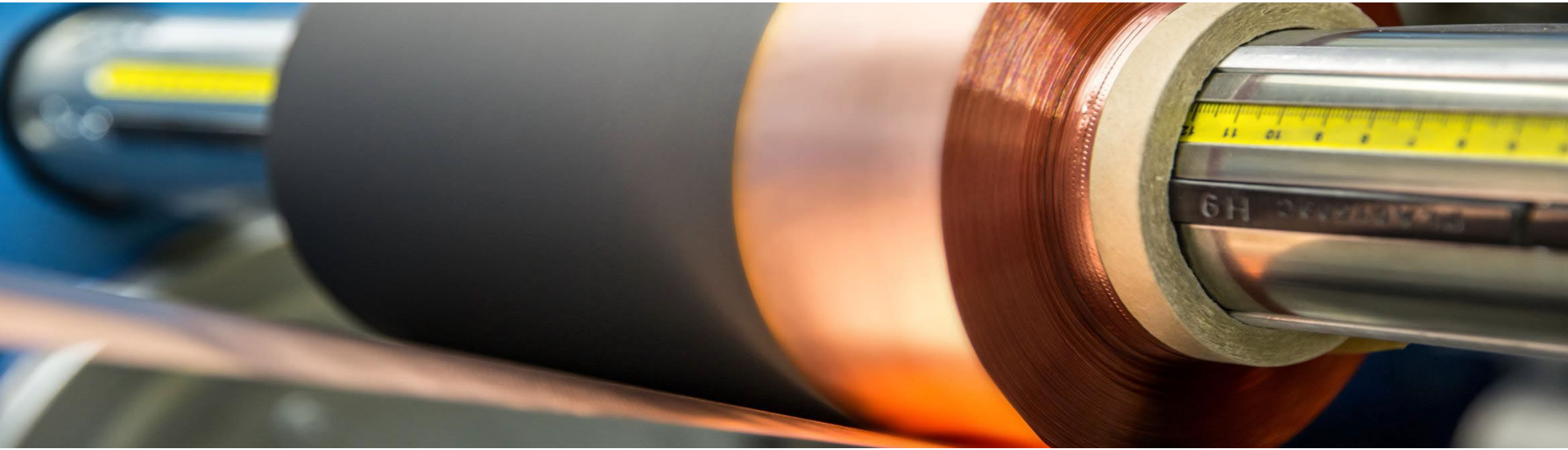
Cathode Materials



Dr. Klaus Brandt
EAS Batteries GmbH

April 2025

EAS Company Introduction

EAS Company History

April 1996

Foundation of GAIA Akkumulatorenwerke GmbH at Nordhausen

Development of cell portfolio of large cylindric cells for hybrid electric applications based on a unique electrode production technology using NCA and LFP chemistries.

September 2011

Foundation of Joint Venture EAS Germany GmbH (Shareholders GAIA 40% & HAWKER GmbH 60%)

August 2012

EAS Germany GmbH fully owned by HAWKER GmbH / Enersys

January 2015

Frazer Nash new owner of EAS Germany GmbH

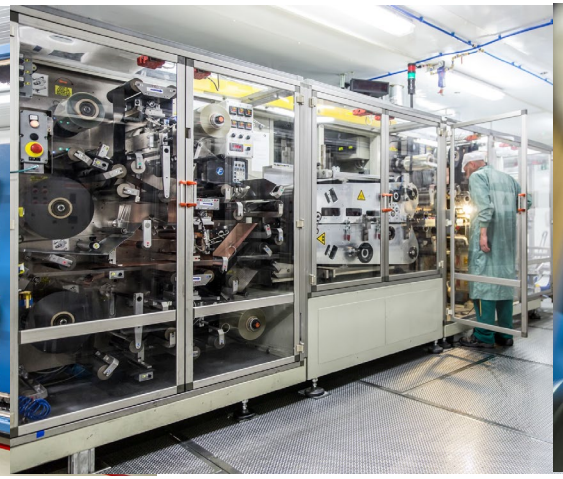
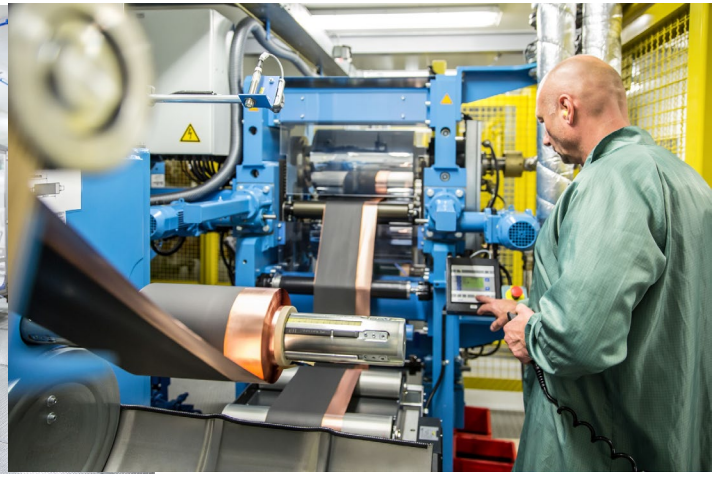
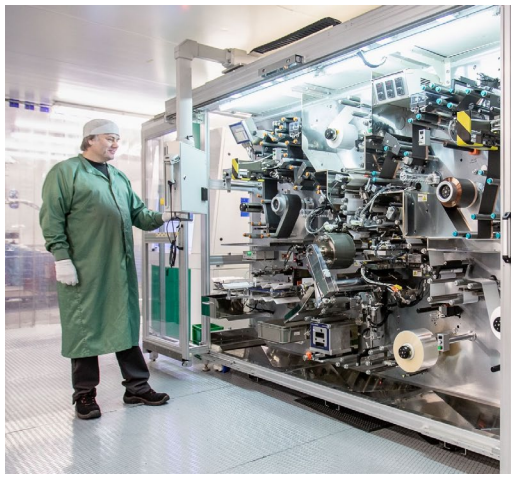
June 2017

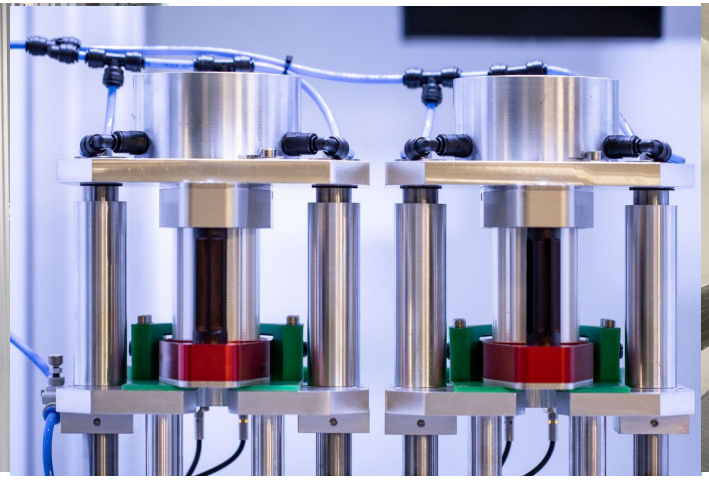
Merger of GAIA and EAS Germany via asset deal into EAS Batteries GmbH with MONBAT as new owner

December 2018

Implementation of new business model with line of business 1-5 including EASy Marine, development services, cells and licensing.

EAS Cell Manufacturing: From Powder to Cell to Battery

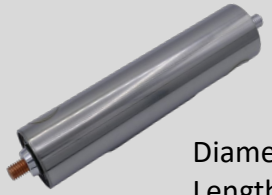



EAS Manufacturing and Development Services - from cell to battery

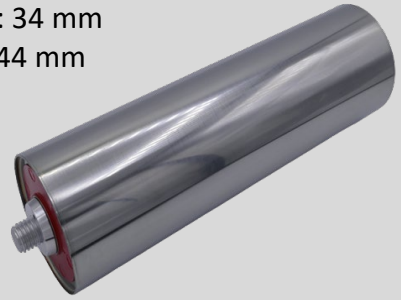
Example Cell Portfolio

Diameter: 168 mm
Length: 210 mm

Diameter: 46 mm
Length: 90 mm

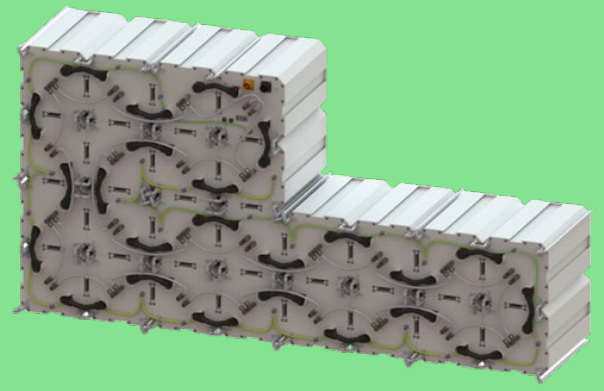


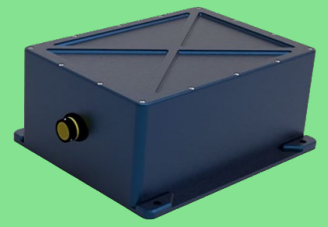
Diameter: 34 mm
Length: 144 mm



Diameter: 60 mm
Length: 203 mm

Battery Systems





Development Services

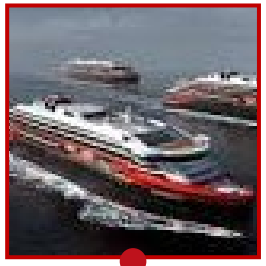
From idea to product

- Cell development (material, jelly roll, mechanical design)

- Custom Battery Solutions

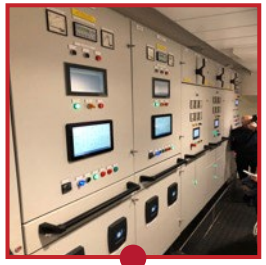
- Analysis & Testing

Value Chain coverage – along knowledge and experiences
Example: EASy Marine ®



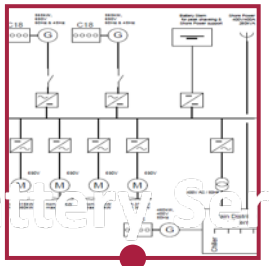
Application requirement

User, ship operator



System requirement

Customer (shipyard, integrator) and EAS



System layout

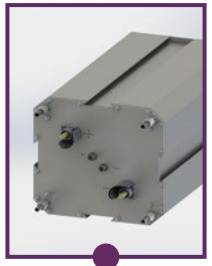
Partner (shipyard) and EAS

System integration

Partner and EAS

Battery layout

BMS, cooling, electrical layout - EAS

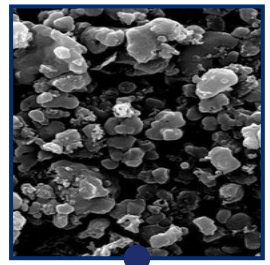


Module

EAS competence made in Germany

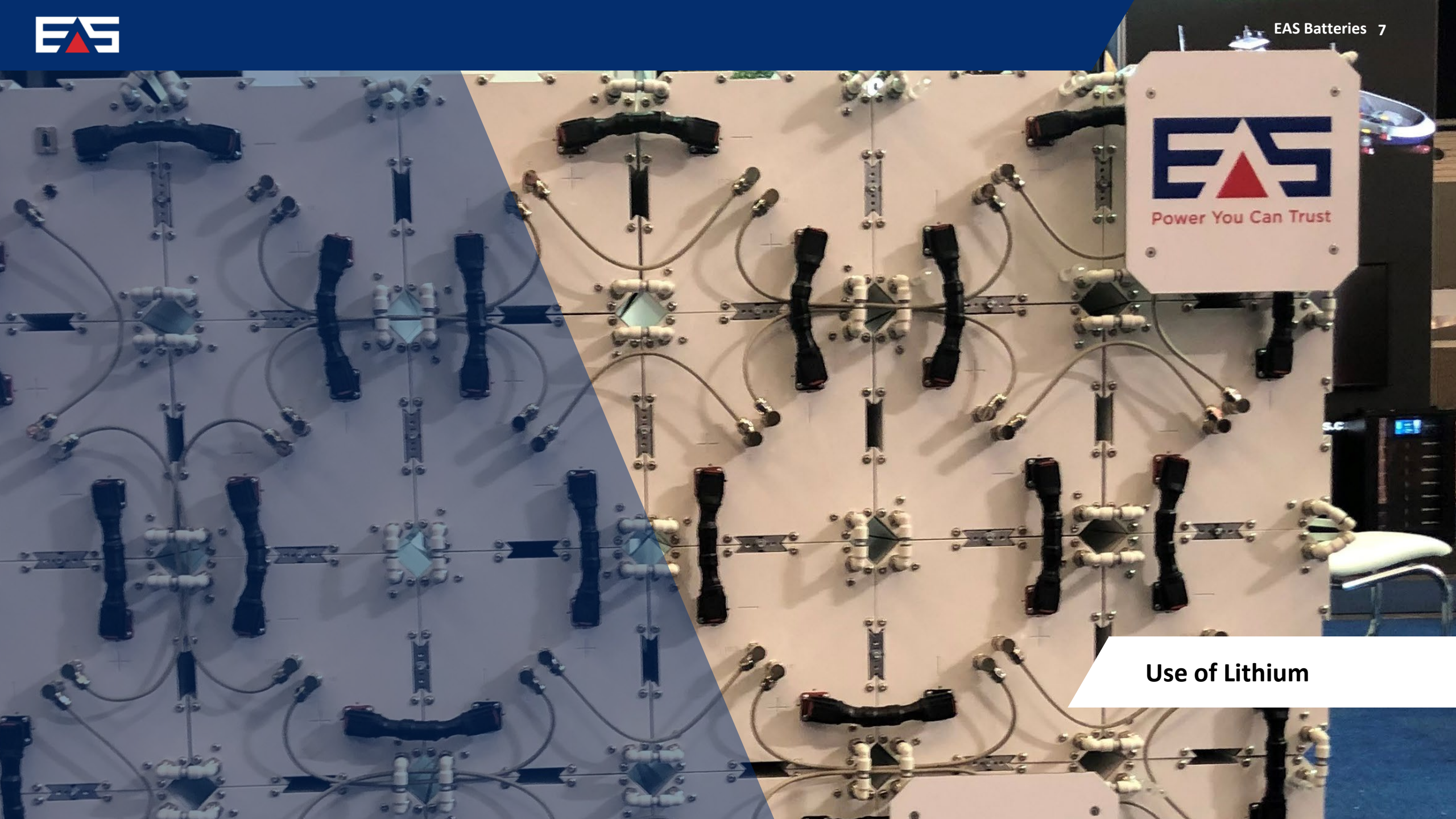
Cell

EAS competence made in Germany



Material

EAS supplier – more than one internally certified supplier for each critical material



Use of Lithium

The Use of Lithium in Li-Ion Cells

- Li-source within the cell is the cathode
  - Lithium iron phosphate cells make 100% of the Li in the material electrochemically available for cell operation
  - NMC cathodes require Li to remain in the structure for stability at around 30% of total Li-content
  - However, the higher voltage of NMC cathodes compensates for this loss due to the higher cell voltage
  - 5 to 10% of the Li from the cathode are used in the passivation layer of the graphite anode during formation of the cell

- Newer developments
  - Advanced anode materials like silicon or silicon oxides require more Li for passivation of the anode
    - This increases the amount of Li per unit energy used in cells with this advanced technology
  - Additional Li can be added to the cell by a number of technologies which are all in the pilot stage
    - Some of these methods require metallic Li

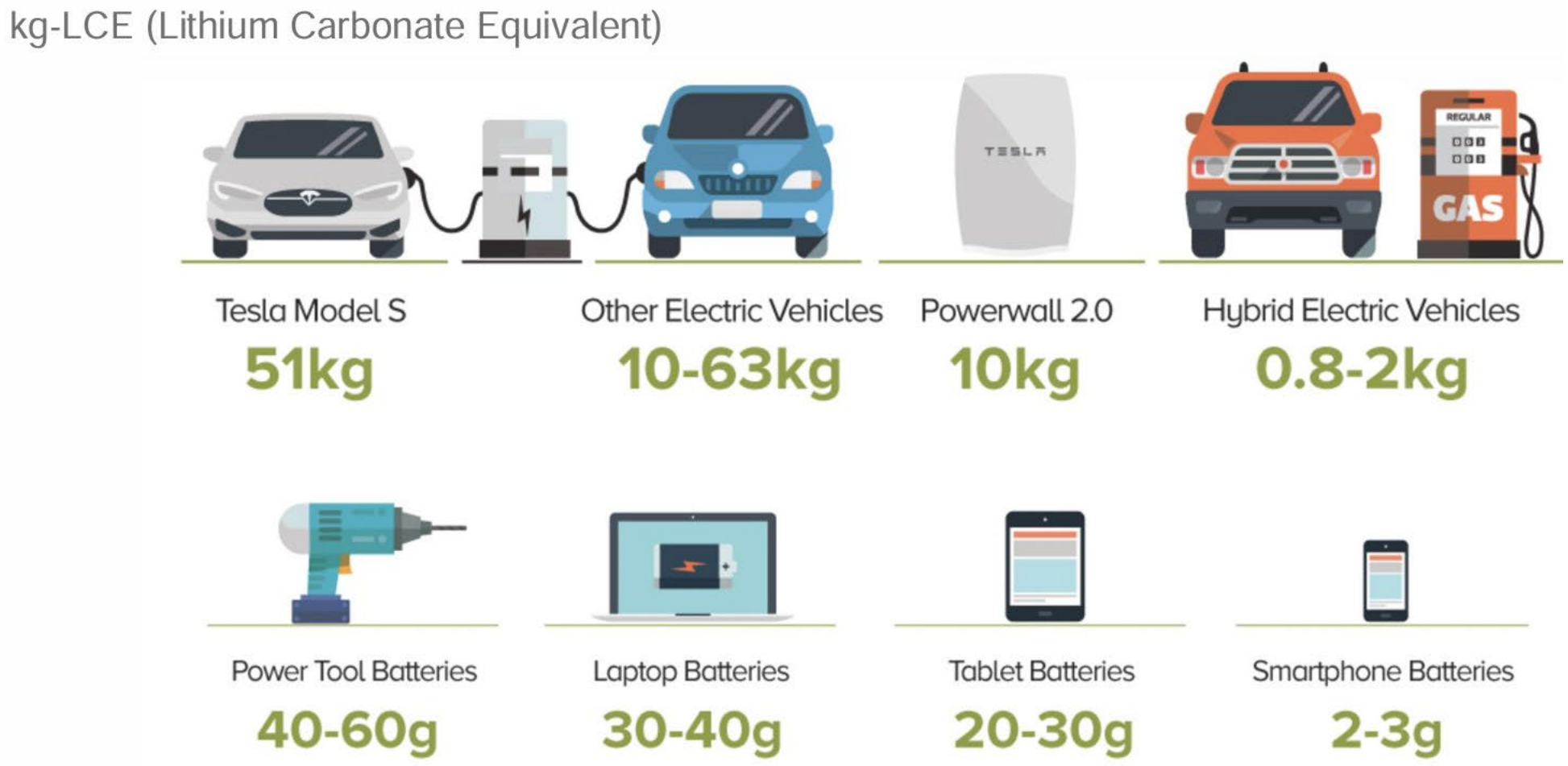
Volume Requirements

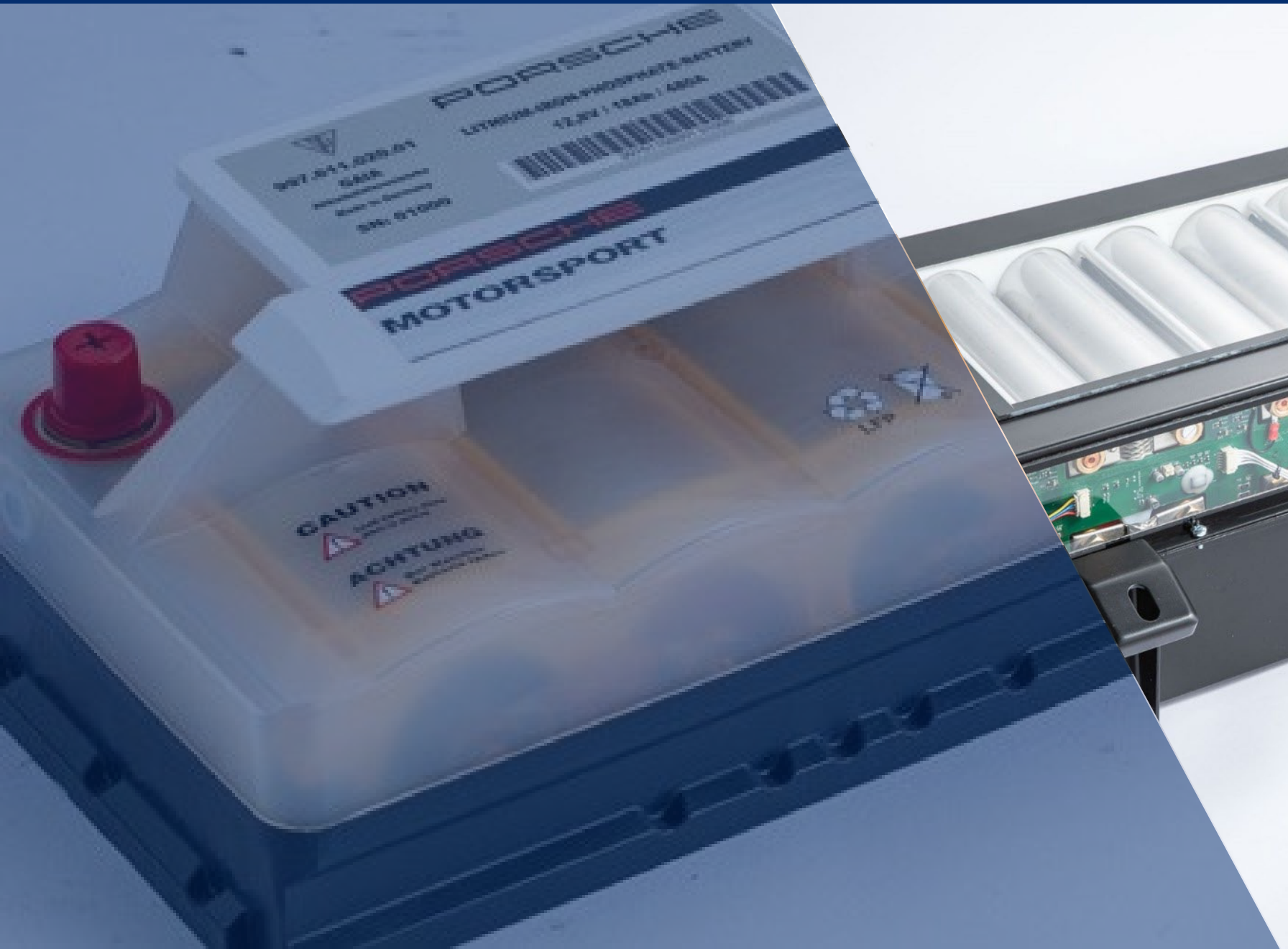
- General
  - Synthesis of cathode materials requires either lithium carbonate (Li_2CO_3) or lithium hydroxide (LiOH)
  - Which salt is required depends on the cathode material and the manufacturing process used

- Lithium volume requirements
  - Li-metal has a capacity of 3.86 Ah per g
  - Including the losses stated on the previous page, about 0.4 g are needed per Ah of cell capacity
  - This corresponds to roughly 0.1 g of Li per Wh
  - Per GWh of capacity, about 100 metric tons of Li are required
    - If Li_2CO_3 is used in the synthesis, about 570 metric tons of the compound are required
    - If LiOH is used in the synthesis, about 370 metric tons of the compound are required
  - One GWh corresponds to roughly 15,000 full electric passenger vehicles

- Cathode volume requirements
  - Example Ni-Mn-Co oxide 8-1-1
  - Per GWh of capacity, about 1,500 metric tons of cathode material are required

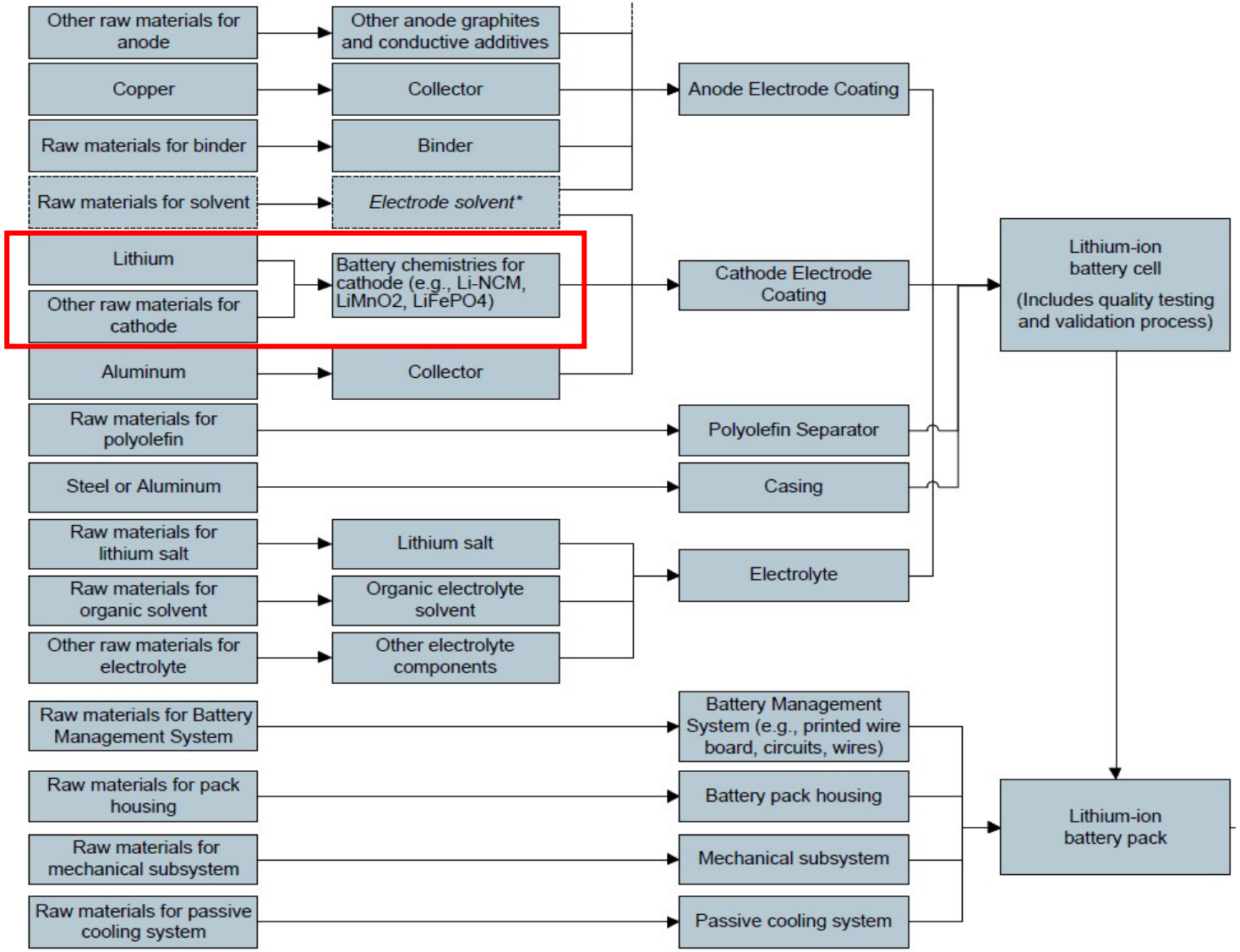
Lithium Volume Requirements Depending on Application





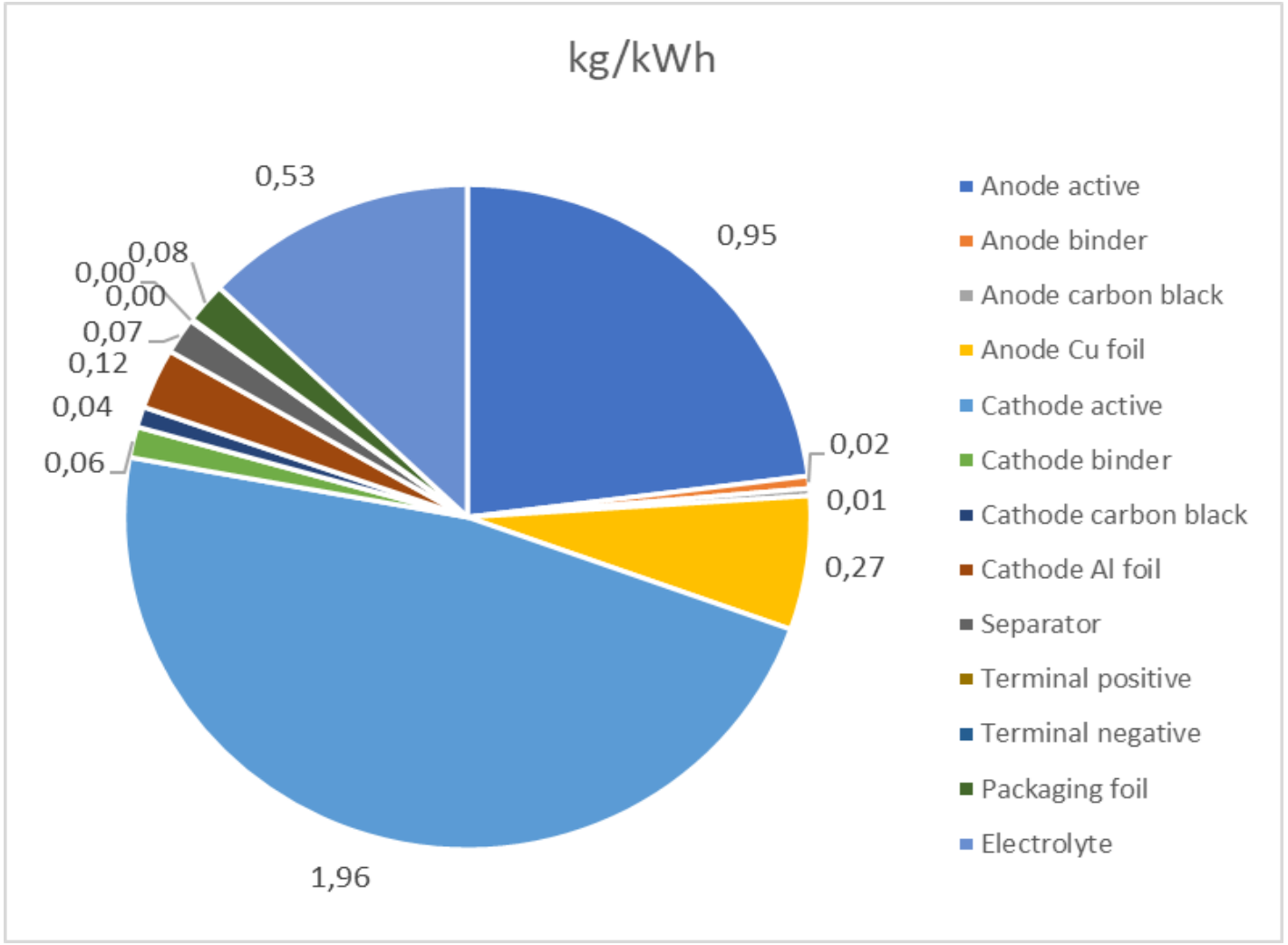
Cathode Material Synthesis

Flow Diagram for Li-Battery Production



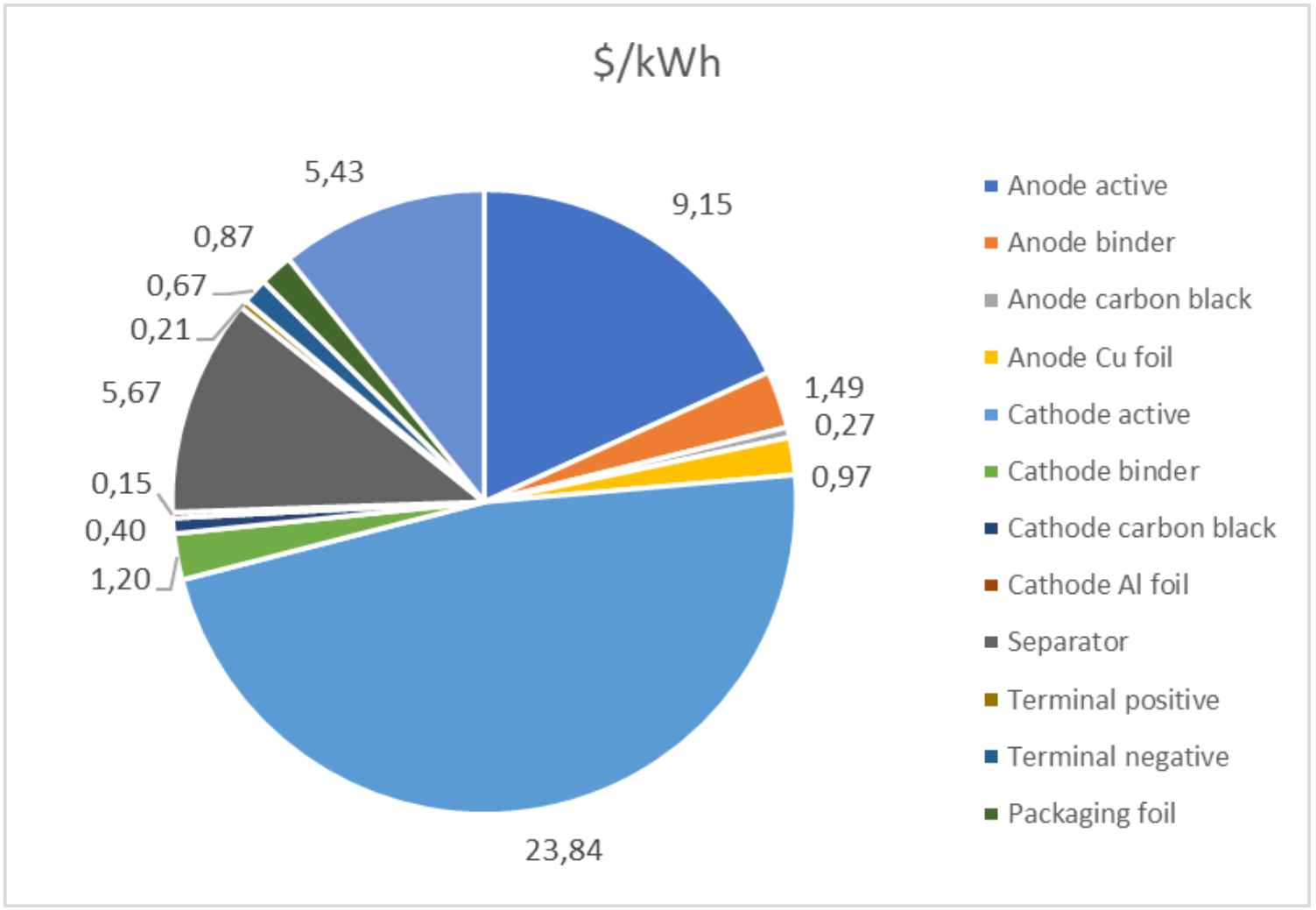
- Cathode material is only a small part of the number of materials and components required for a Li-ion battery

Share of Li-Ion Cell Components by Weight



- Example pouch cell with lithium manganese oxide cathode (LMFP) and graphite anode
- By weight, cathode material makes up nearly half of the cell materials
- This ratio depends on materials, the type of packaging (cylindrical, prismatic, or pouch), and the cell size

Share of Li-Ion Cell Components by Cost



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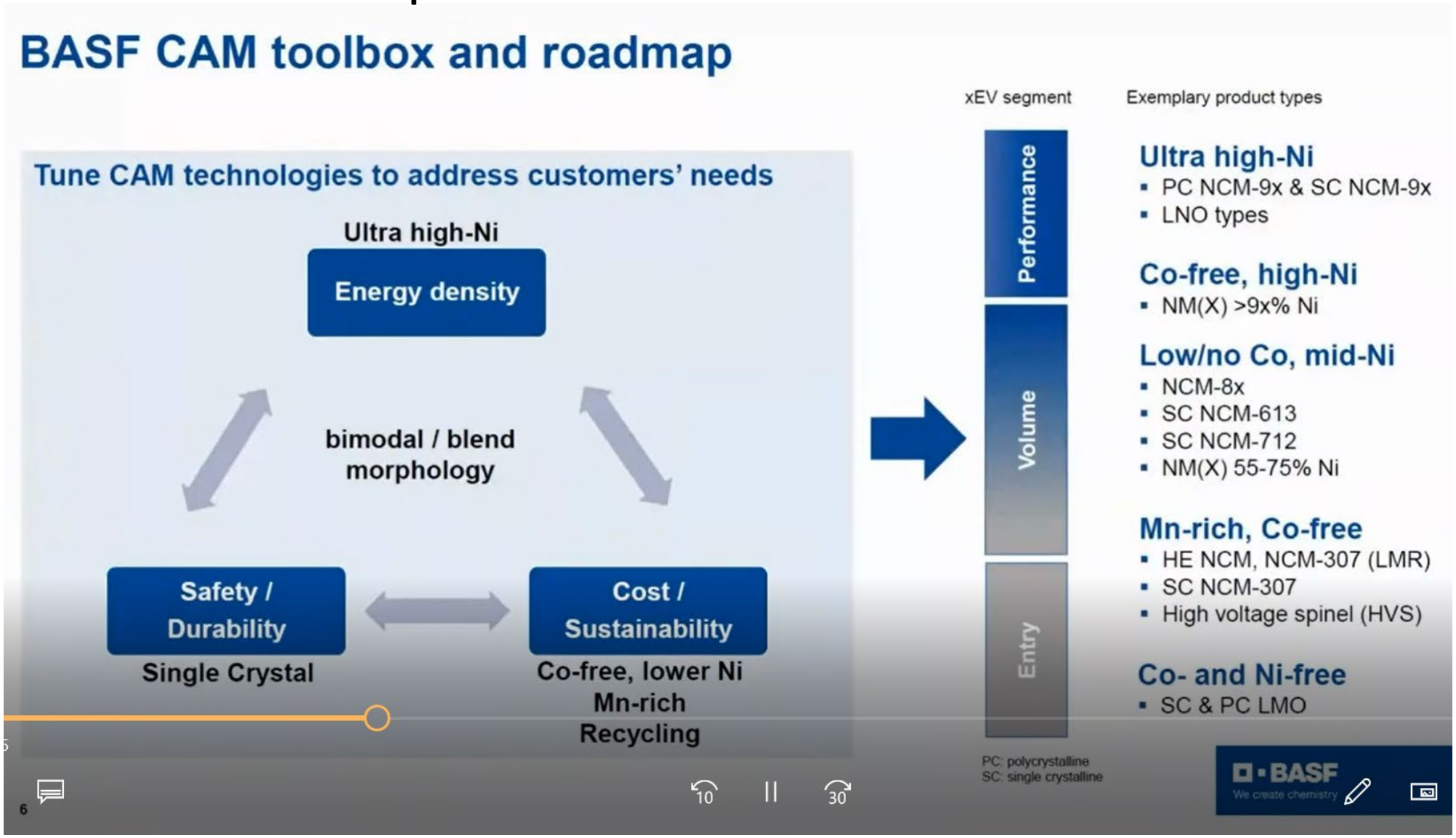
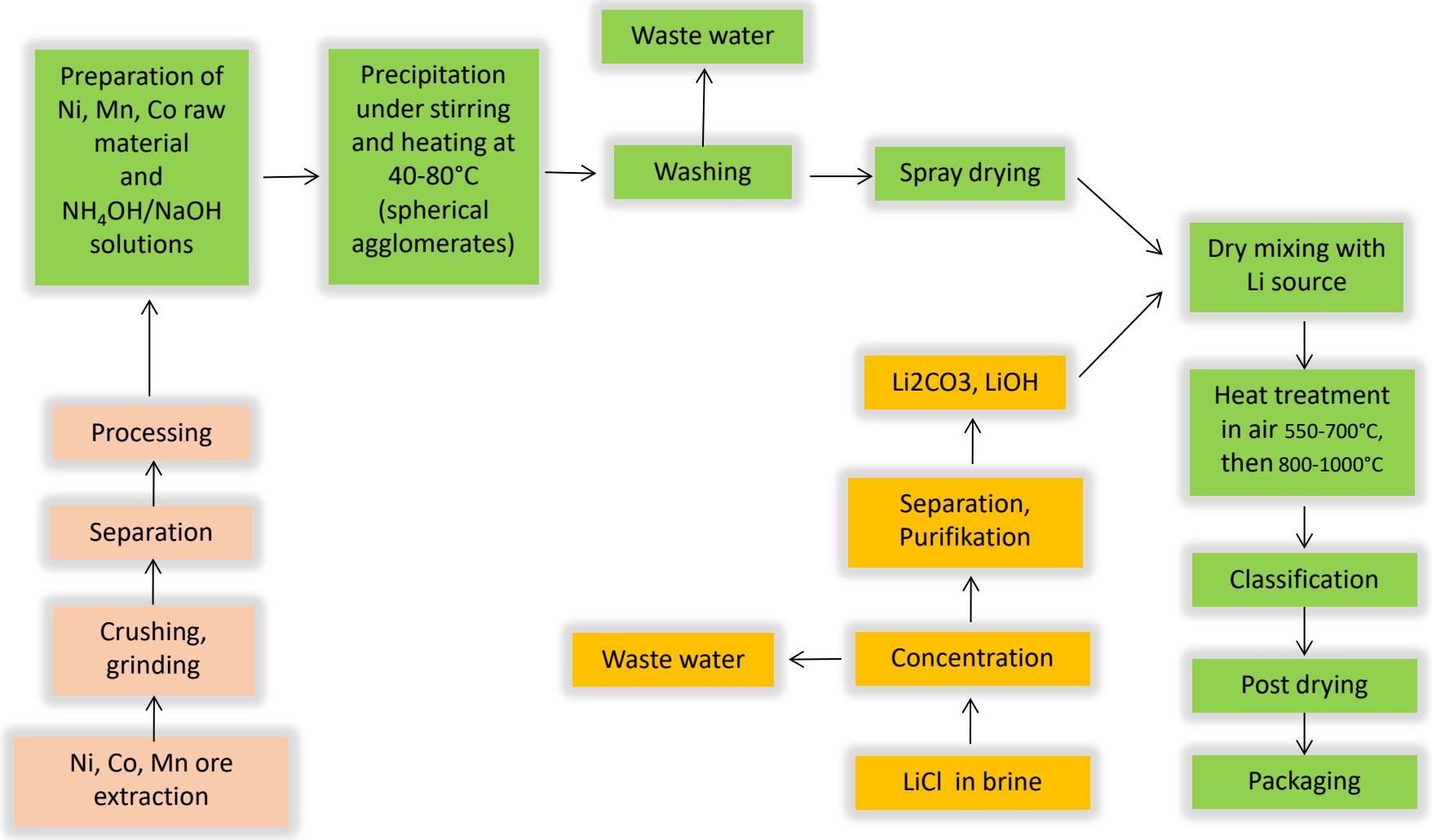
Types of Cathode Materials: Example BASF

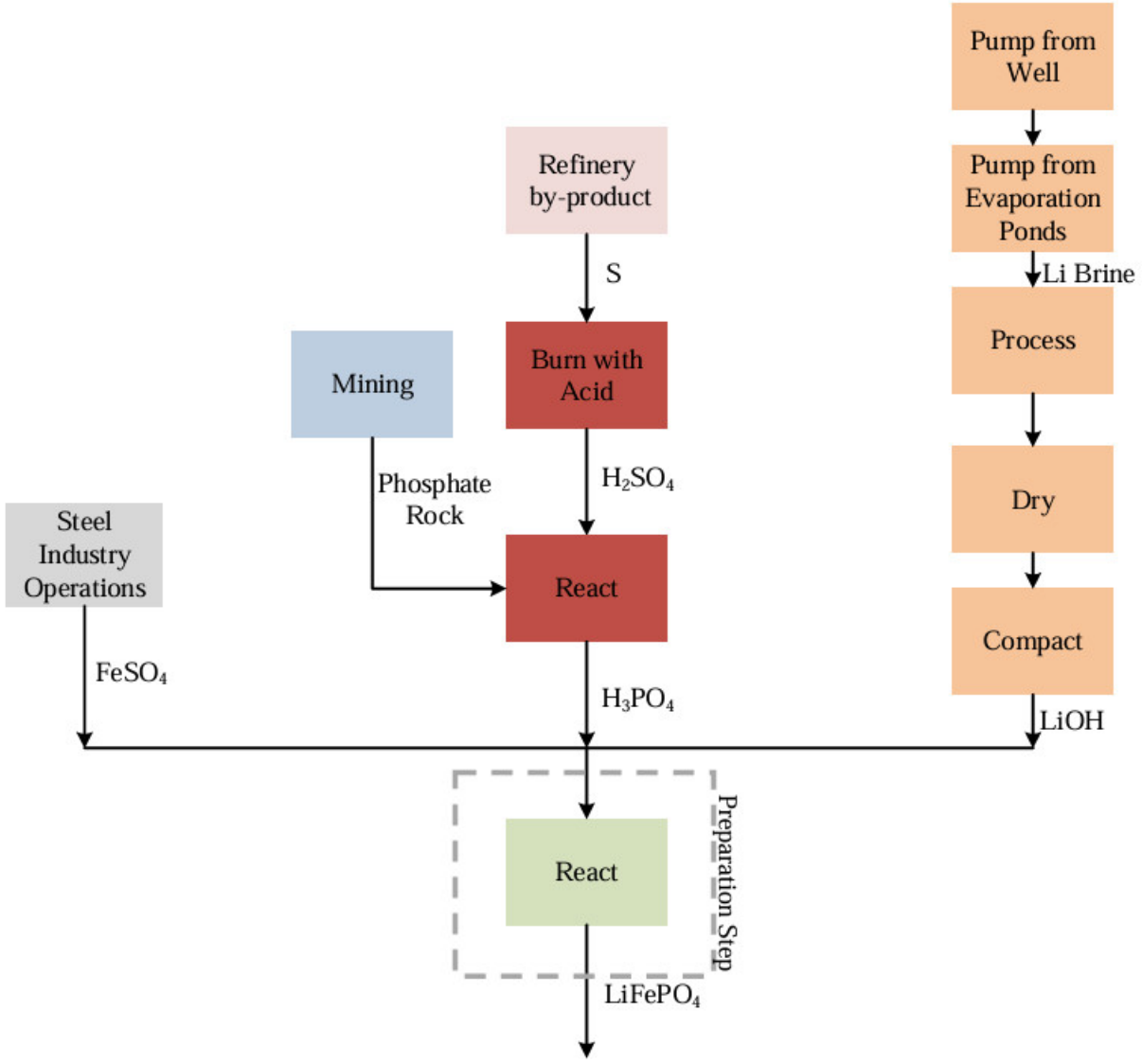


Synthesis of Cathode Materials: Process Flow for NMC Materials, PCAM and CAM



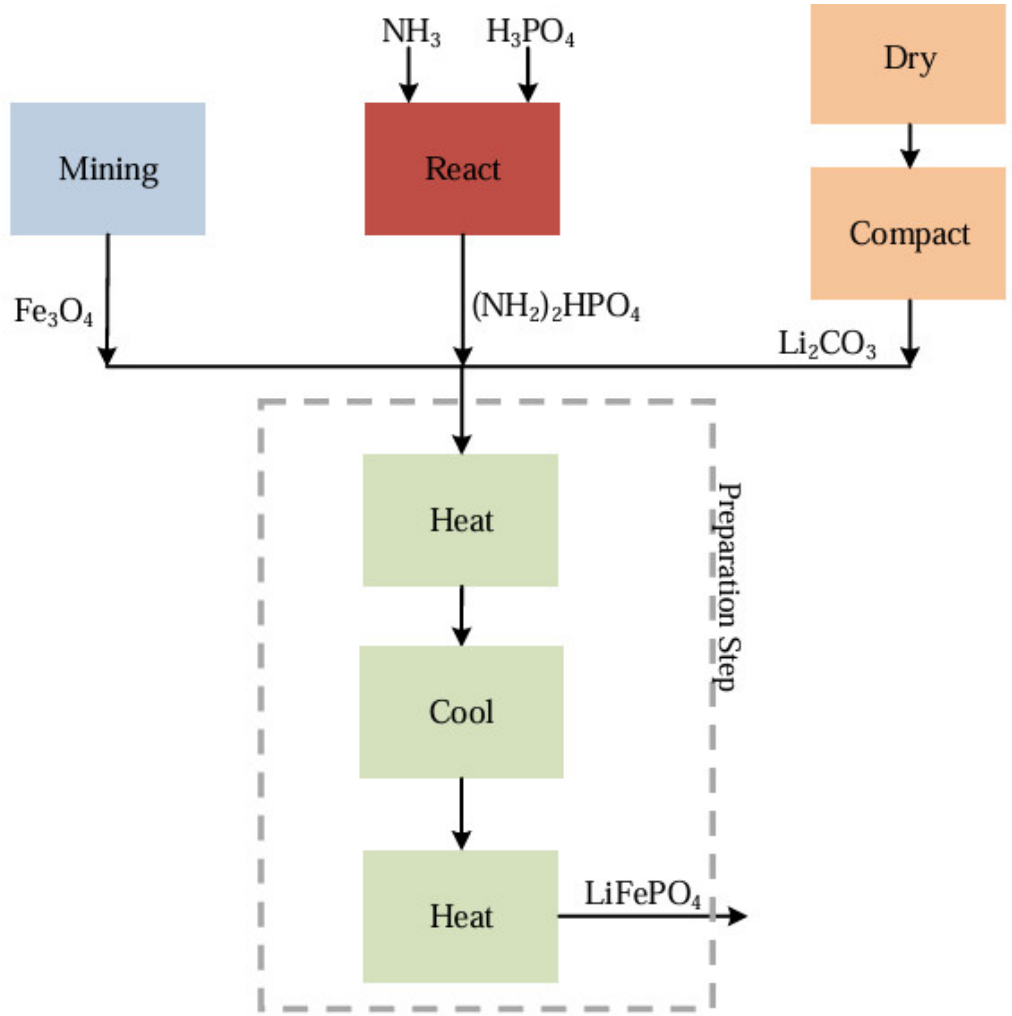
- Starting materials
  - Transition metal sulfates
  - Sodium hydroxide
  - Lithium hydroxide
- Waste materials
  - Sodium sulfate
- Process consists of two steps
  - PCAM an aqueous process
  - CAM a high temperature process

Synthesis of Cathode Materials: Process Flow for LFP Materials



- Process with the following starting materials
  - Iron source is iron sulfate
  - Phosphor source is phosphoric acid
  - Lithium source is lithium hydroxide
- High temperature synthesis

Synthesis of Cathode Materials: Process Flow for LFP Materials



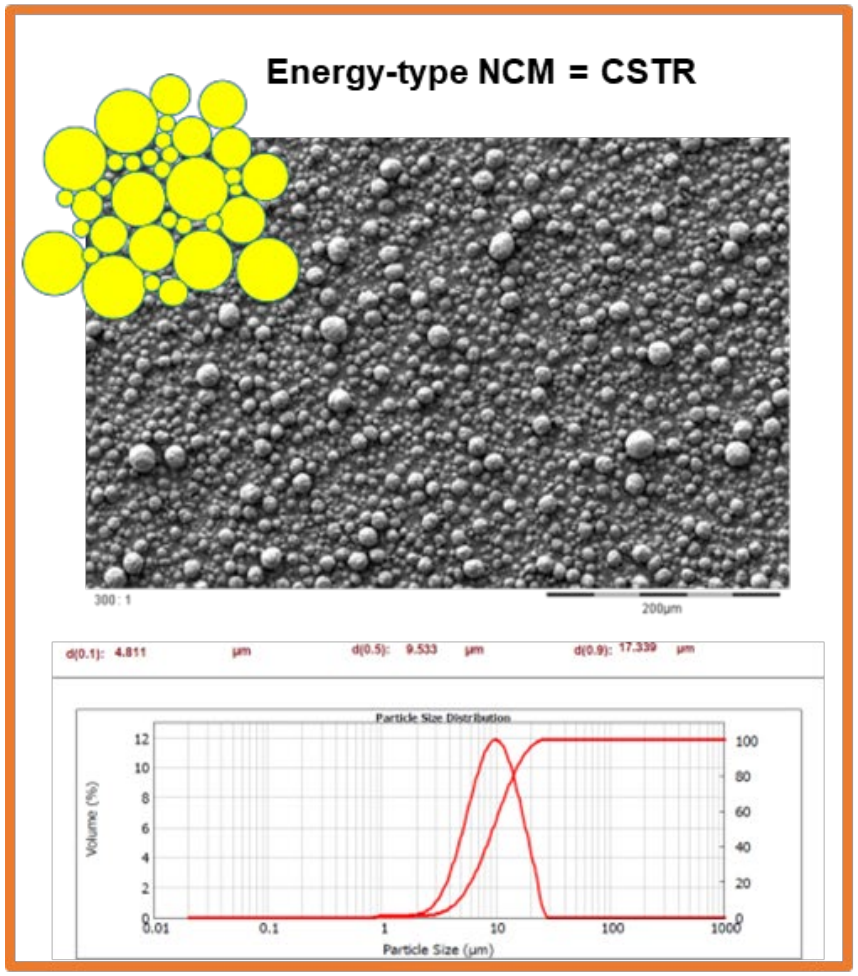
- Process with the following starting materials
  - Iron source is iron oxide
  - Phosphor source is phosphoric acid
  - Lithium source lithium carbonate
- High temperature synthesis

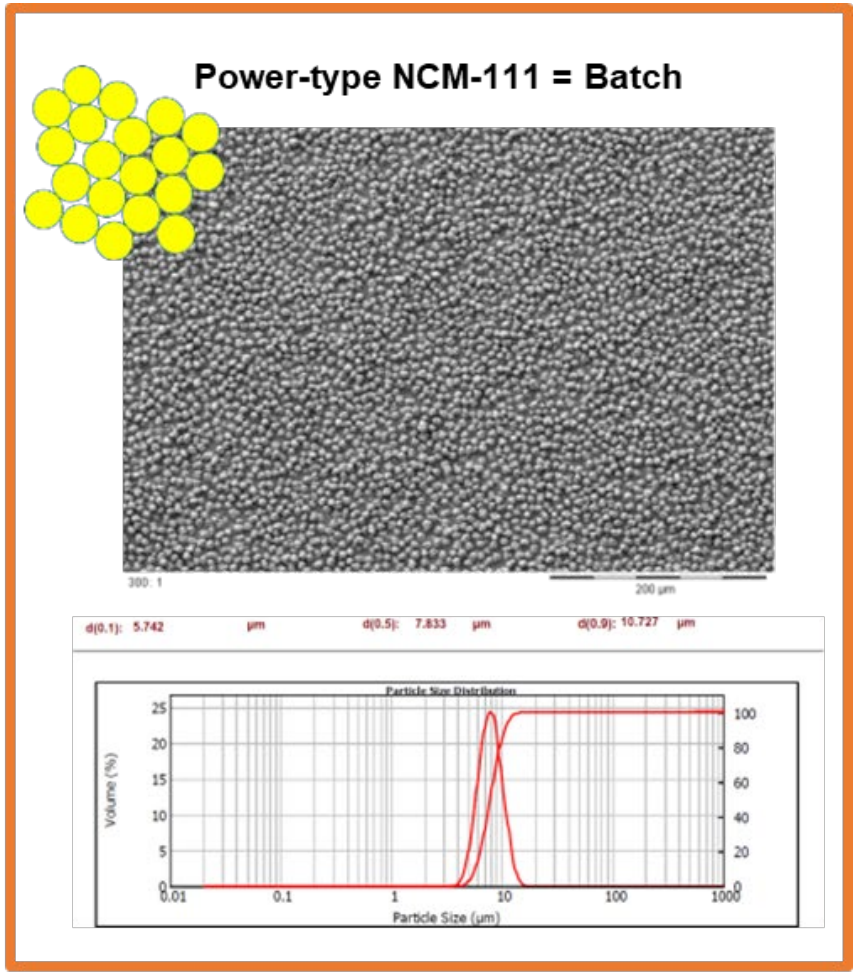
Agglomerates and Coatings

- Agglomerates
  - Cathode materials consist of sub-micron primary particles
    - Primary particle size is a trade-off between surface area to reduce electrolyte decomposition that causes surface degradation and Li-ion transport rate that effects rate capability.
  - These particles are agglomerated to spherical secondary particles of a size of about 3 to 10 µm
  - This size of secondary particles can be handled in electrode processing
  - Hardness of the agglomerates is important to avoid breaking at electrode processing steps

- Coatings
  - Cathode materials are often coated
    - LFP cathodes are coated with a carbon layer to improve electronic conductivity
      - The thickness of this layer is of the order of one nm
    - NMC materials are sometimes coated to reduce the electrolyte decomposition at high voltages
      - Inert castings are used in this case

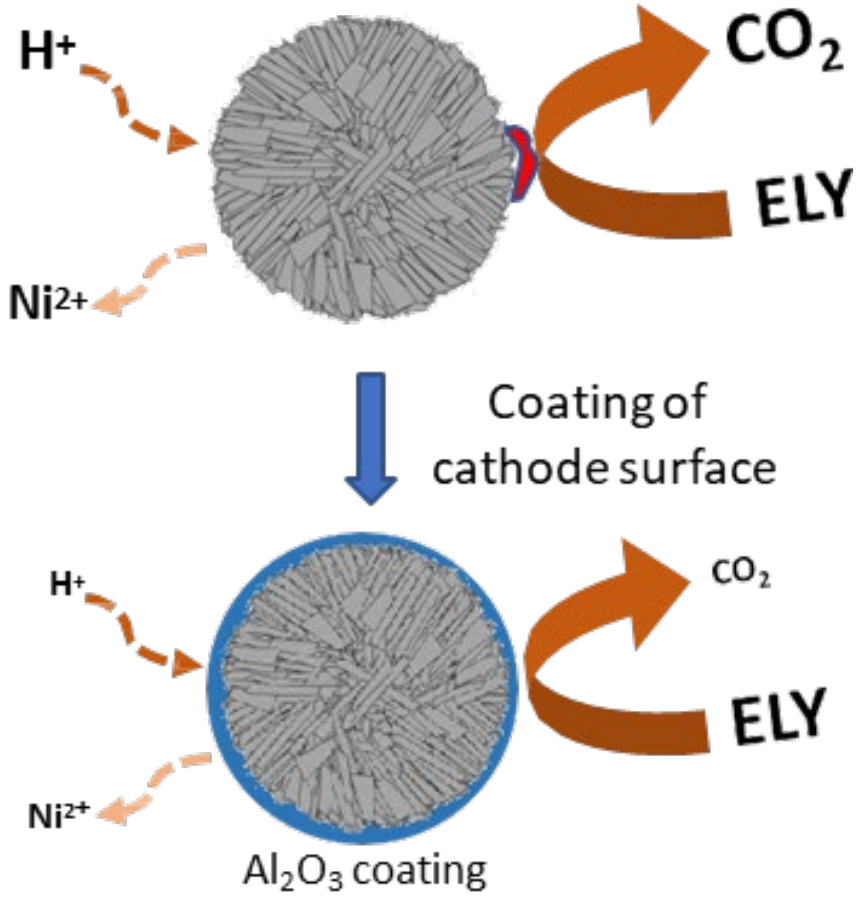
Example of Agglomerates for Different Types of Applications





- Different applications require different sizes and size distribution of the agglomerates
- High-rate capability requires smaller and more uniform agglomerates
- High energy density can be better achieved by a wider distribution of agglomerate size

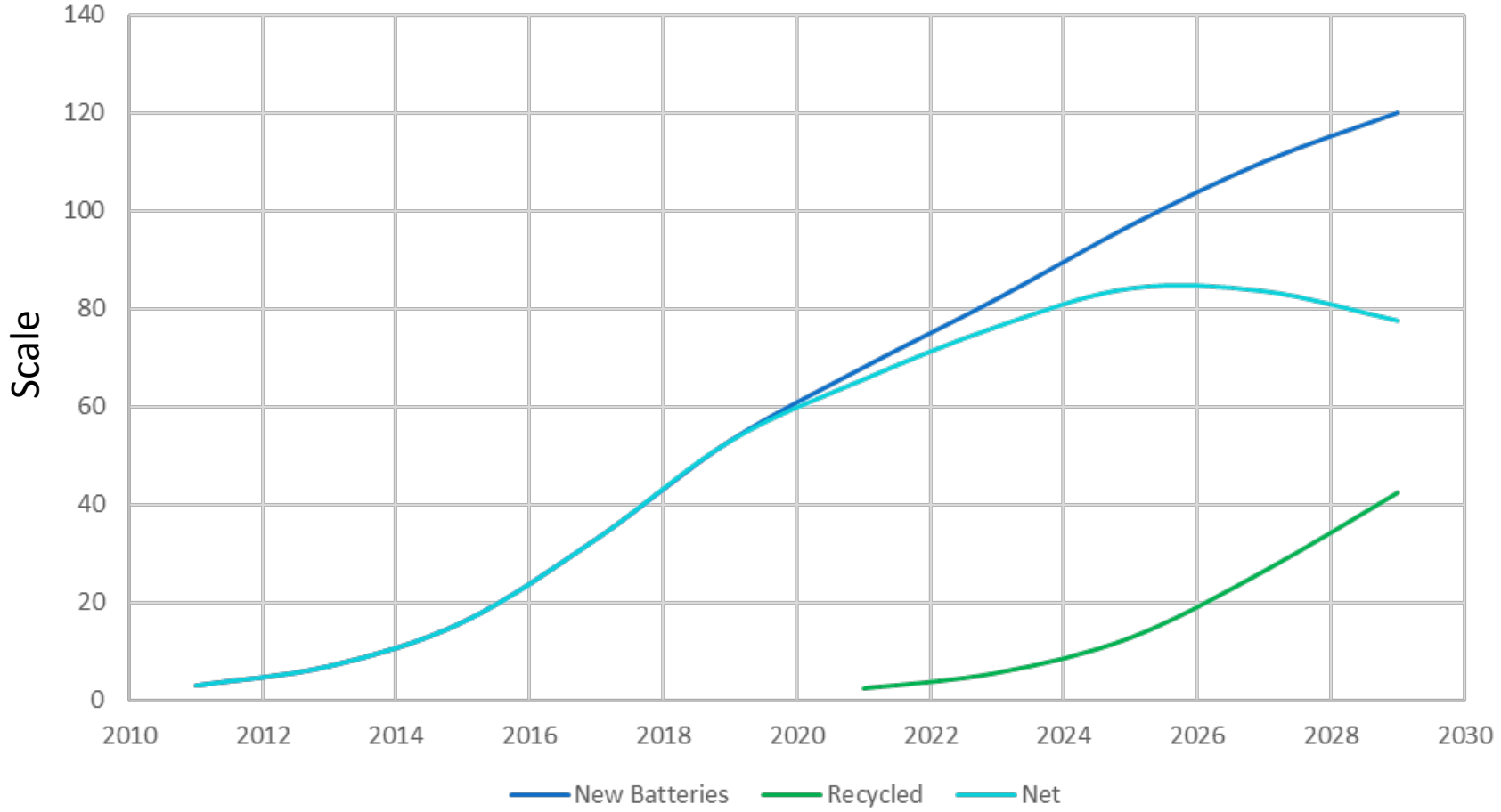
Surface Coating



- Surface coatings with electrochemically inert materials like alumina can be used to reduce the decomposition of the electrolyte
- Electrolyte decomposition leads to gassing

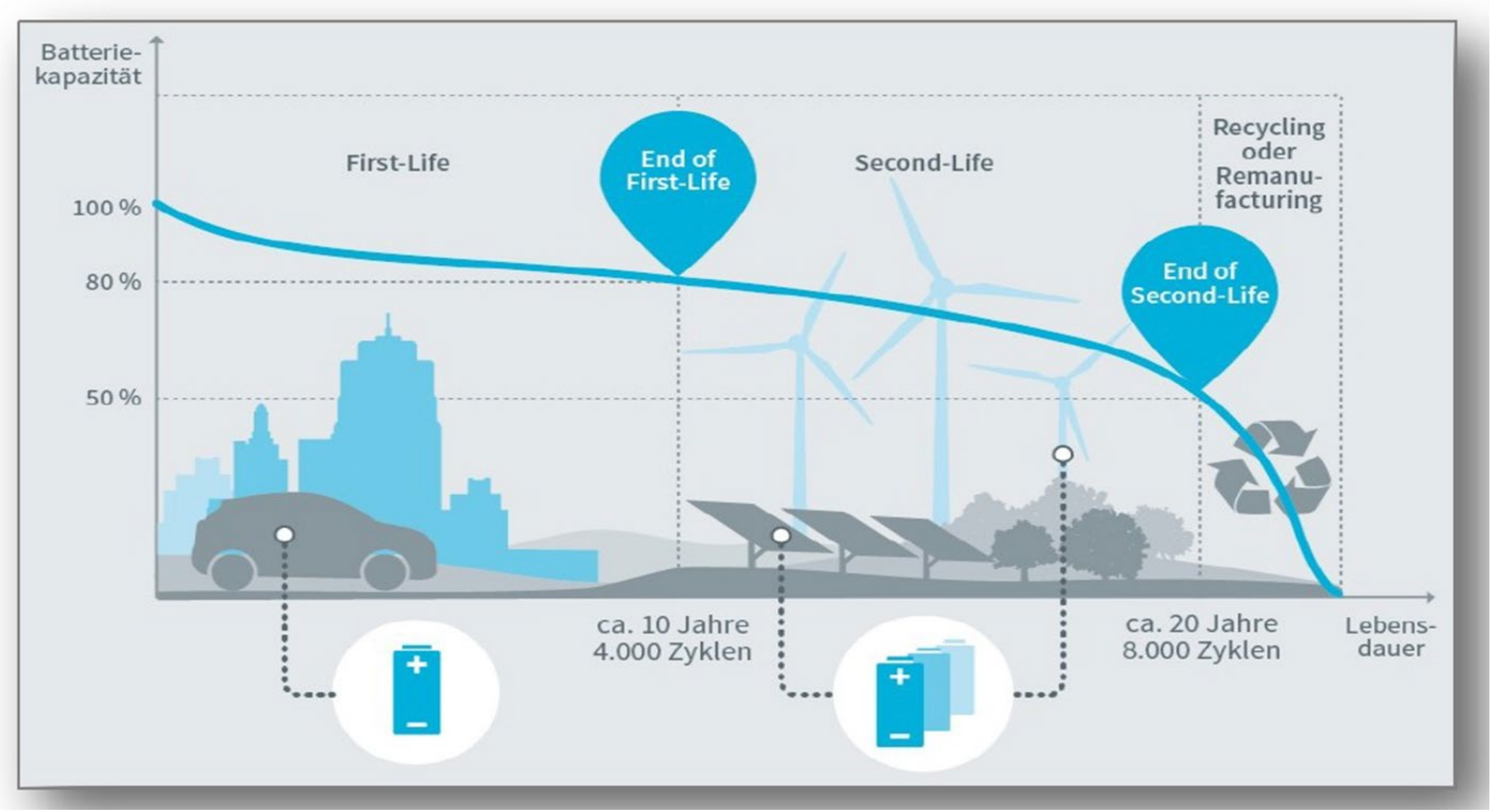
Recycling

Volume Requirements and Recycling



- Initial recycling focused on reclaiming Ni, Co, and Li
- Processes are under development to reclaim and refurbish active materials
- Foils such as current collectors may also have a use
- The use of used batteries from BEV in stationary storage has also been investigated

Example of Second Life Use of Automotive Batteries



POWER YOU CAN TRUST

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