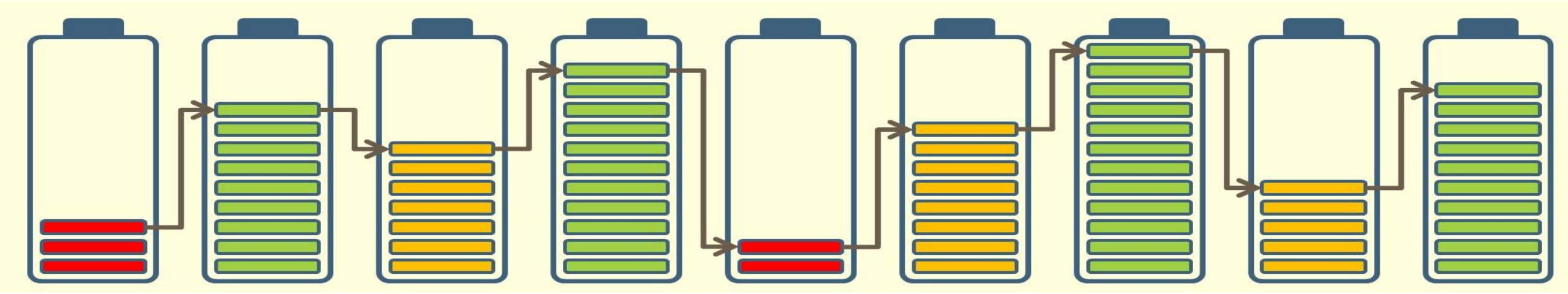
From materials to vehicle – what, why, and how?
→ From vehicle to materials

Helena Berg

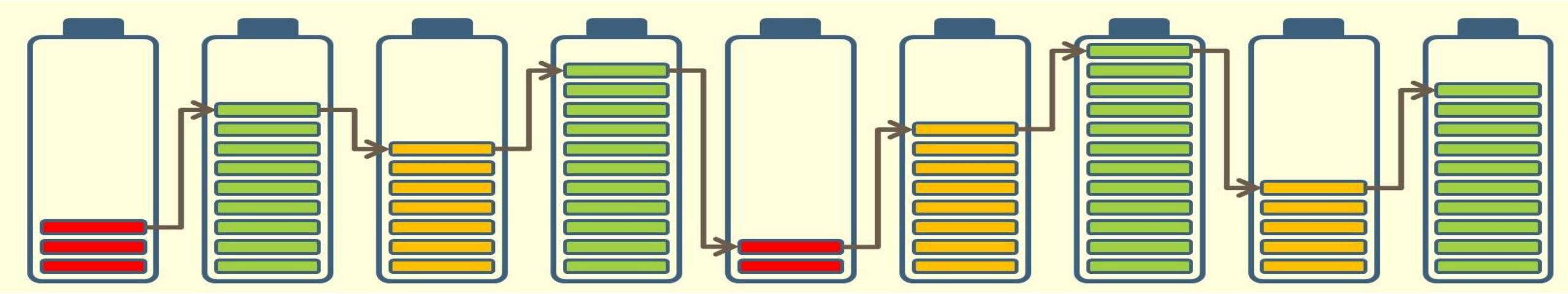


Libergreen

Outline

1. Electric vehicles and requirements
2. Battery packs for vehicles
3. Cell selection
4. Material requirements
5. Li-ion materials
6. From material to cell
7. From research to production

1. Electric vehicles and requirements



Types of electric vehicles (xEV)

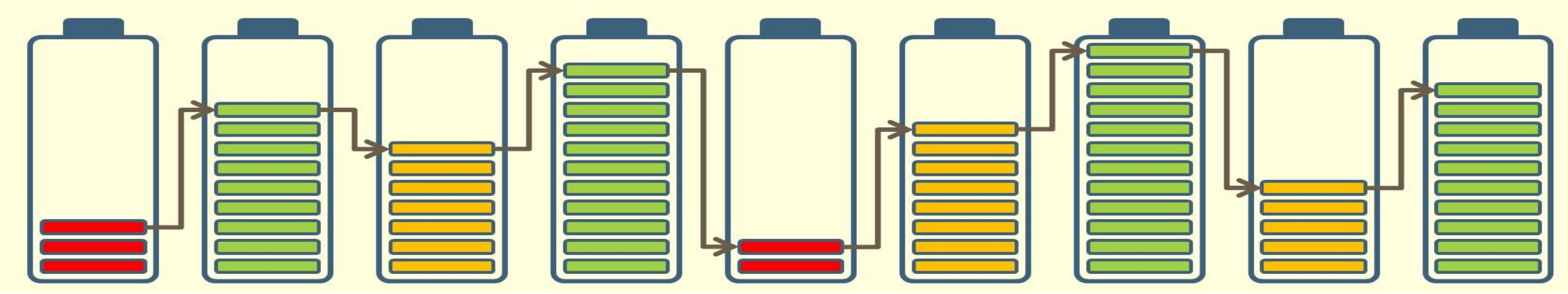
- Start/Stop
- Mild hybrids (HEV)
- Strong (or full) hybrids (HEV)
- Plug-in hybrids (PHEV)
- Full electric (EV, BEV, PEV)
  - PEV can also be FCEV or FCV

Vehicle requirements

- Electric driving range
- Vehicle weight
- Roll and drag resistance
- Packaging limitations
- Operational conditions incl. auxillary loads
- Performance (e.g., BMW's 'fun to drive')
- Climate/Geographical constrains
- Durability
- Cost
- Service needs
- Charging

All must be met

2. Battery packs for vehicles



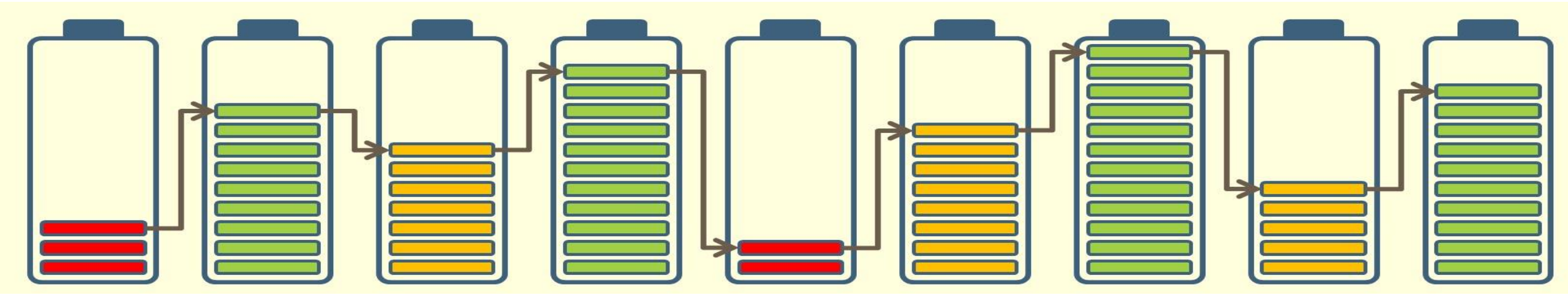
A battery pack includes….

- Cells
  - Often in modules
  - Connected in Series (and Parallel) – e
- Electronics
  - Supervision and Balancing
- Wires for current distribution (often Cu)
- Cooling
  - Liquid or Air; Active or Passive
- Control unit
- Fuses
- Disconnect unit
- Connectors
- Housing and safety protection

Cells 50-75 % of pack weight and ca 75 % of pack cost

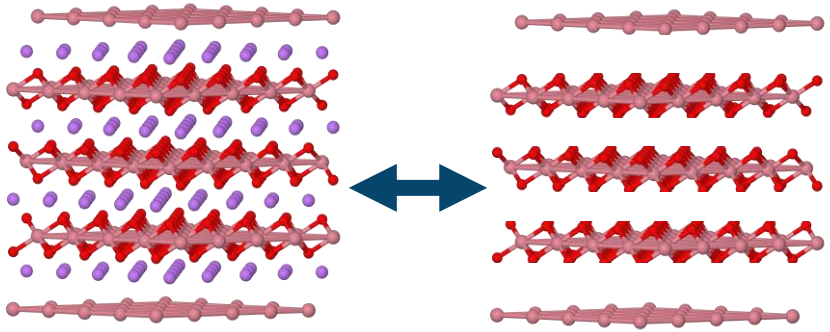
Battery control

- State of Charge (SOC) - minutes
- State of Power (SOP) - seconds
- State of Health (SOH) - months



State of Charge

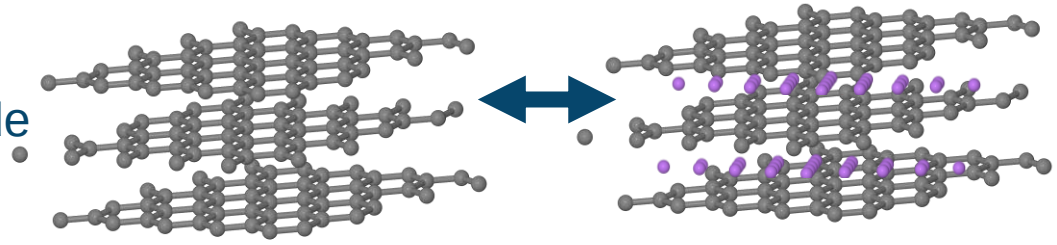
Cathode

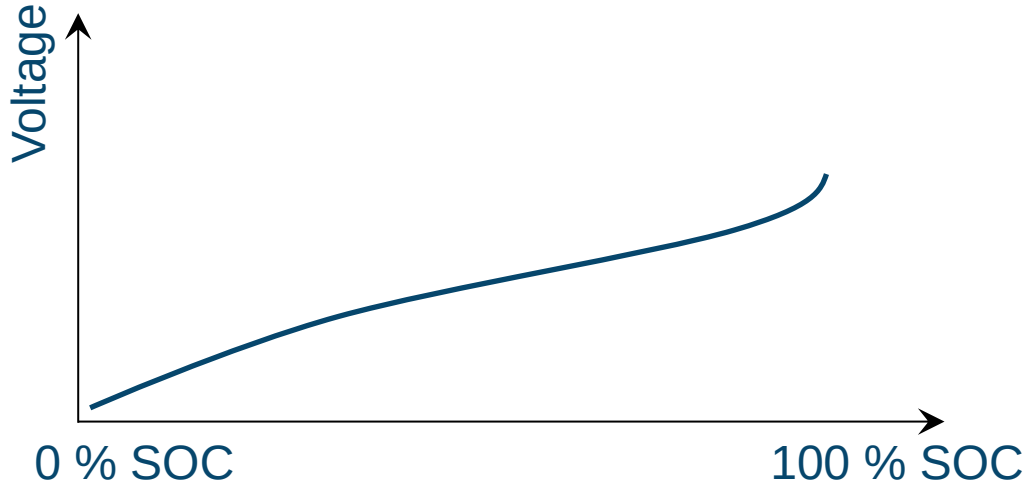


SOC 0 %

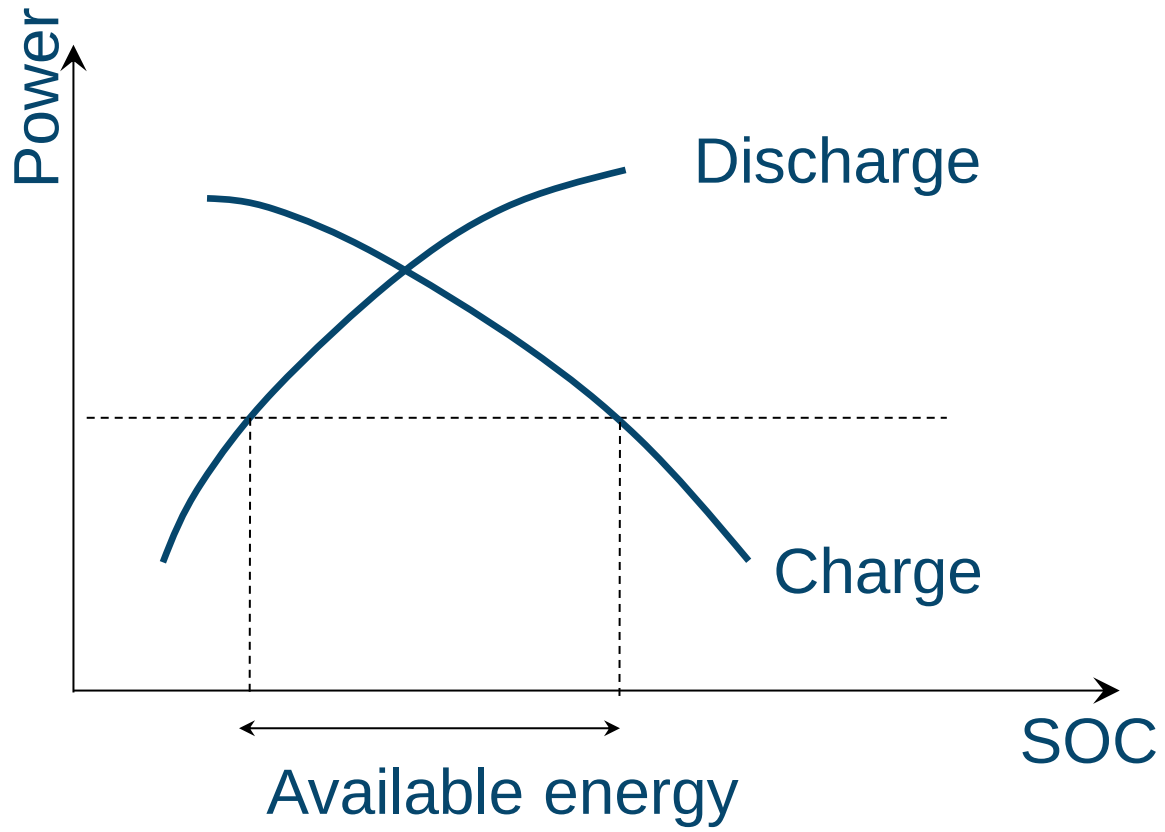
SOC 100 %

Anode



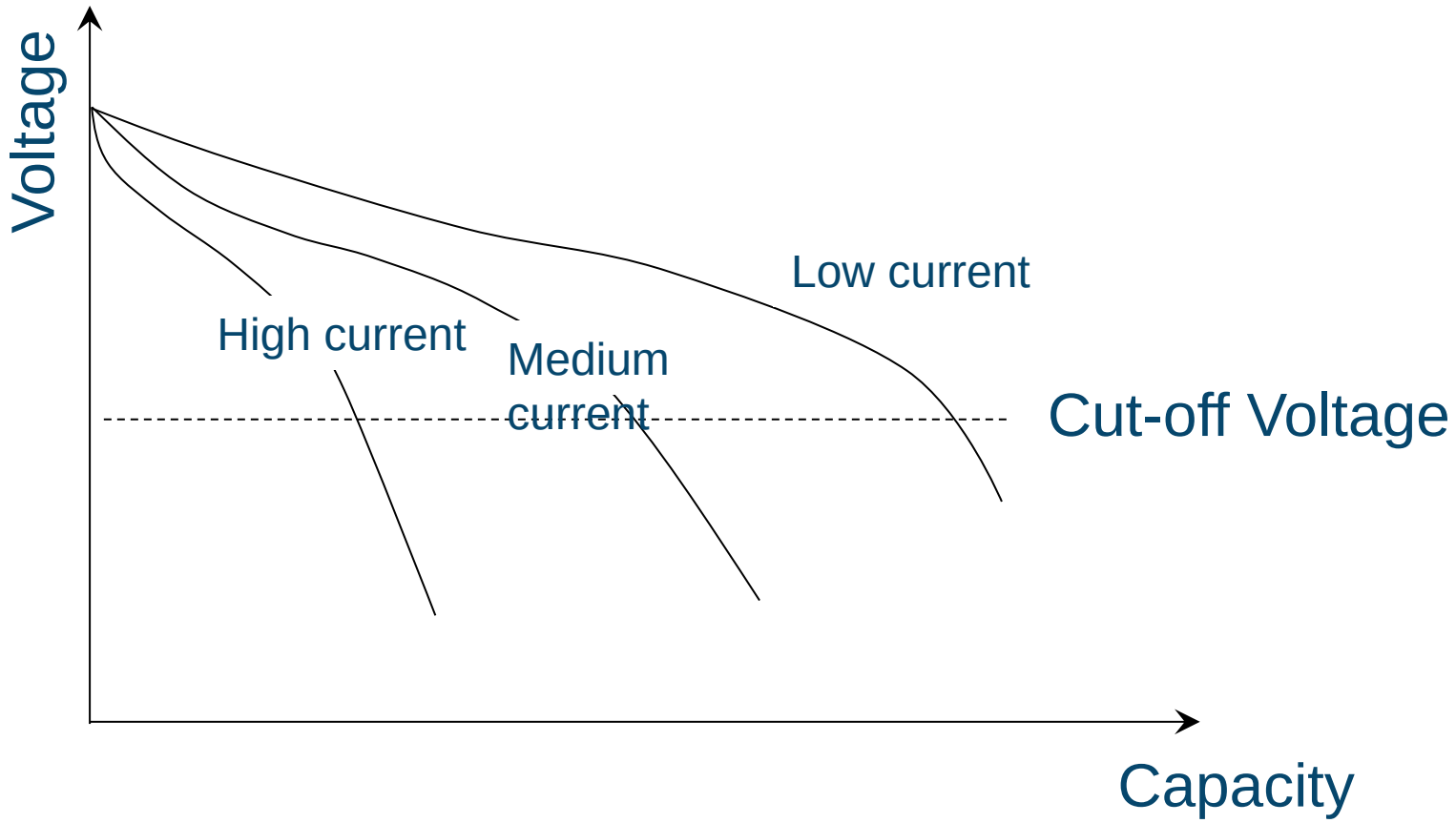


State of Power vs. State of Charge

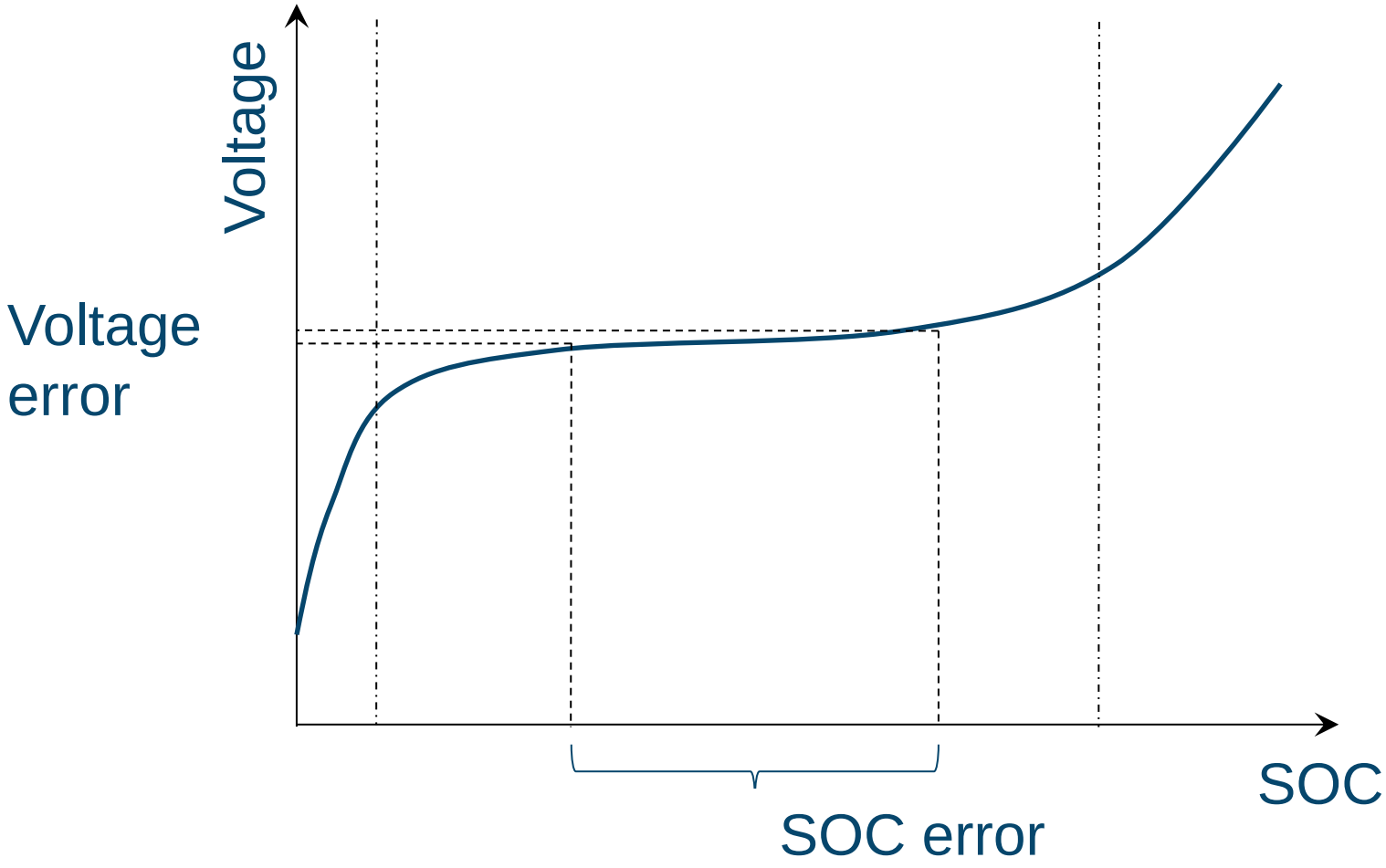


Libergreen

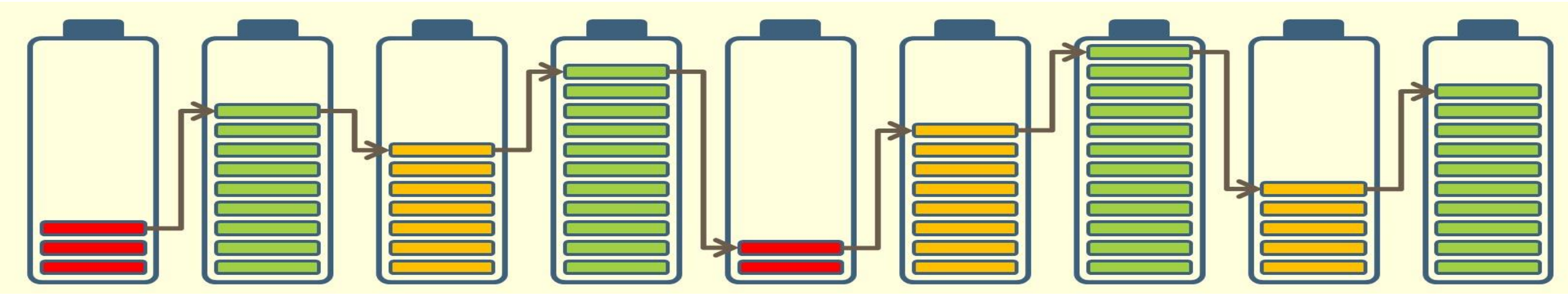
Current effects



Control accuracy



3. Cell selection



Type of vehicle; Degree of electrification; Electric driving range; Vehicle weight;
Roll and drag resistance; Usage profile; Auxillary loads; etc.

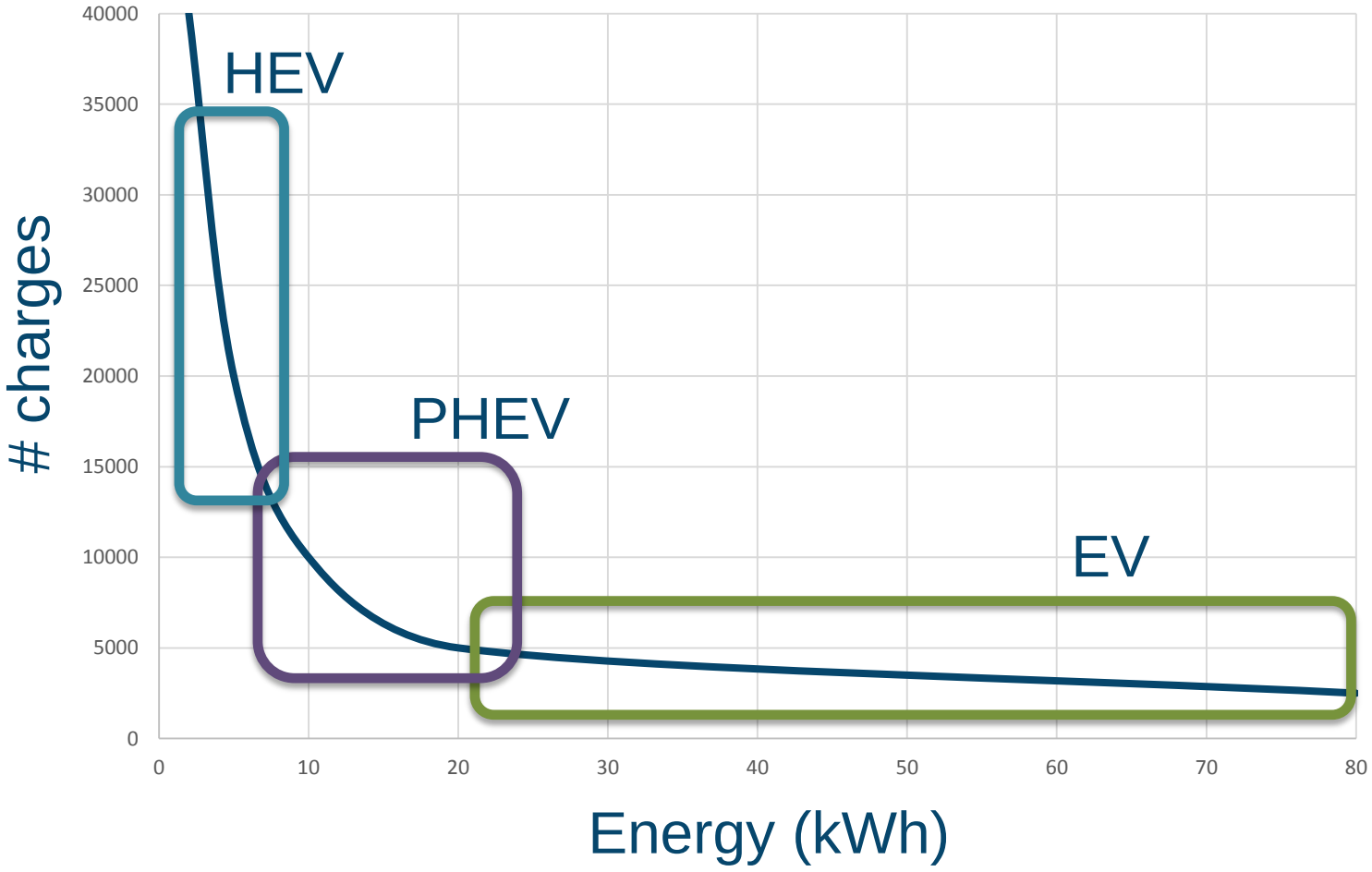
Energy and Power Requirements

+

Packageing and climate constraints

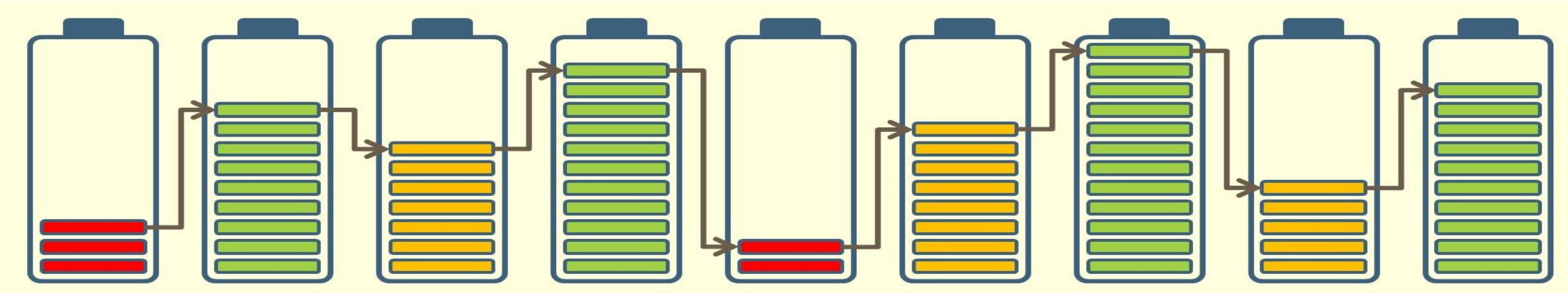
Battery weight & volume; Voltage and SOC range;
Operational conditions; Durability; Cost; Service needs; etc.

Charging



Libergreen

4. Material requirements



Energy

500 Wh/kg → 2 km

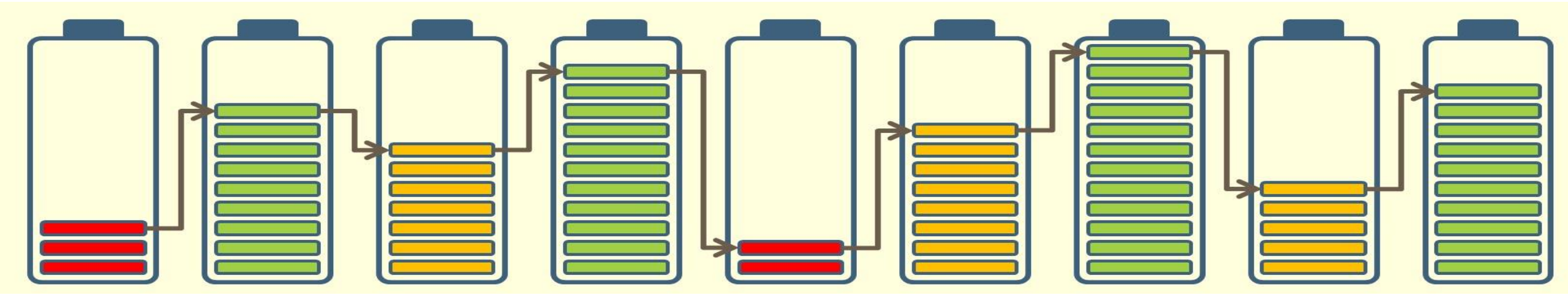
250 Wh/kg → 1 km

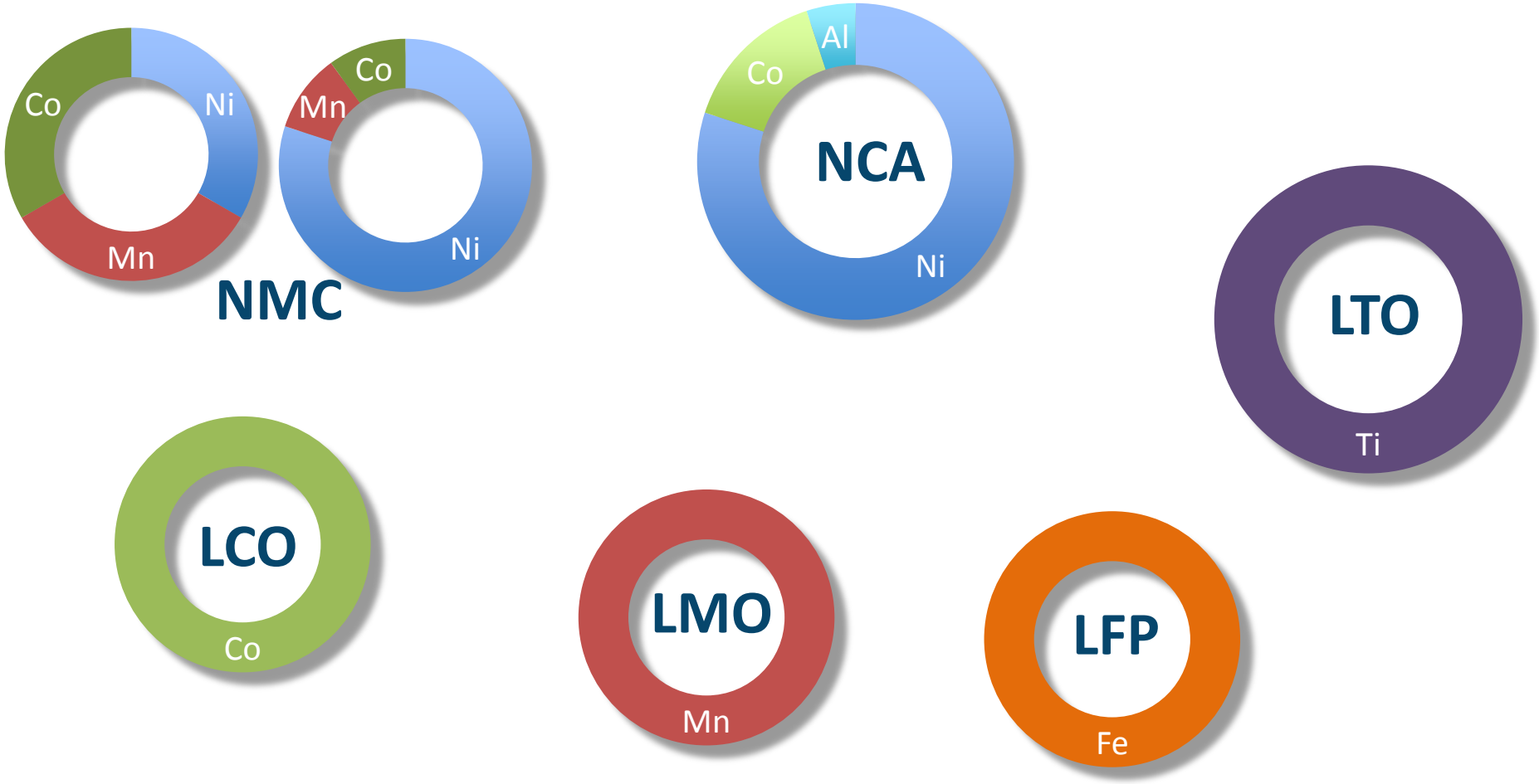
125 Wh/kg → 0.5 km

Material properties needed

- High capacity (mAh/g) → high energy density
- Low impedance → good power
- High ion conductivity → fast-charging and accelerations
- Stable materials within wide potential and temperature ranges
- Number of charges → long durability
- Sustainable materials and production proceses → low cost?
- Stable in air → handling and cell production
- Low toxicity → handling
- Low-cost materials → low-cost cells?
- …

5. Li-ion materials

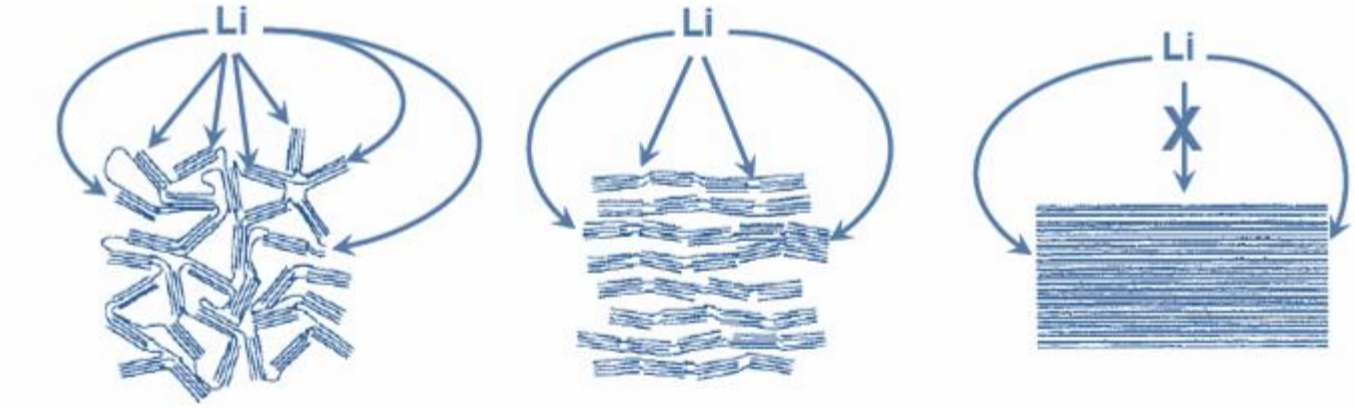




Libergreen

Anodes: carbons most commonly used

Hard Carbon | Soft Carbon | Graphite

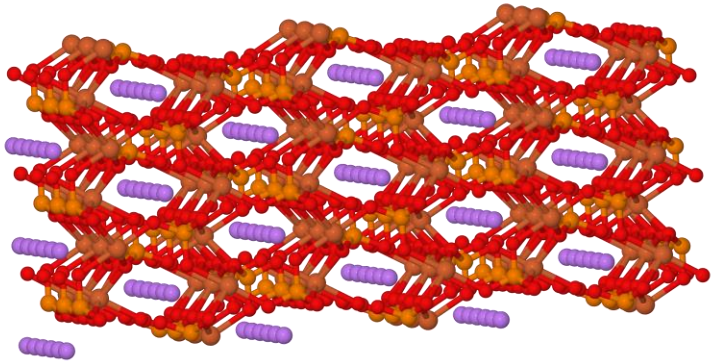


High power ← - - - - - - - - - - - - - - - - - - → Low power

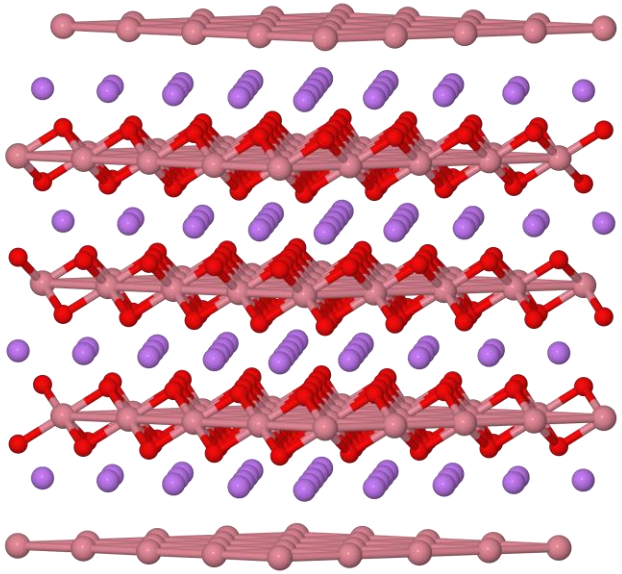
Anodes: comparisons

Material	Energy	Power	Safety	Cycling stability	Cost (per Ah)
Graphite					
Hard carbon					
LTO					
Si					
Li-metal					

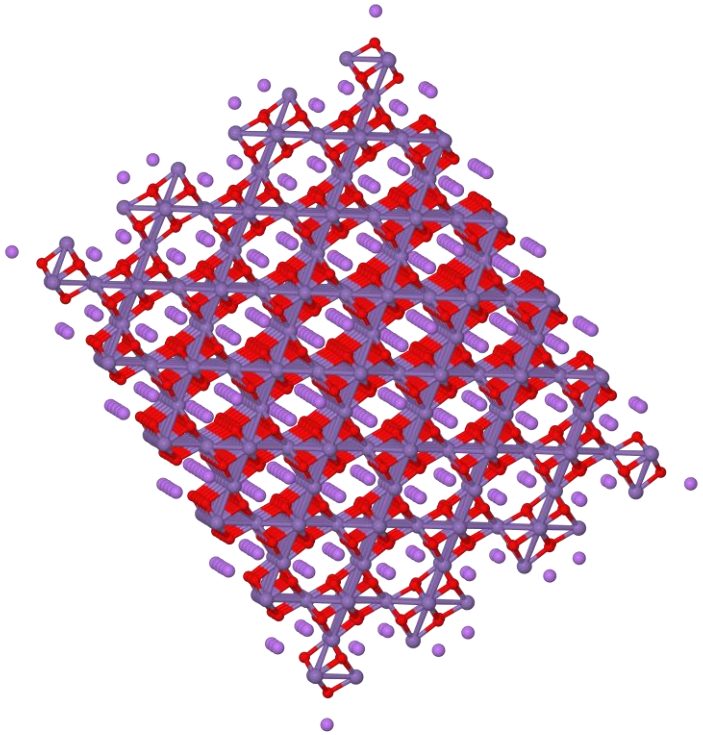
Cathodes: transition metal oxides/phosphates



$LiFePO_4$



$LiCoO_2$, $Li(NiCoAl)O_2$, $Li(NiMnCo)O_2$

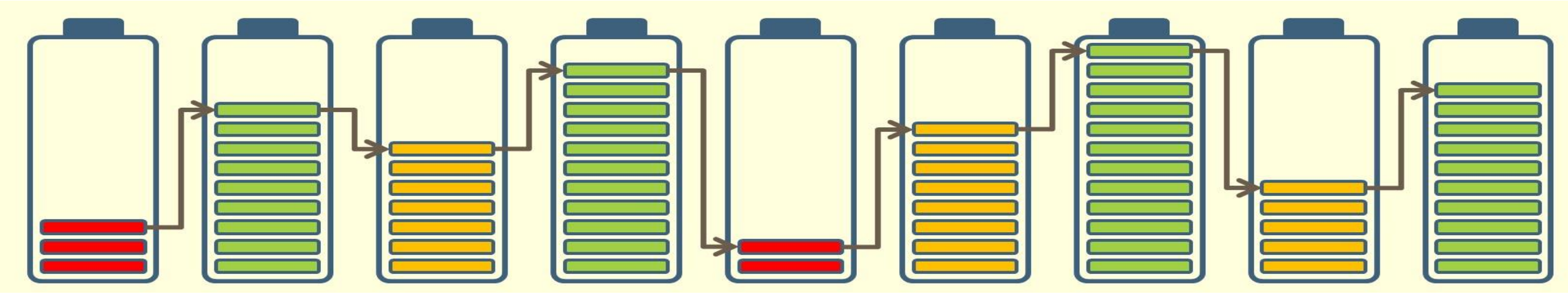


$LiMn_2O_4$

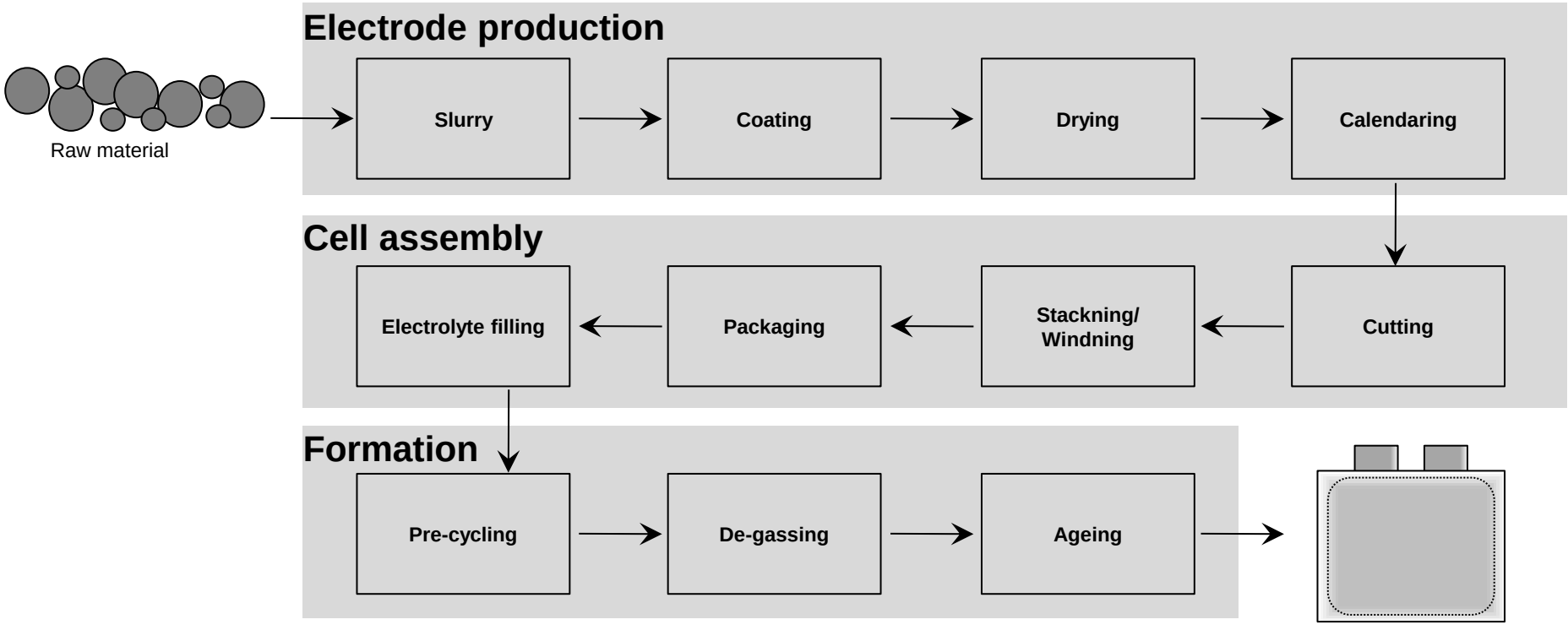
Cathods: comparisons

Material	Energy	Power	Safety	Cycling stability	Cost (per Ah)
LCO					
NCA					
NMC					
LMO					
LFP					
LMO-NMC					

6. From material to cell

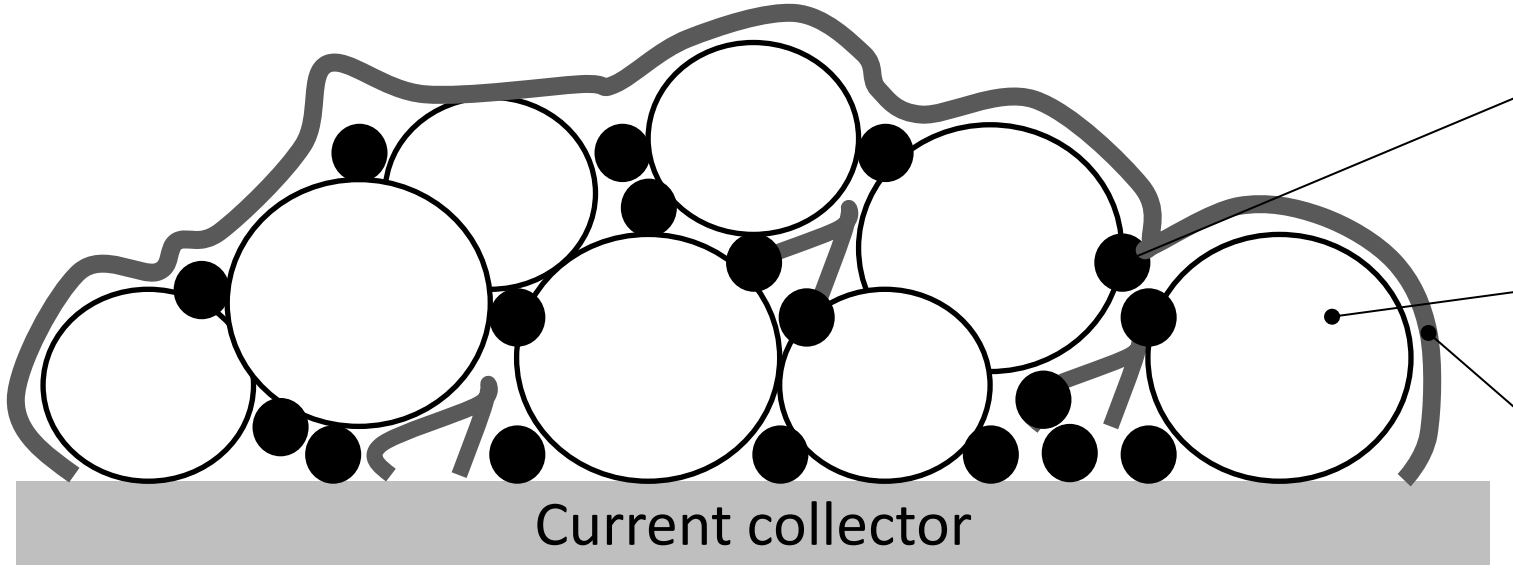


Cell production



Libergreen

Electrode design



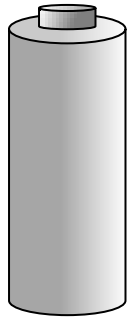
Electronically conducting particles

Active material

Binder

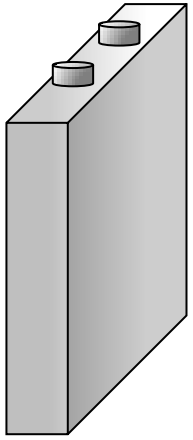
Thickness: ~50-250 μm
Loading: ~5-50 mg/cm^2
Porosity: ~40%

Cell format

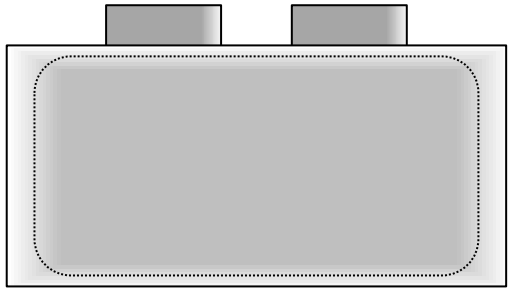


Cylindrical

Ex 18650

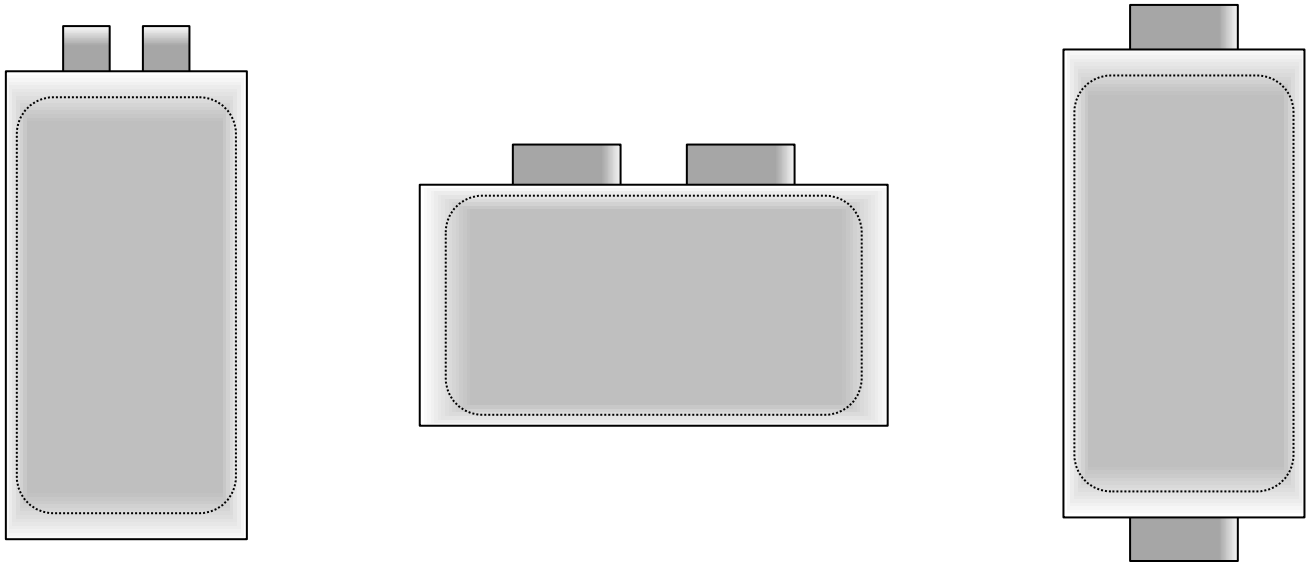


Prismatic

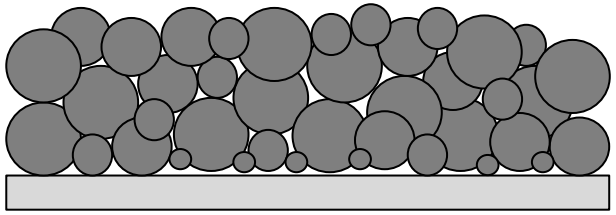


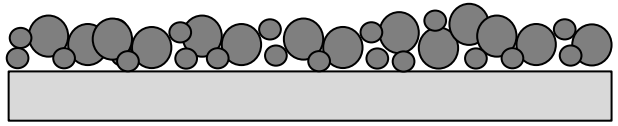
Pouch

Cell format



Energy or power optimised cells

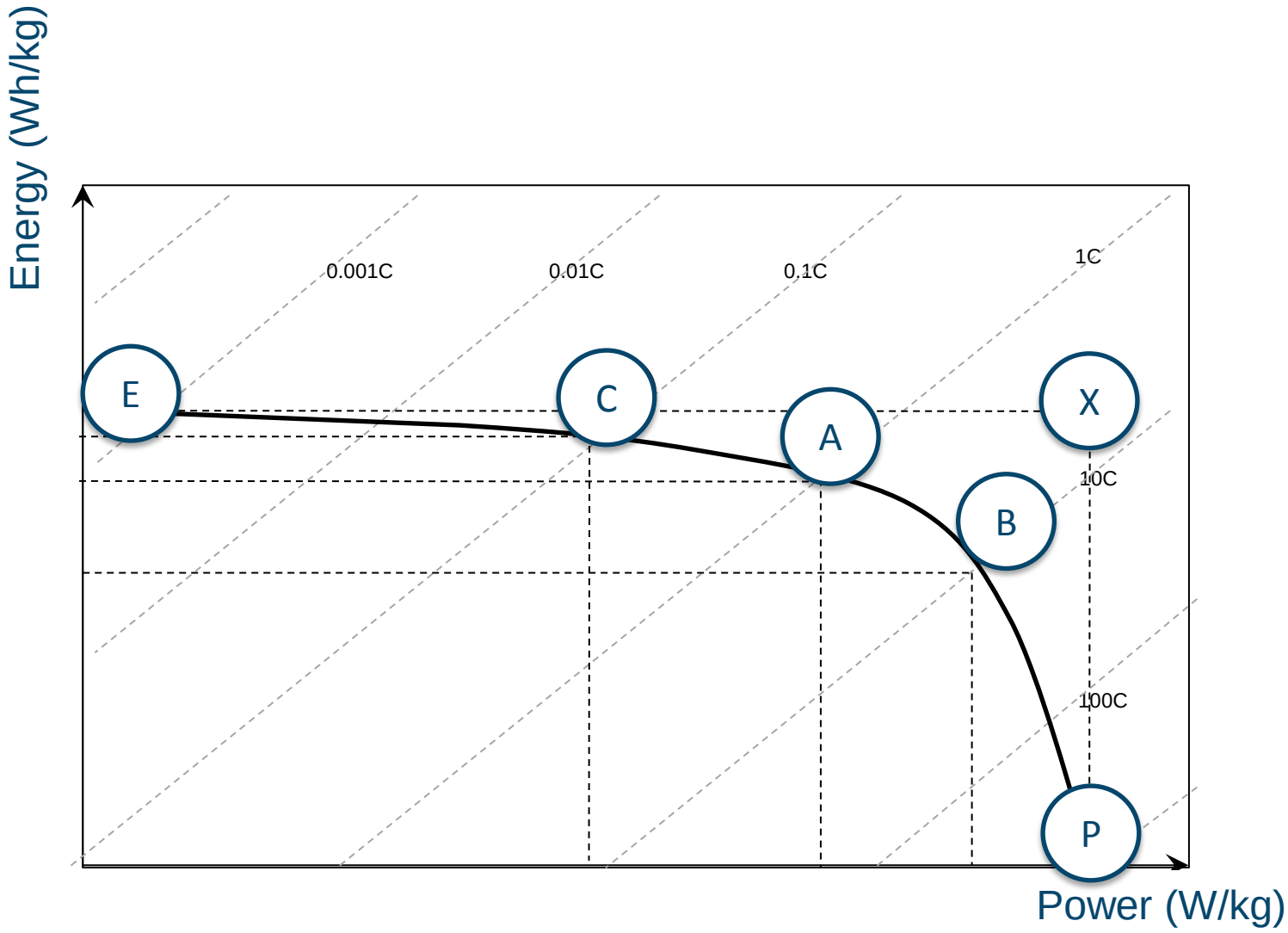




- Higher loading per cm^2
- Low currents to enable mass transfer, solid state diffusion, …

- Smaller particles
- Thicker current collectors to enable high currents (temperature issues if too thin)

Ragone plot

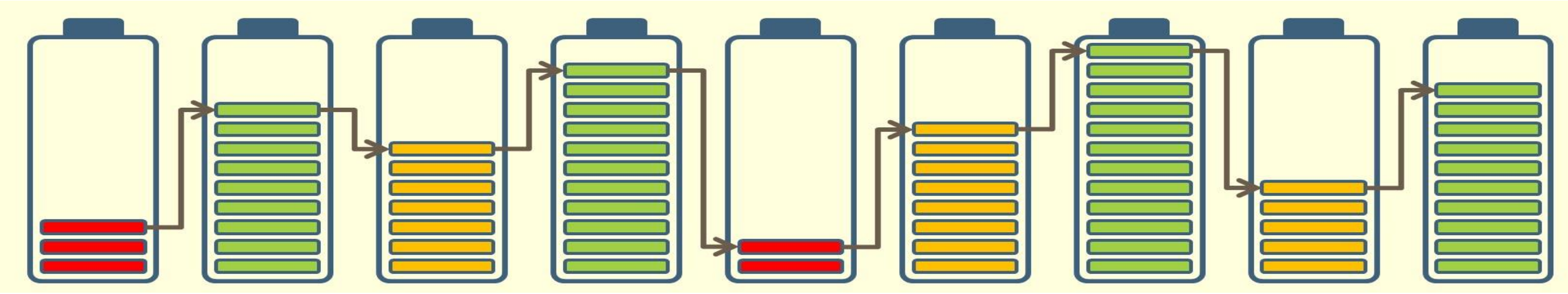


Energy & Power

- How to increase Energy?
  - Increase the cell voltage
  - Use a cathode and anode materials with higher reversible capacity
  - Use a concept enabling higher cell voltages
  - Use concepts involving multivalent charge carriers
- How to increase Power?
  - Active materials with high Li ion diffusion
  - Electrode design – thickness, porosity, conductivity, particle size
  - Minimise resistance in materials, electrodes, cell and battery
  - Select active materials enabling fast ion diffusion

→ All related to material properties

7. From research to production



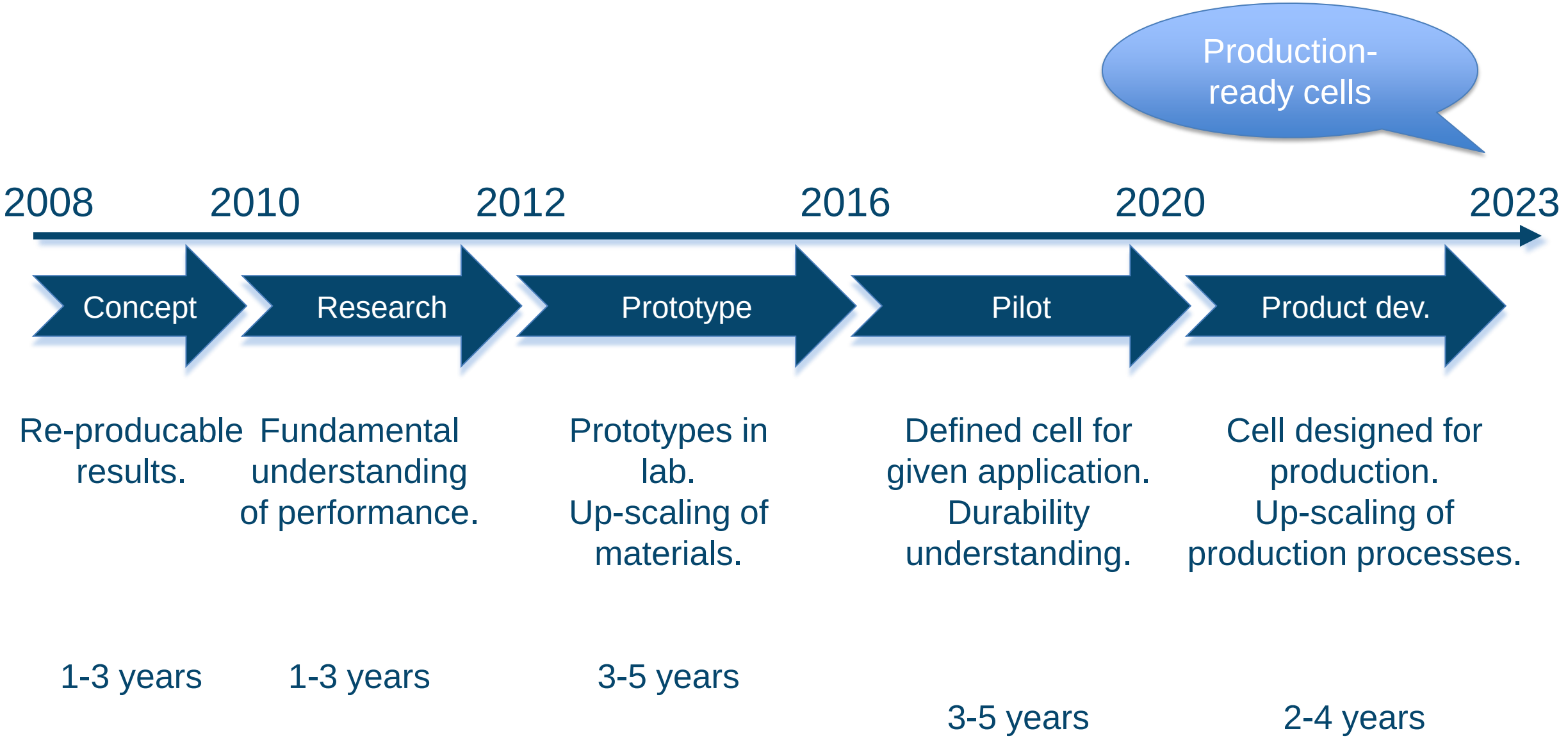
2018 2023 2026 2030

Cell development

Adv. Engineering

Product development

Production-ready cells for given application

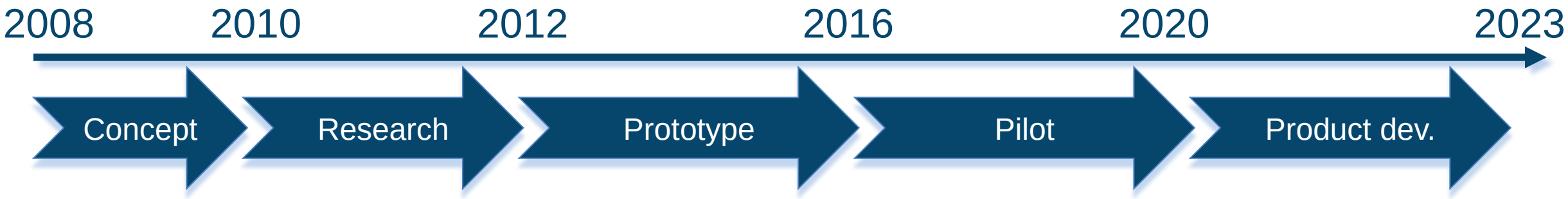


Libergreen

- Li/Na-air
- Ca, Al

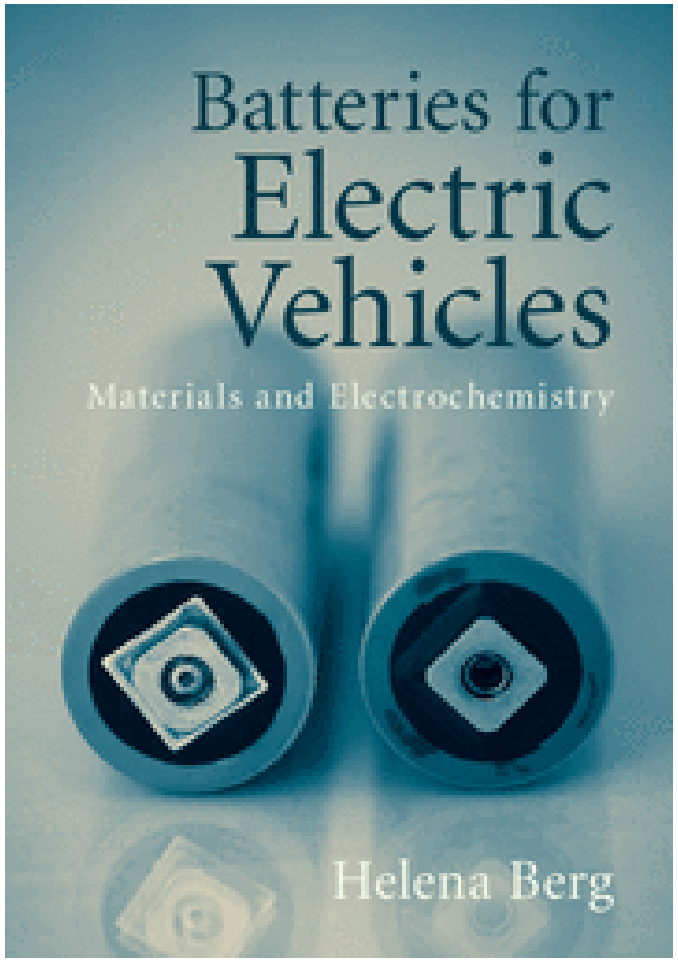
- Solid-state
- Mg

- Improved Li-ion
- Na-ion
- Li-S



- Production processes
  - Energy usage, etc.
- Minimize inactive materials
- Optimize specific properties
  - Optimize material properties
- Application-adapted cells

Further reading…



Thank you…