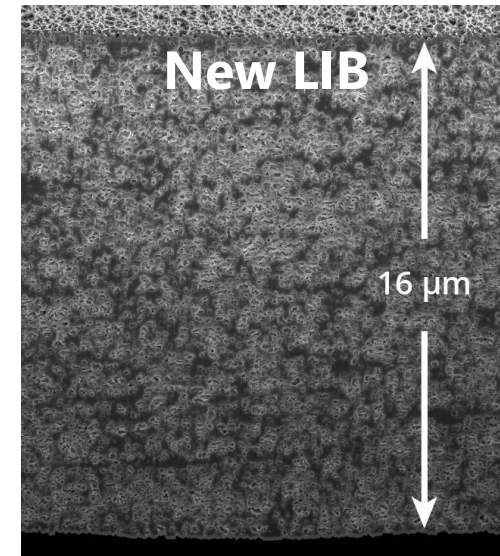


[1] R. Zahn et al., *Applied Materials and Interfaces* (2016).

Separators: Optimizing structure & chemistry



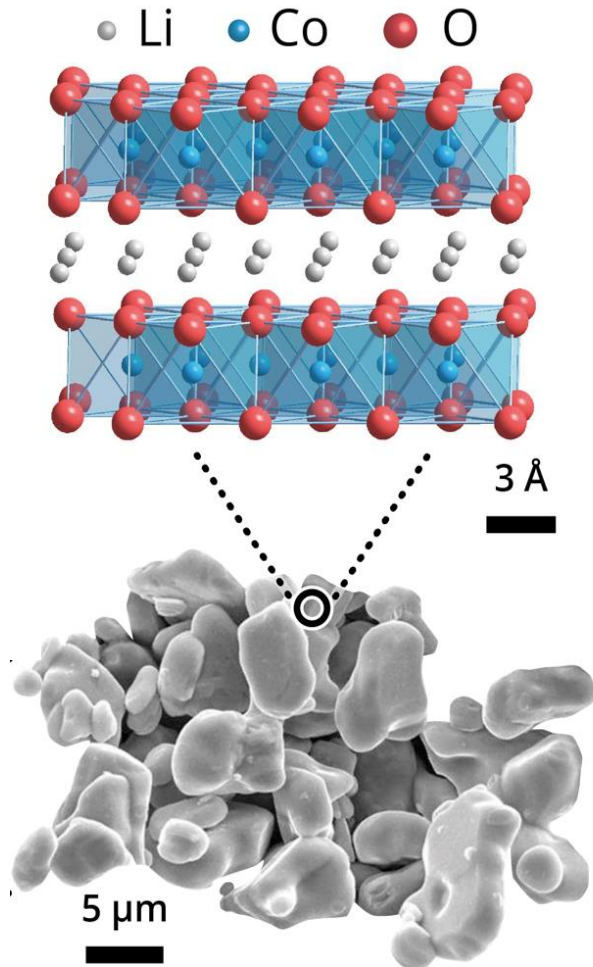
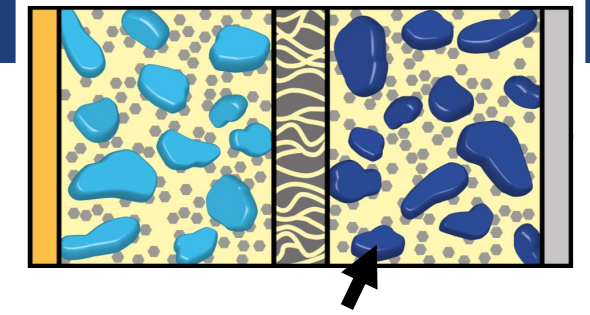
- Polyolefin member (12-20 microns thick w/ 40% porosity)
- ***Inactive component?***
 - Surface chemistry (wettability & interaction with Li-ions) ^[1]
 - Pore structure (mechanical stability vs. electrochemical performance) ^[2]



[1] R. Zahn *et al.*, *Applied Materials and Interfaces* (2016).

[2] M.F. Lagadec *et al.* *J. Electrochem. Soc.* (2018).

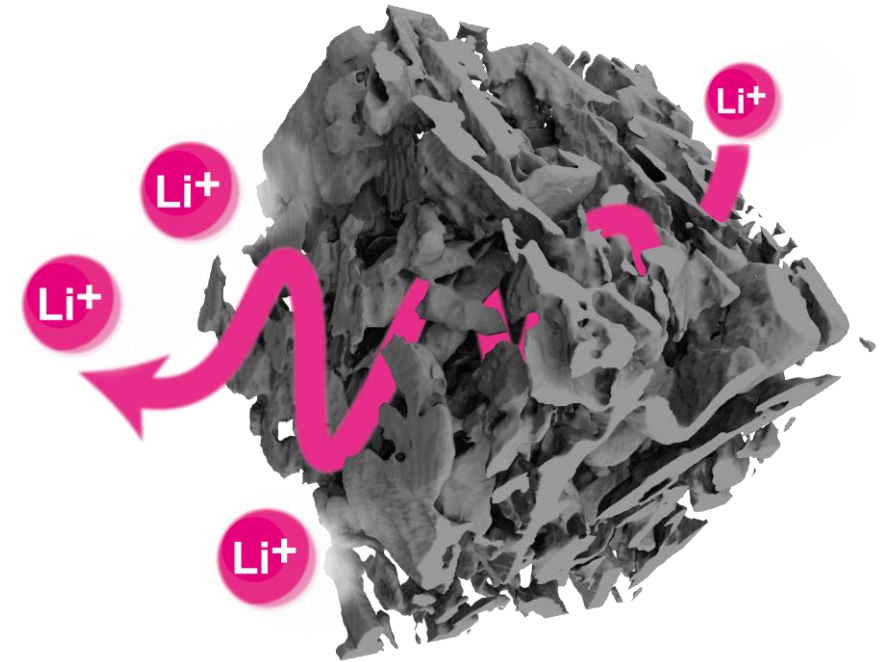
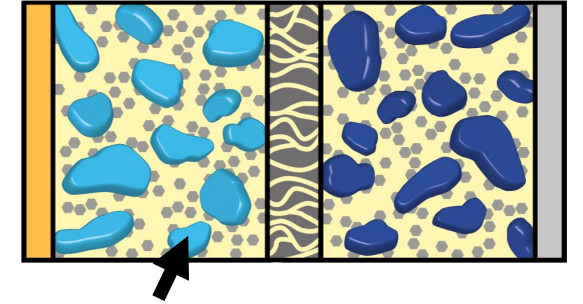
Cathodes: Optimizing structure & chemistry



- 1999: Co atoms in LiCoO_2 can be replaced by Ni or Mn to create metal-substituted cobalt oxides $\text{LiM}_x\text{Co}_{1-x}\text{O}_2$
- $\text{LiNi}_{0.5}\text{Mn}_{0.3}\text{Co}_{0.2}\text{O}_2$ (NMC 532) and $\text{LiNi}_{0.8}\text{Co}_{0.15}\text{Al}_{0.05}\text{O}_2$ (NCA) are used today
- Increase nickel content (e.g. NMC 811) for higher voltage, higher capacity, and lower cost

Anodes

- > 95% of lithium ion batteries use graphite
- Mechanically robust & low cost (battery grade graphite < 5 USD/kg)
- Pore structure of graphite electrode limits charging speed ^[1]

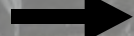


flake
graphite

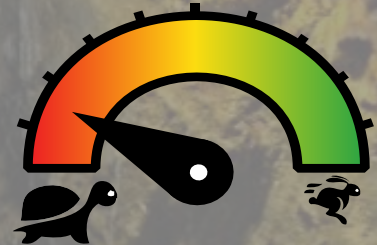
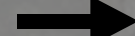
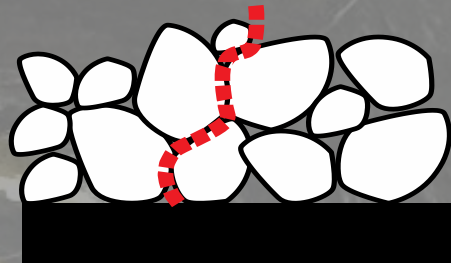
rounding

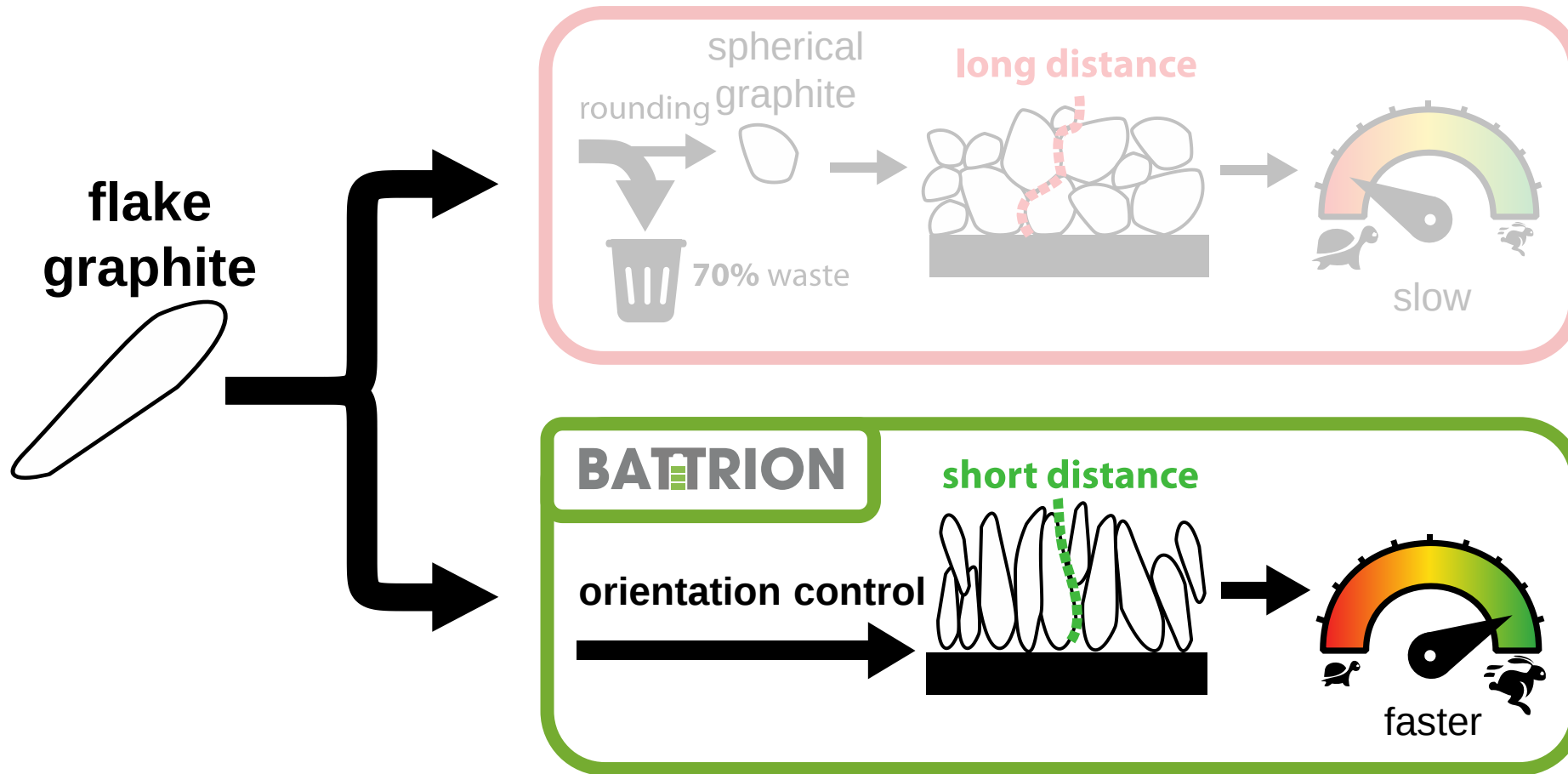


70% waste

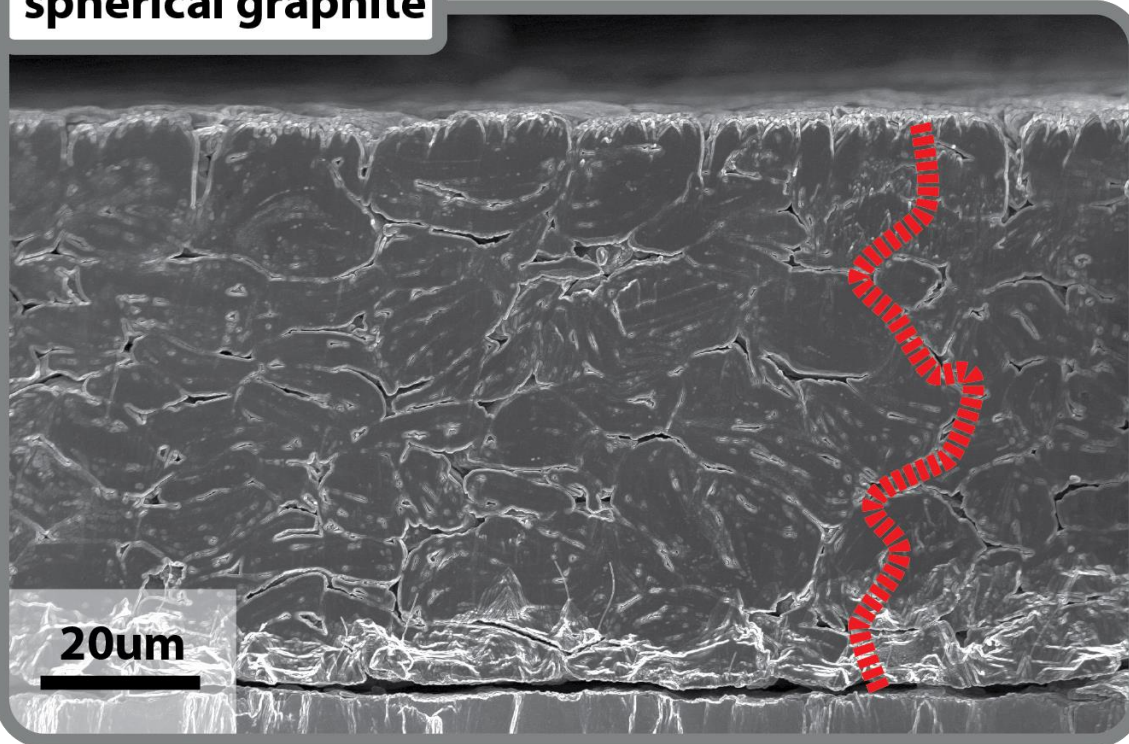


long distance

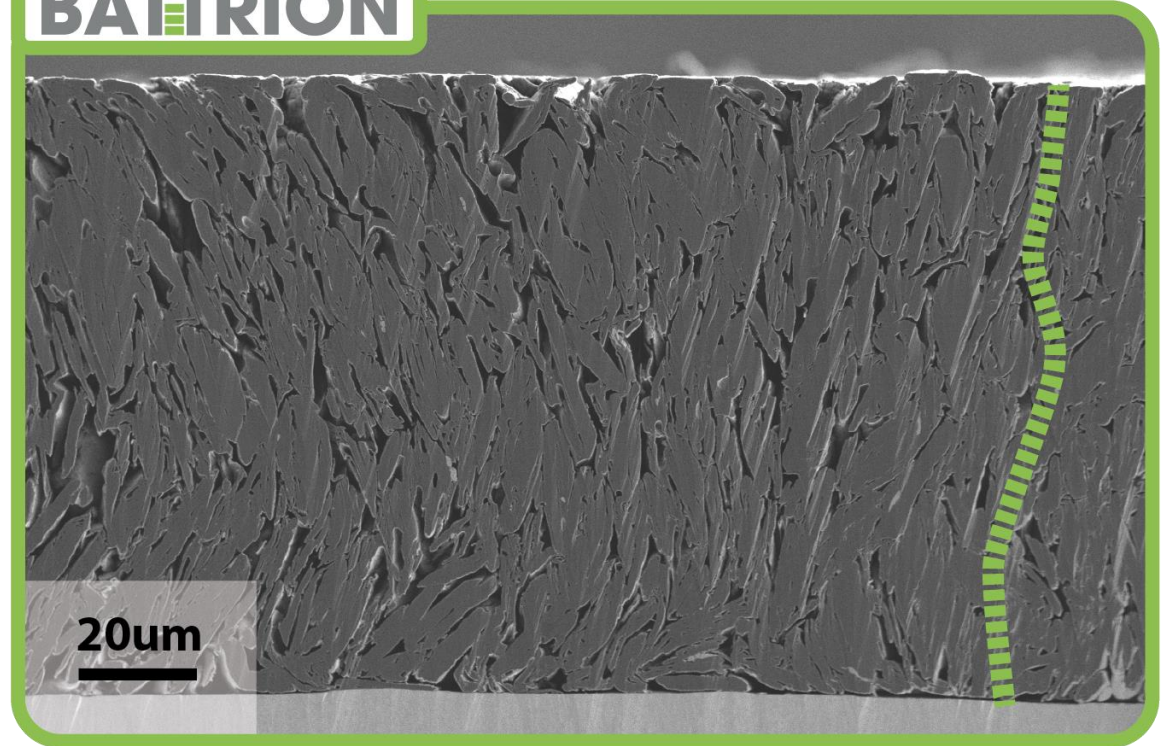




spherical graphite



BATRION





Complex interplay between
electrochemical and mechanical effects

Conclusions

- Lithium-ion batteries have proven themselves as a storage technology
- The myth of new technology with “X-fold” improvement
- Batteries are complex, dynamic systems, where understanding lags behind development
- As understanding of internal processes improves, opportunities to improve cycling protocols & battery management systems
- Continuing innovations in materials and manufacturing have the potential to improve lifetime, energy density, and rate capability while lowering costs