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Current and future trends within lithium-ion battery chemistry

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IFE
Institute for Energy Technology
Non-profit foundation
Research on energy

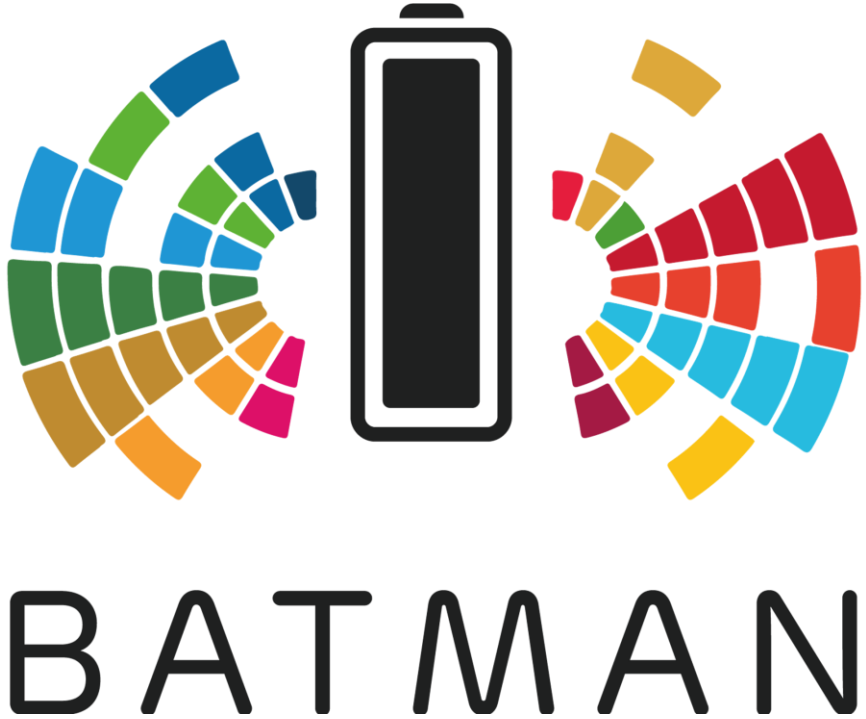
Battery Technology department at IFE

- Large research group working on batteries for 10 + years
- Working on a broad range of topics in the battery value chain
- Specializing in
  - Silicon-based materials as anode
  - Materials, cell development and testing at R&D scale
  - Lifetime and degradation testing of commercial battery cells

The BATMAN project

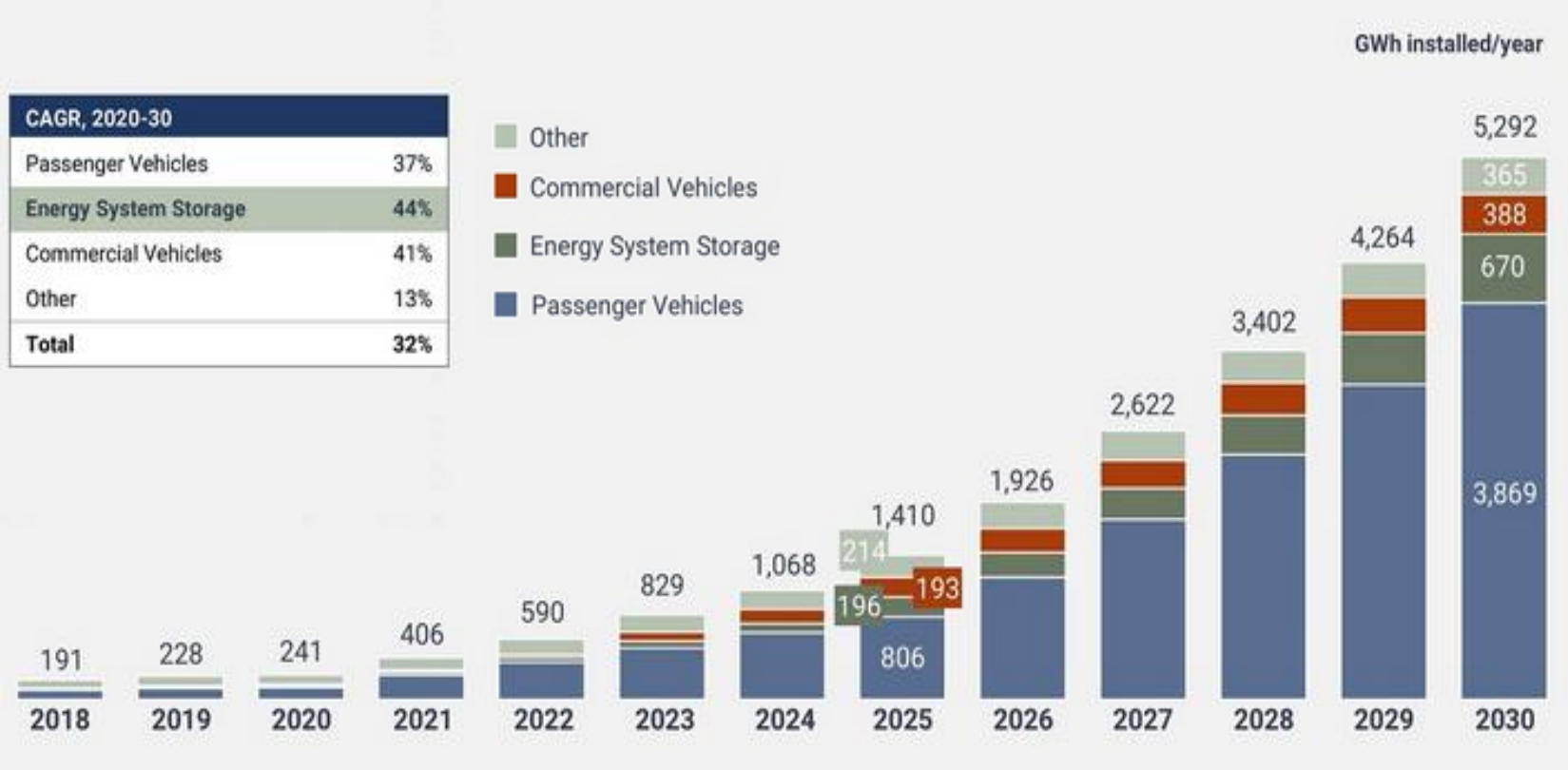
- BATMAN - Lithium ion BATteries – Norwegian opportunities within sustainable end-of-life MANagement, reuse and new material streams
  - Lead by EydeCluster (2019-2022)

- The main goal is to make it possible for Norwegian companies to take leading positions in the rapidly growing international battery market
- The project will develop a predictive model that defines the demand for material and secondary use/recycling volumes which can be used as a strategic tool for the industry
- IFE is responsible for giving input to this model by delivering a scientific report on LiB technology mapping



Global battery demand

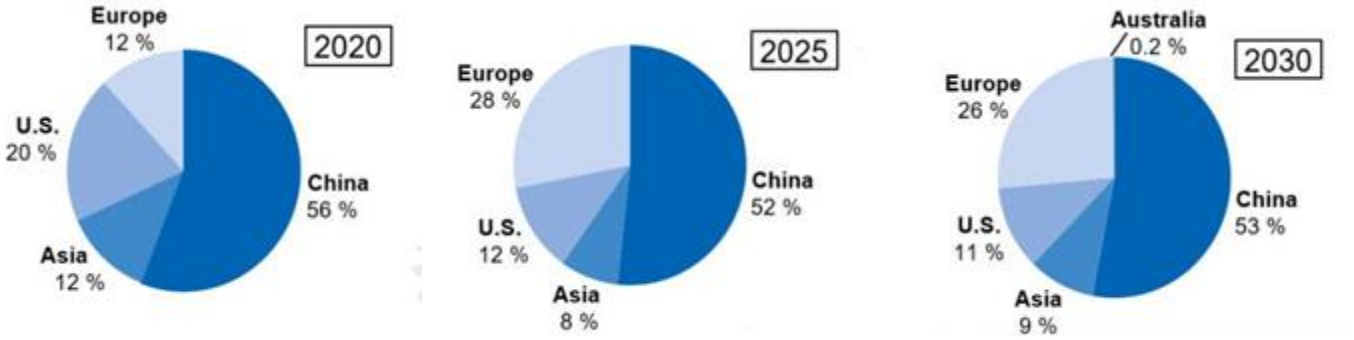
- Prediction of future battery demands vary in amount
  - Trend is the same for all studies, exponential increase
  - Estimations for 2030 vary between 2600 – 5300 GWh
- Also expect larger increase in stationary storage segment



Ref. Freyr presentation at Watts up!, 2021

Production of battery cells

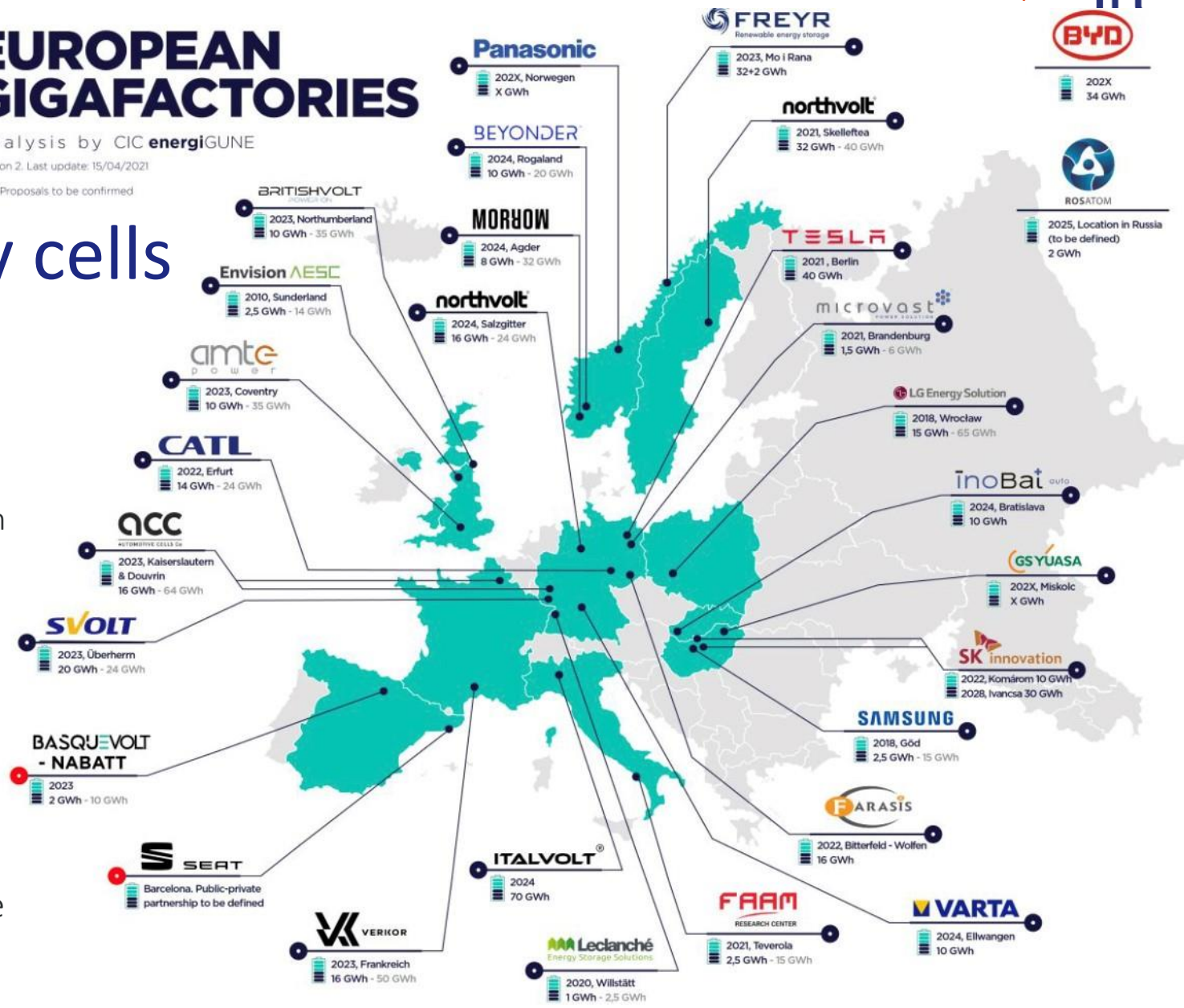
- Today, 400 GWh of cell production capacity
- 1600 GWh production projects are announced
- Might see short-comings of battery cells in 2023/2024
- Asia still dominating the production:
  - > 50 % will be located in China



Source: BNEF BMI

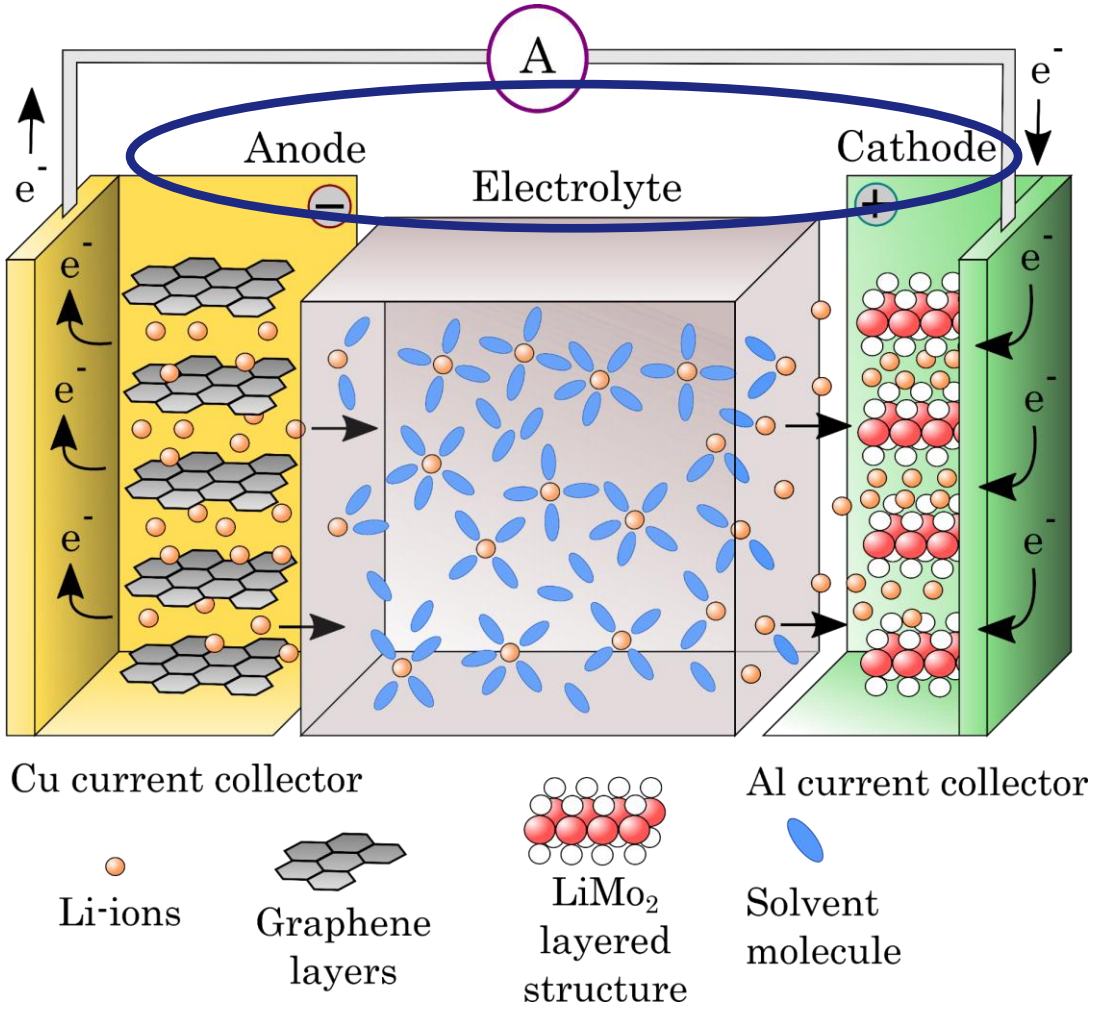
Production of battery cells

- Several new initiatives in Europe
  - New actors
    - Freyr, Morrow, Northvolt
  - Established manufacturers setting up base in Europe
    - Tesla, CATL, Panasonic
- Often strategic alliances between battery producers and car manufacturers/OEMs
- Current manufacturing capacity in Europe is 26 GWh
  - Expected to increase to 500 GWh by 2030



Source: CIC energiGUNE

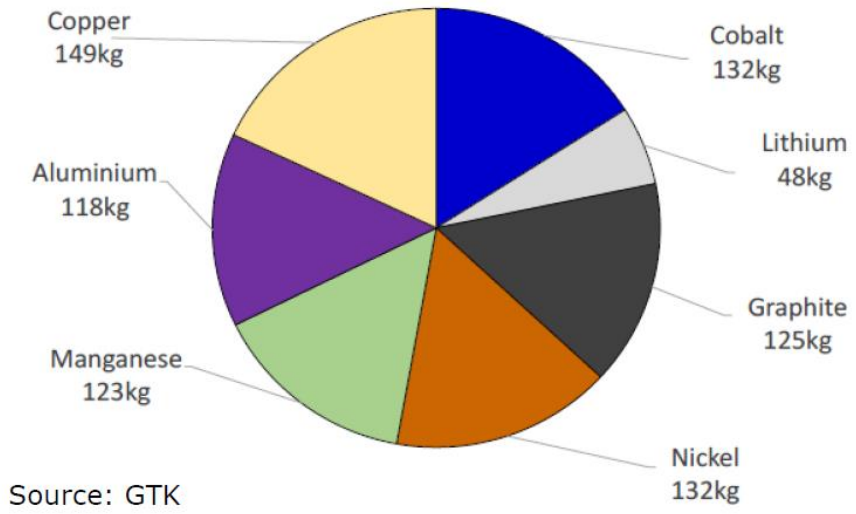
Battery cells and battery components



- Raw materials going into the anode and cathode:
  - Lithium
  - Cobalt
  - Nickel
  - Manganese
  - Graphite
- Electrolyte
- Separator
- Current collectors
  - Aluminium
  - Copper

Li-ion raw materials

- Focusing on most critical and high volume elements:



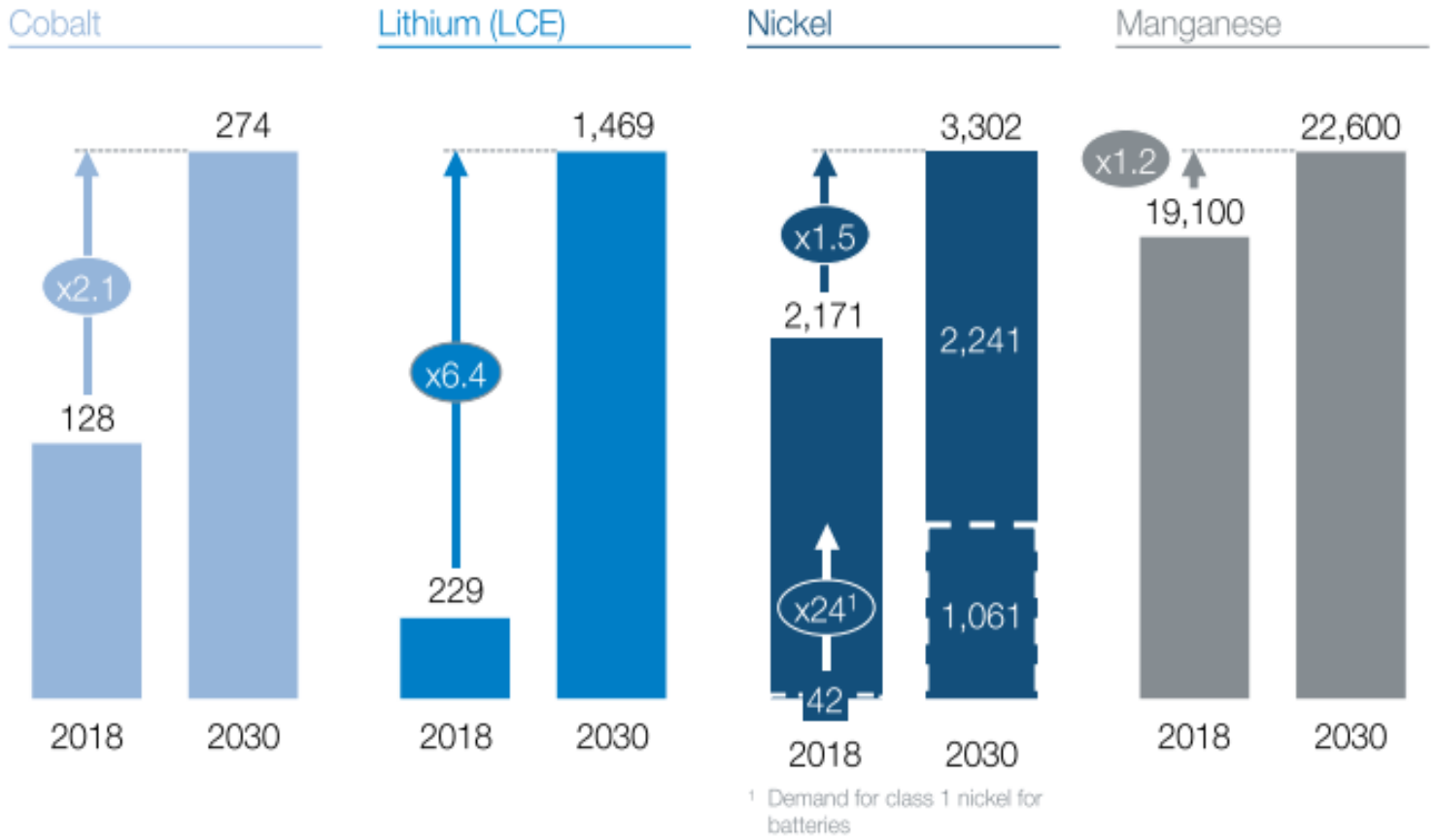
Source: GTK

Based on 300 kWh EV (public transport) battery pack - NMC

- Lithium
  - 50 % of global market used for LIBs
  - Overall ok supply, but highly concentrated geographically
- Cobalt
  - 37% of all Co is used in batteries
  - Global production concentrated around Congo, EU resources come from Russia
  - General trend to reduce the Co-amount in cathodes
- Nickel
  - Mostly mined for the stainless steel industry, expected 25 % in battery sector by 2030
  - Increasing demand for cathodes with higher Ni content
- Carbon
  - Graphite has 91 % of anode share:
    - artificial graphite – increasing share
    - natural graphite

Future needs raw materials

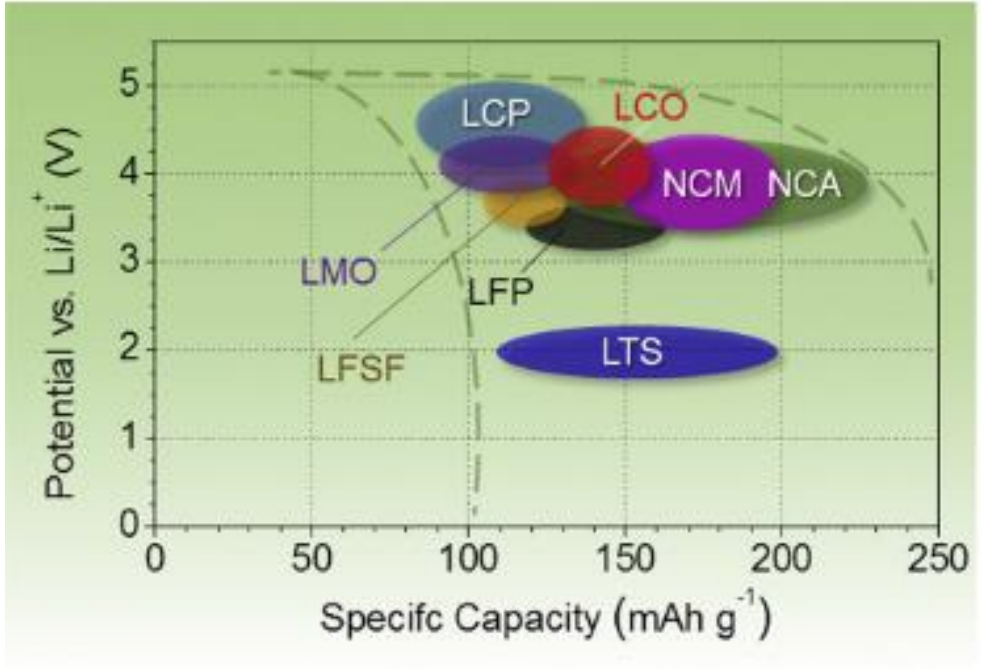
- For all chemistries, Li demand is expected to increase
- Even with focus on less cobalt in cathode, Co demand will increase
- Overall Ni-demand will increase
  - Class-1 high purity Ni 24 times increase
- New gigafactories will require direct supply of raw materials
  - Mapping and mining activities will need to ramp up at same speed



Source: McKinsey analysis 2019

Cathodes

- Li-ion batteries are mainly classified according to the cathode material in use



Source: N. Nitta et al. Materials, 2015

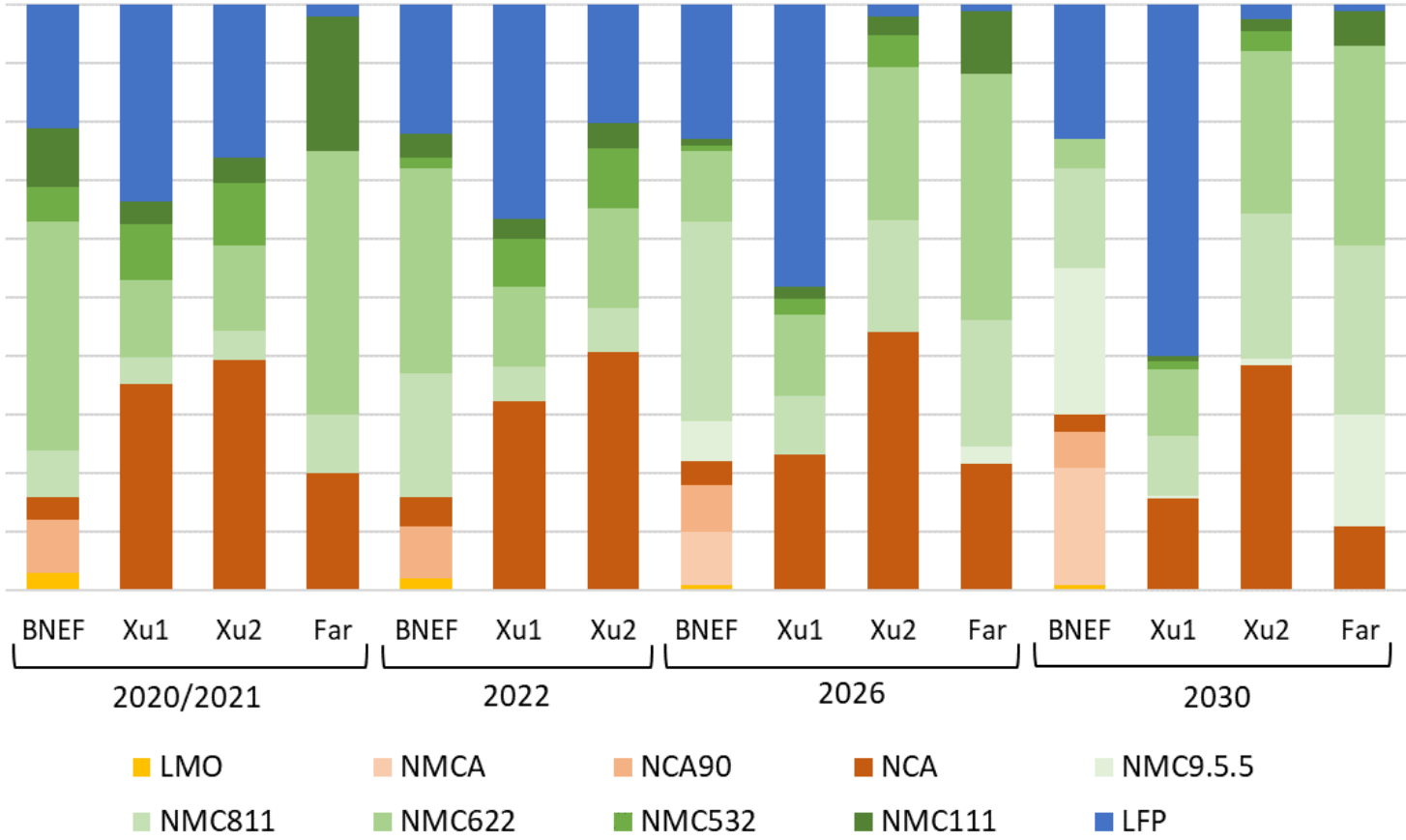
- LCO:
  - First commercialized cathode
  - Leading cathode material in portable electronics
  - Used in some small EVs
- LFP:
  - Low energy density, not widely used in EVs today
  - Safe and sustainable
- NMC:
  - Preferred cathode for most EV batteries
  - Higher capacity and lower cost than LCO
  - Changing composition to reduce Co amount and increase Ni amount
  - Evolution: NCM111-NMC532-NMC622-NMC811-NMC955
- NCA:
  - High capacity and calendar life
- LMO:
  - Lower capacity, but high power density
  - Often mixed with NMC (blend) to get both longer range and power properties
- LNMO:
  - High voltage, Mn rich
  - Challenges with cycle life and thermal stability

Future battery chemistries

Cathodes

Summarizing the different scenarios for cathode development to 2030:

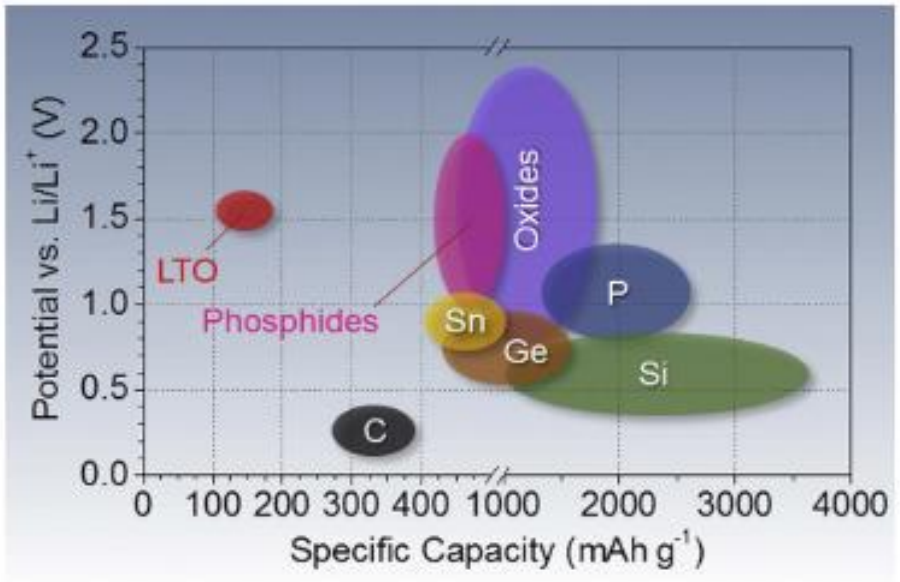
- General increase in Ni-content:
  - NMC-pathway
  - NCA approach
- Different LFP scenarios between the reports
- LMO and LCO demand expected to decrease
- Most agree that the demand for NMC cathodes will increase
  - Will go towards NCM 811/9.5.5



Expected developments of the market share of different battery chemistries. A summary combing reports from most recent reports from BNEF, Xu et al. and the Faraday institute. BNEF includes all types of batteries, while Xu and Faraday only include EV batteries. Xu1 refers to a scenario with increased focus on LFP, Xu2 to a more standard scenario

Anodes

- Commercial anodes concentrated around two anode chemistries:
  - Carbon
    - Pure carbon (graphite)
    - Carbon + small amount of silicon (oxide)
  - LTO ($Li_4Ti_5O_{12}$)



Source: N. Nitta et al. Materials, 2015

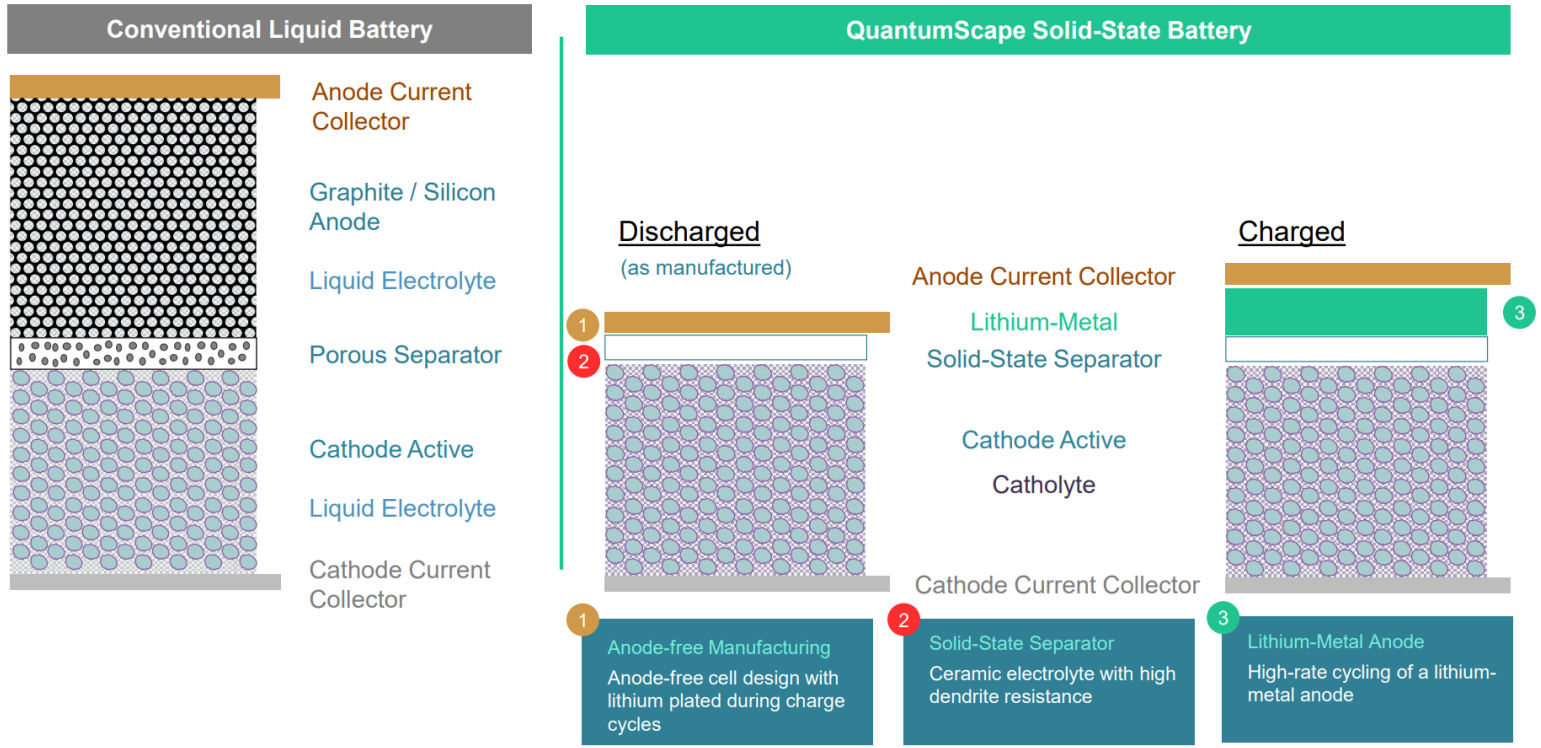
- Graphite:
  - Main anode for LIBs for 20 years, and will continue to be main element in foreseeable future
  - Combines low cost with good cycle life
- LTO:
  - More expensive than graphite
  - Used in niche markets where power density, high cycle life is necessary and lower capacity is not an issue
- Si/C:
  - SiOx/Si/C
  - Silicon is added to boost the capacity
  - To increase fraction of Si, expansion issues needs to be overcome

Electrolyte developments

- Large research focus on replacing the commercial liquid electrolyte with solid-state electrolyte
  - Will increase energy density of batteries and enable disruptive technologies

1. Inorganic solid electrolyte
2. Polymer solid electrolyte

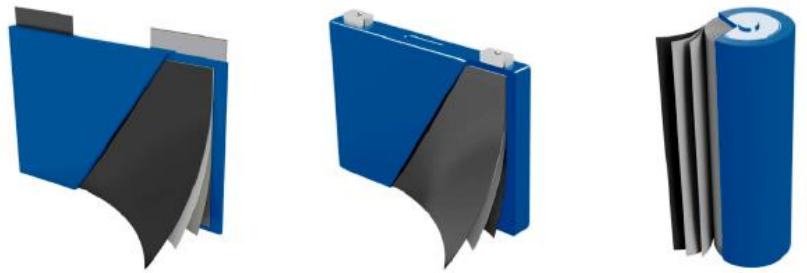
- Some OEMs (e.g. Volkswagen) have a defined roadmap towards solid-state electrolytes
  - Implementation after 2025?

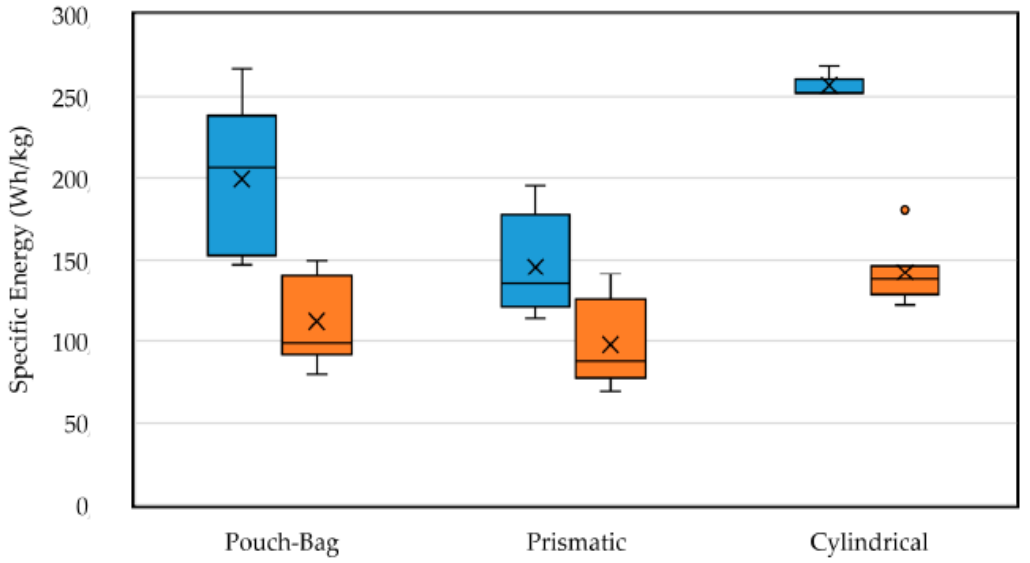


Source: Source: Quantumscape, 2021

Batteries: from cell to system level

- Variations in cell type
  - Pouch cell
  - Prismatic cell
  - Cylindrical cell
- Market not dominated by one cell type
- Moving from cell to system level (adding cooling systems, casings, BMS) will reduce the energy density
  - Variations depending on cell type





Source: Löbberding et al., World Electric Vehicle Journal

Beyond Li-ion

- Possible emerging battery technologies:
  - **Lithium-metal**
    - Including Li-sulfur and lithium air
  - **Sodium-ion**
  - Zn and Zn-air
  - Redox-flow batteries

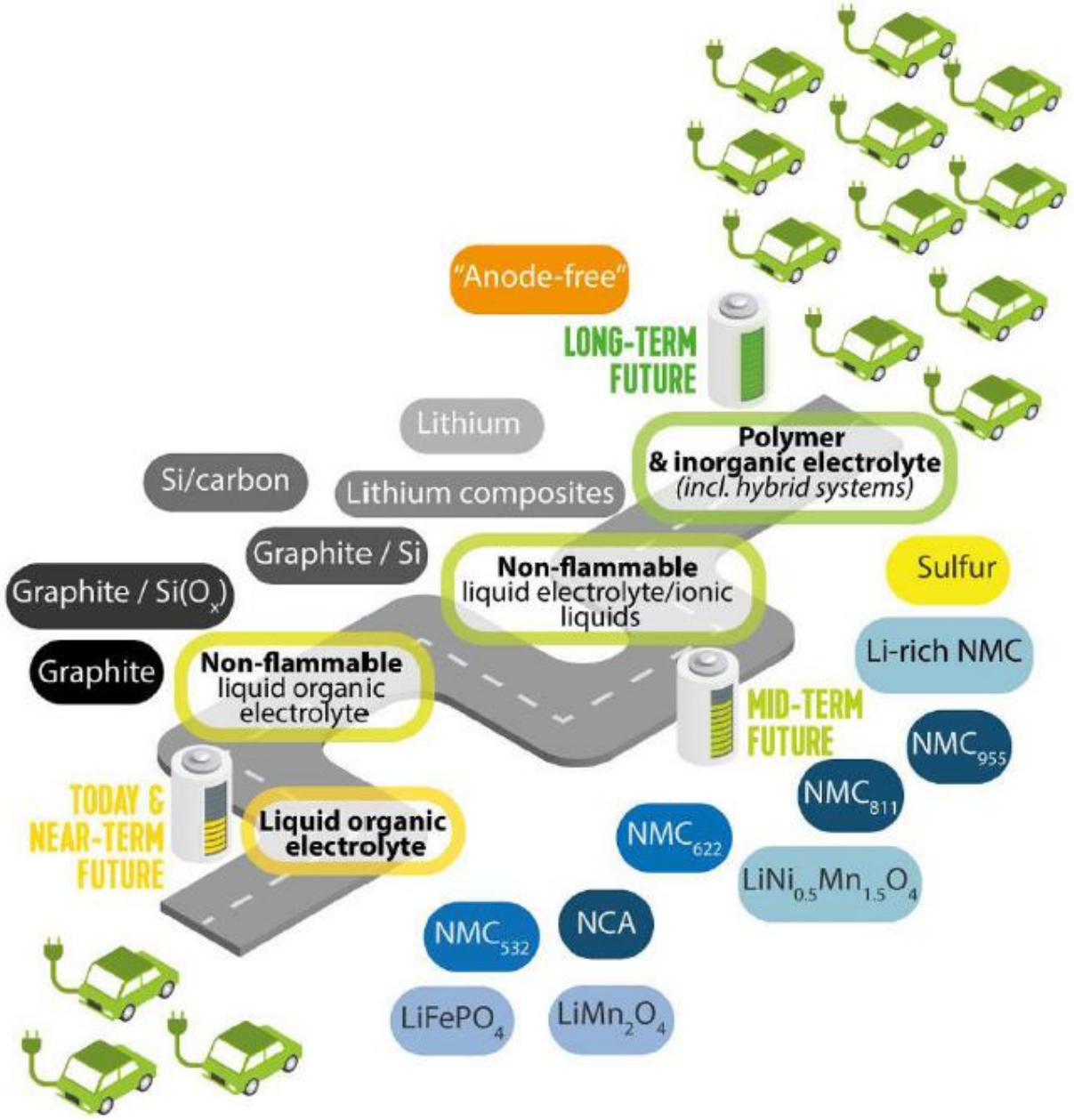
  - Need solid state electrolytes to be implemented

- Generally considered that LiB will outperform close-to-market technologies in next 10-20 years
  - Na-ion potential candidate if safety is improved and price reduction of LIB is slowing down

Future battery chemistries

- Mid-term future:
  - Carbon will remain main anode material
    - Introduction of more silicon
  - NMC is main cathode material
    - Trending towards higher Ni-content
    - NCA and LMNO are also potential candidates
  - Electrolyte will remain liquid

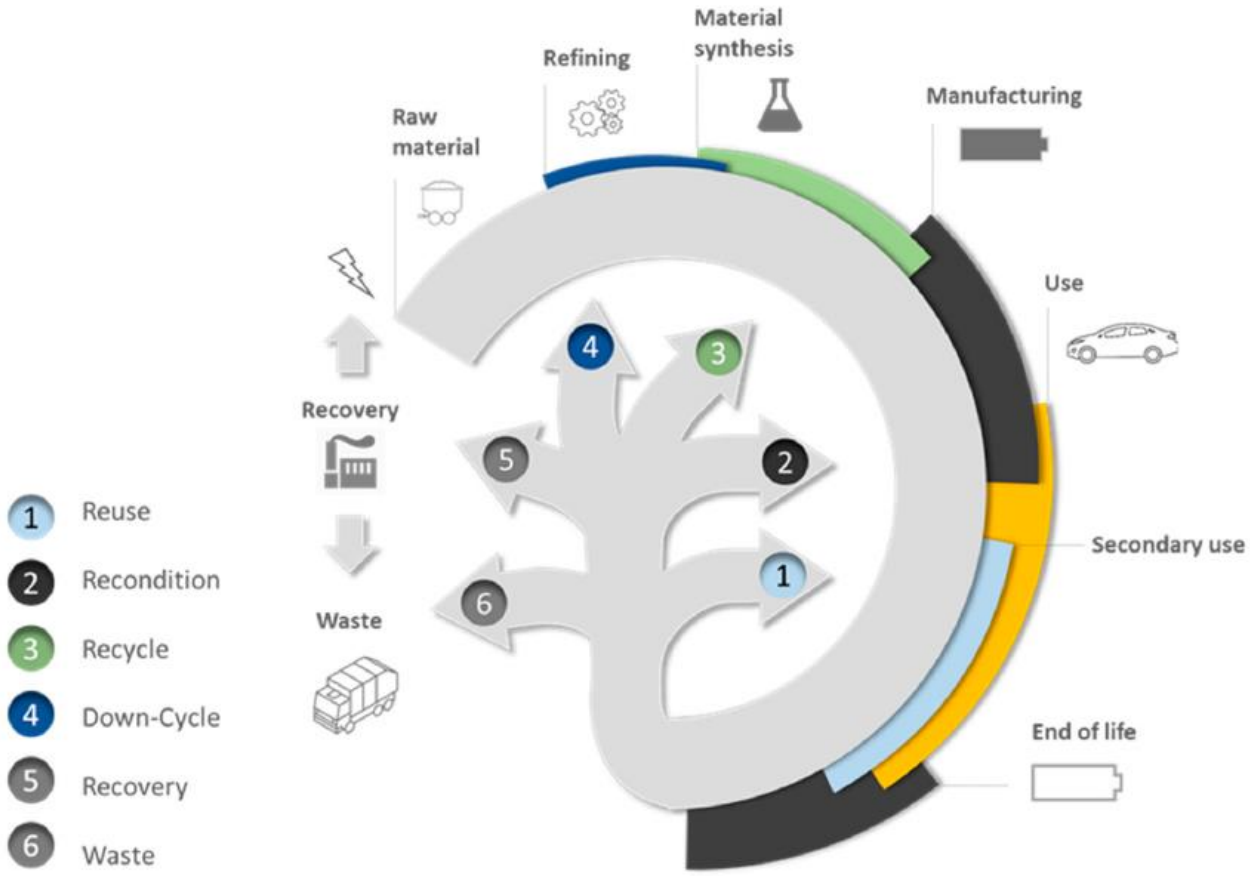
- Long-term future:
  - Solid state electrolyte
  - Lithium-metal



Source: Passerini et al., Journal of Power Sources, 2020

Reuse vs. recycling

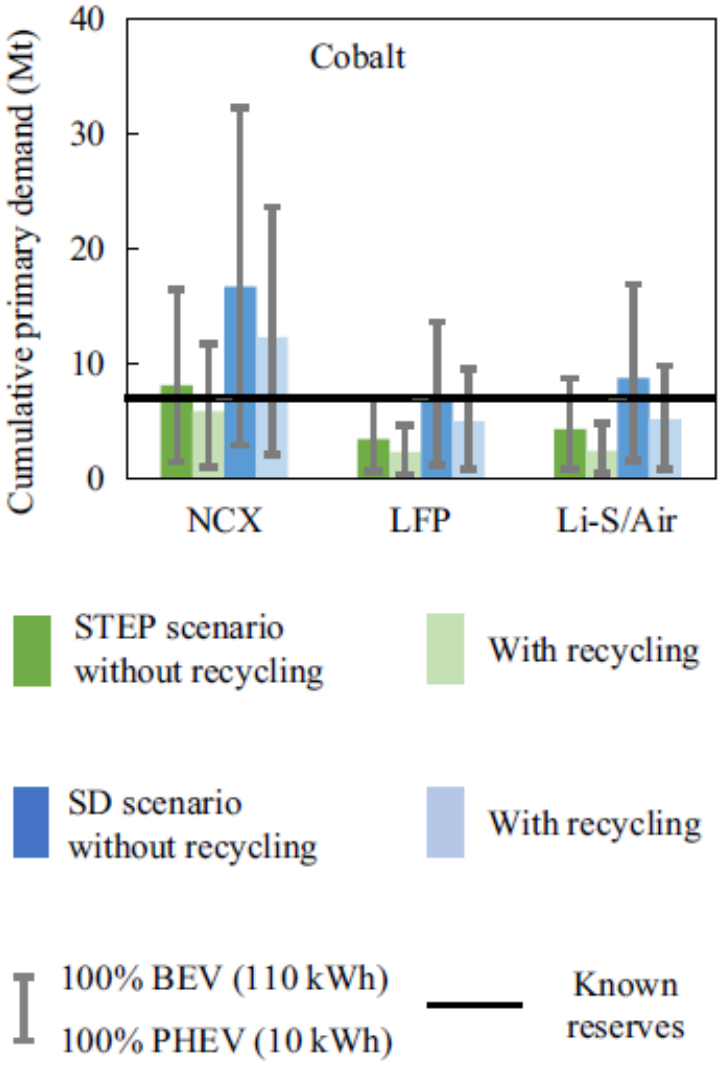
- Reuse/2nd life has to be considered before recycling step
- End-of-life of EV batteries is normally defined at 80 % of initial capacity
- Some pilot cases of 2nd use already in use
  - Used for stationary storage combined with PV panels
  - Currently not implemented with EoL batteries
  - Requires more research on diagnostics of SoH, safety, technoeconomic assessment and LCA



Source: Zaghib et al., Materials, 2020

Recycling potential

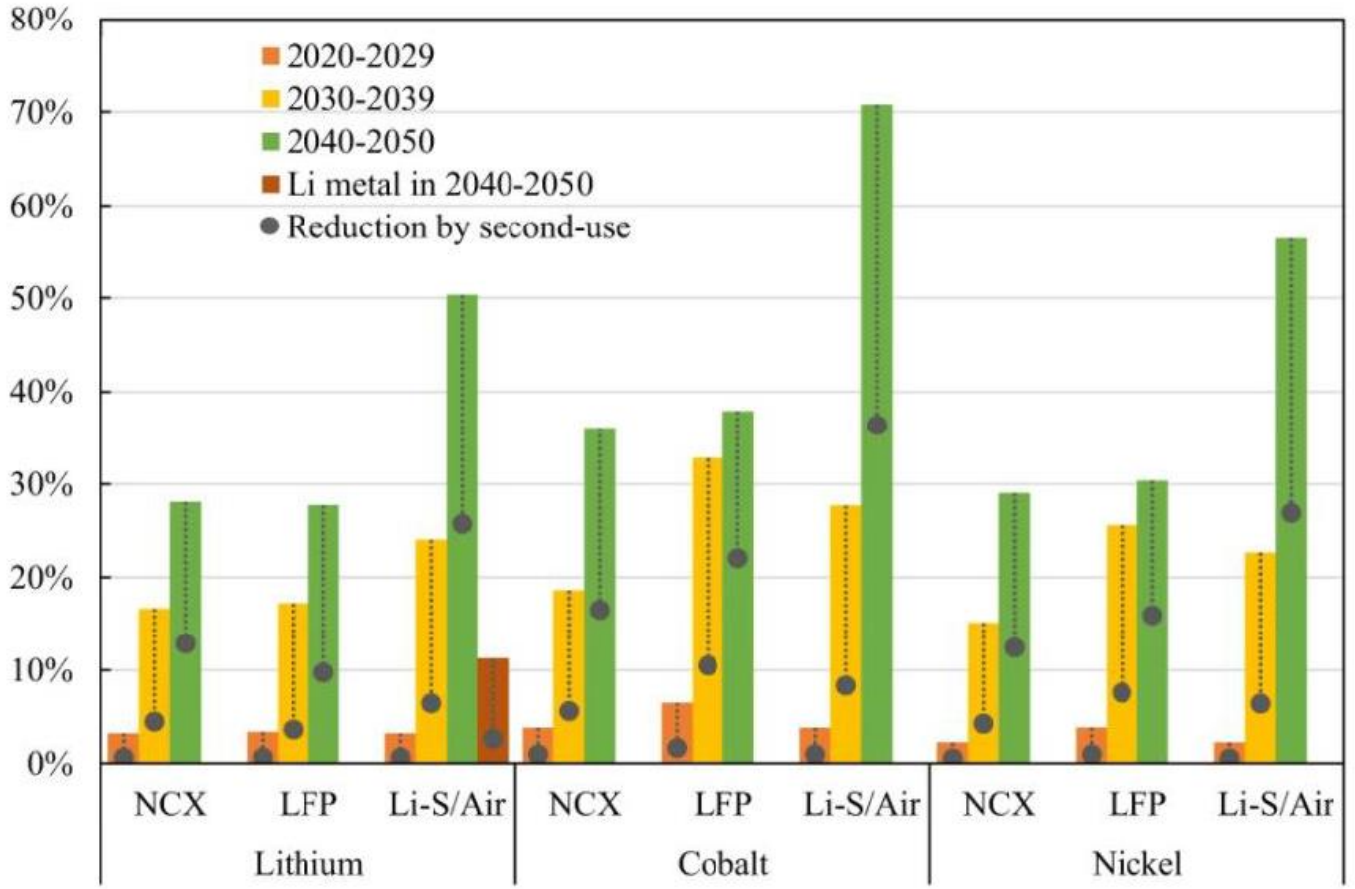
- Some battery materials might be dependent on recycling
- Recycling potential of Li, Co and Ni expected to increase greatly
  - Different chemistry scenarios
- Major output of the BATMAN project to evaluate the recycling potential in Norway
  - Material demand and recycling volumes by MFA



Source: Xu et al., Communications Materials, 2020

Recycling potential

- Some battery materials might be dependent on recycling
- Recycling potential of Li, Co and Ni expected to increase greatly
  - Different chemistry scenarios
  - Second use will postpone the time of recycling
- Major output of the BATMAN project to evaluate the recycling potential in Norway
  - Material demand and recycling volumes by MFA



Source: Xu et al., Communications Materials, 2020

Summary

- Increased need for raw material with estimated future battery demand
  - Mining + recycling efforts necessary

- Chemistries
  - Cathode:
    - NMC is main cathode: reduce Co, increase Ni
    - NCA and LMNO possible alternatives
  - Anode:
    - Graphite main component, progress on implementing higher Si content
  - Electrolyte:
    - Solid state electrolytes gain market share 2025-2030

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BATMAN

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Thank you for your attention!