We create chemistry

BASF Innovation in Cathode Active Materials

Dr.-Ing. Hannes Wolf

Battery Materials, BASF SE

4. Batterieforum Berlin-Brandenburg

BASF Battery Materials

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BASF – We create chemistry for a sustainable future

68.9 b€
(USD 74Bn)
2023 sales

Our chemistry is used in almost
all
industries

6 Verbund sites
and 234 other
production sites

78,000
customers from
various sectors
globally

111,991
employees

1 We are committed to **reduce our absolute CO_2 emissions by 25% by 2030** and **aim net zero emissions by 2050**.

2 We are a **leading chemical supplier** to the **automotive industry.**

3 We meet your needs with **one of the industry's broadest CAM portfolios.**

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We are the first company with a truly global footprint

North America

Elyria, Ohio, USA
CAM
& R&D (Beachwood)

Battle Creek, Michigan, USA
CAM

Europe – 2023

Schwarzeide, Germany
CAM,
Black Mass (‘24) &
Base Metal Refinery
Protoyping (‘24),
R&D (Ludwigshafen),
HQ (Mannheim)

Harjavalta, Finland
PCAM

Japan – BASF TODA Battery Materials

Onoda site, Yamaguchi
CAM & R&D
Capacity increase ‘24

Kitakyushu site, Fukuoka
CAM

China – BASF Shanshan Battery Materials

Shizuishan site, Ningxia
CAM & PCAM

Ningxiang site, Hunan
CAM

Dachangsha site, Hunan
CAM & R&D

Evergreen, Fujian
Recycling & PCAM

Yongshan, Hunan
Refining

● Production sites ● JV partnerships ● **Battery metals management** CAM: Cathode active material, PCAM: precursor CAM, HQ = BASF Battery Materials Headquarters

Map for indicative purposes, not adjusted for completeness or accuracy

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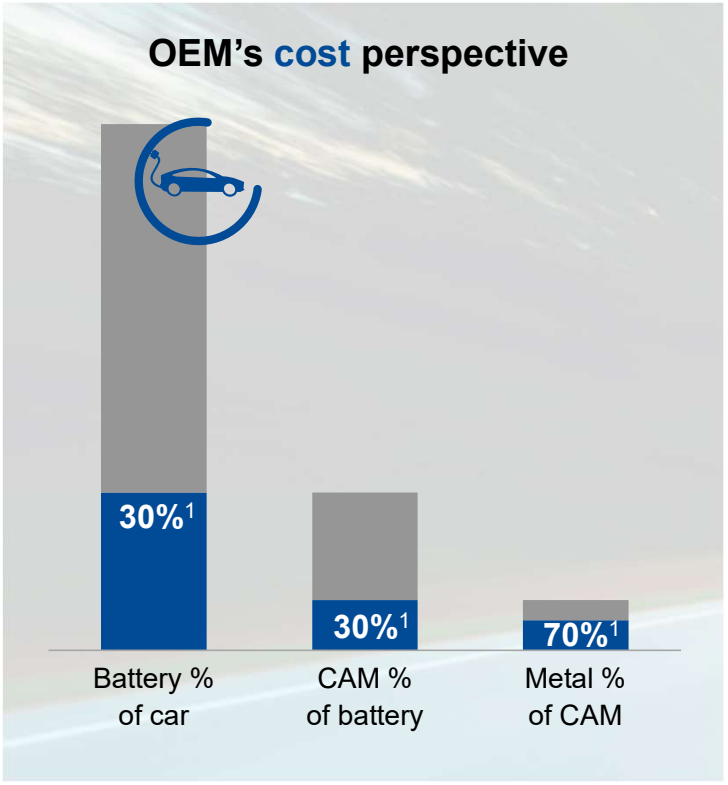
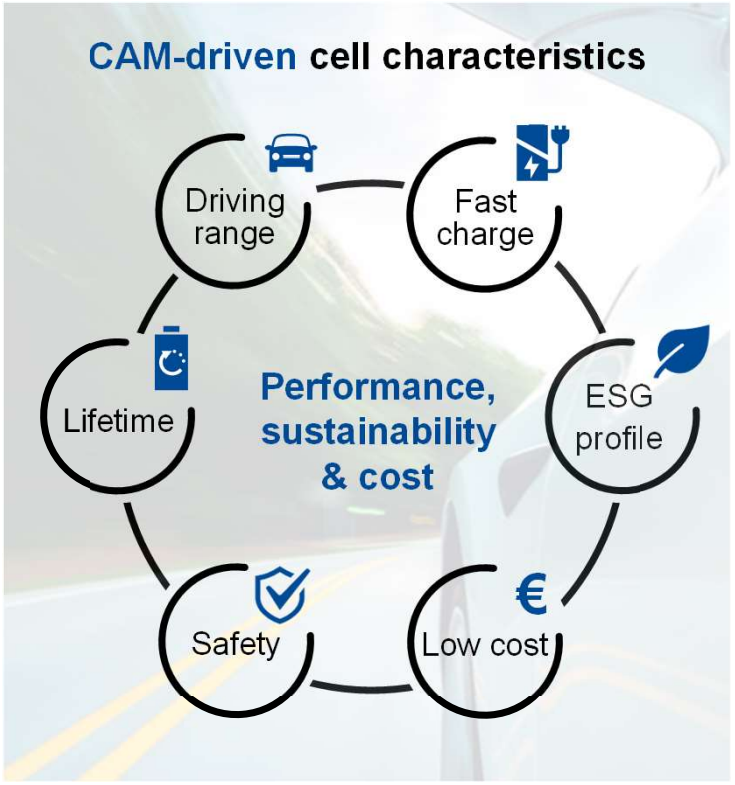
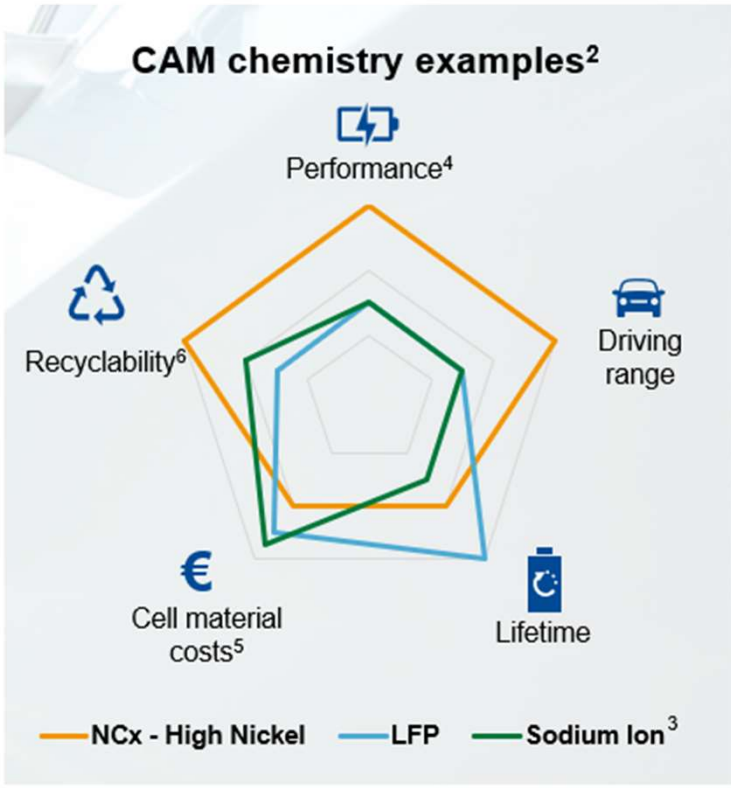
Within the electrified powertrain, CAM allows for the greatest level of differentiation and holds the largest material value







[1] Based on average values for NCM 811 cell chemistry; [2] Performance on pack/battery level might differ. Outer ranges in diagram indicate better evaluation; [3] CAM suitable for Sodium-Ion applications in development, potentially subject to changes. [4] Fast charging, general power performance (internal resistance / cold temperature performance); [5] Based on metal prices Q1 2024; [6] Recyclability incl. technical feasibility and profitability

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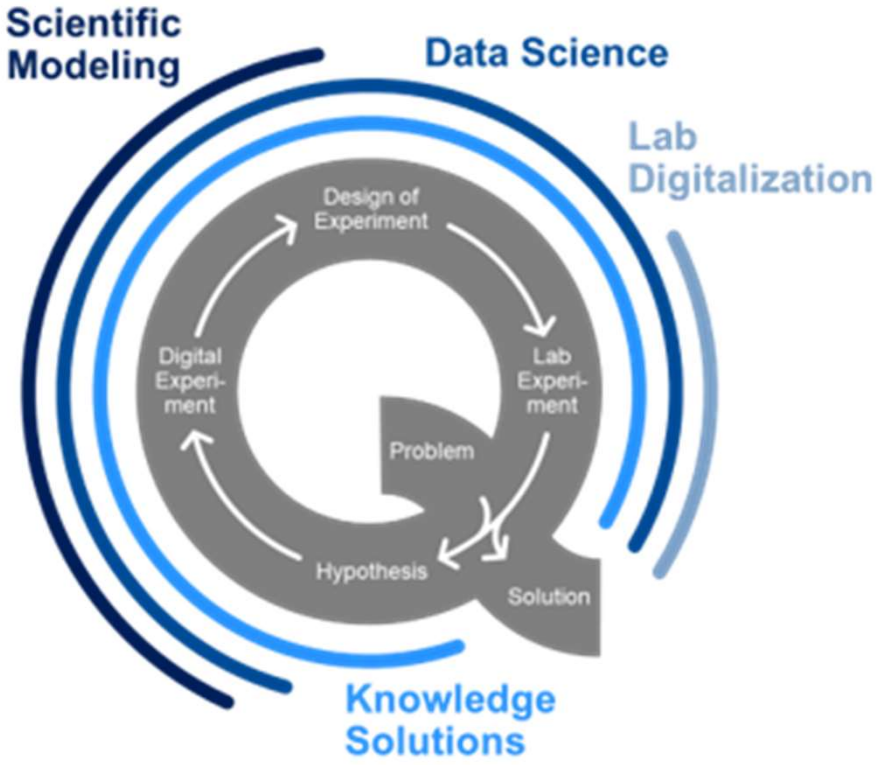
We innovate for our CAM portfolio ready today – to be ready for the future

- We leverage BASF's Group innovation fingerprint with **world-class R&D** capabilities and experienced scientists **specialized on battery materials**
- We offer an **extensive** and **strong IP portfolio**
- We focus on next generation battery systems, recycling and backwards integration of metals, and **optimizing our products tailored to the specific requirements of each application segment**
- We foster a **strong collaboration** with both, **academia** and **industry**

BASF CAM innovations for eMobility

Our Path to Data-centric R&D

Facilitate our development cycle via data-based experimental design



Screening Highway – high-throughput experimentation

Key aspects

- smaller sample size
- higher throughput
- standardized workflow
- increased process control and monitorability
- FAIR data
- data-based experimental planning & new evaluation strategies

→ Improved lab infrastructure to accelerate experimental R&D

→ Improved data quality via standardization and lab automation

Increase the output of our performed experiments by enlarging our database and advancing in data analysis.

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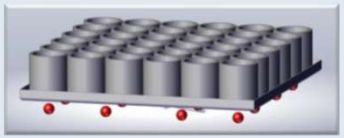
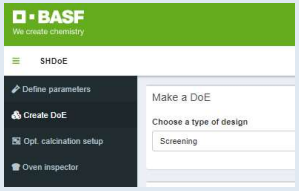
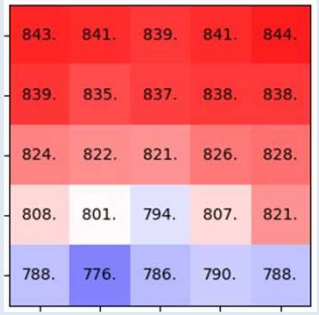
Manual Screening Highway: lab infrastructure

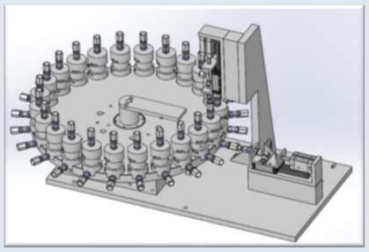
Precipitation



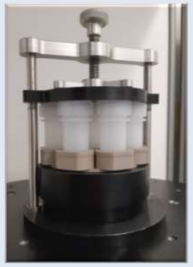




25 crucibles per furnace instead of 4



Automated washing station



8-12 slurries instead of 1

EC testing & analytics

Opportunities

- Higher throughput via parallelization & partial automation
- Standardized workflow
- Automated data handling
- Data-based experimental planning & new evaluation strategies

Challenges

- Scale down
- Less flexibility
- Dependency on digital infrastructure

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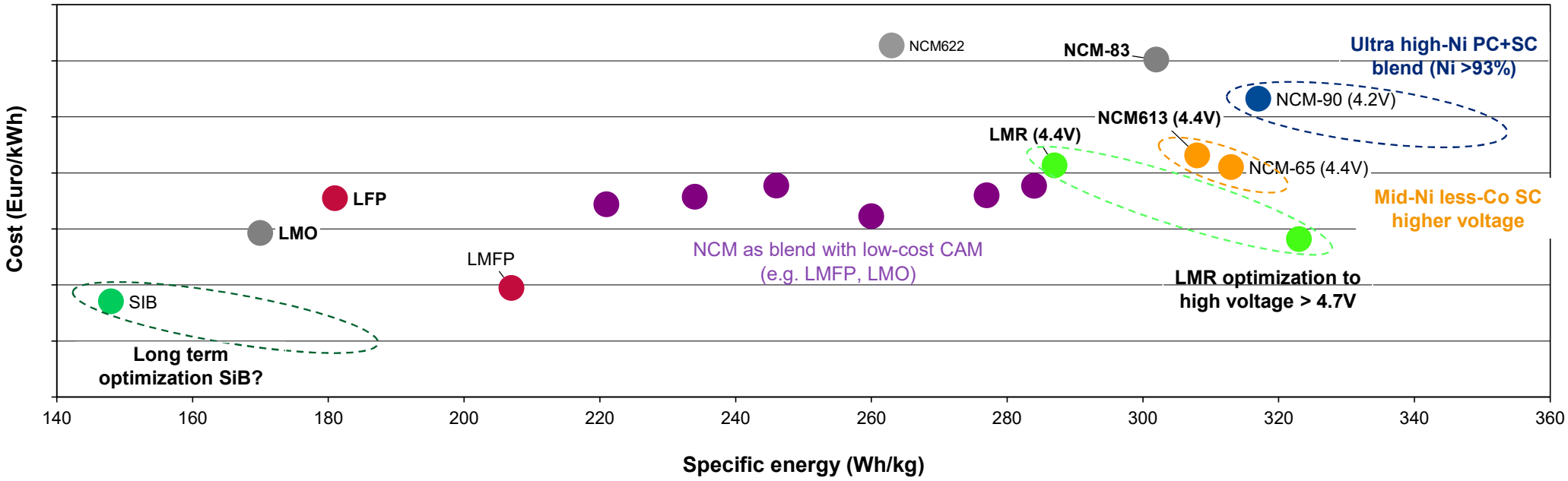
Optimization of cost vs performance – drivers for different CAM



Parameter field to optimize cost vs performance on CAM material level

With significant additional levers on pack level (cell to pack, cell to chassis etc)

Available space and allowable weight in combination with cost and range requirements drive CAM selection

Disclaimer: Cost strongly depend on metal price scenario

PC: poly crystal
SC: single crystal

LMR: lithium-manganese rich CAM
SIB: sodium-ion battery

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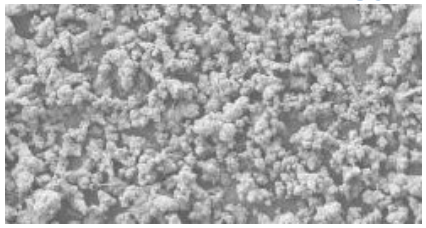
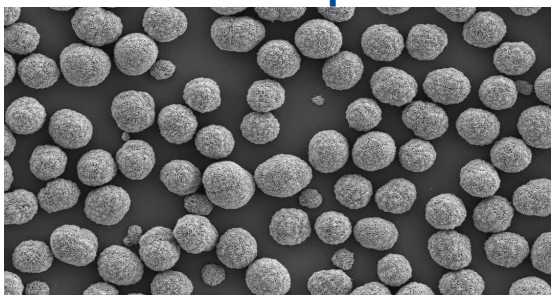
Cobalt free, manganese rich NCM-307™

- Safety profile comparable to mid-Ni NCM systems (DSC onset temperature) with capacity of high Ni NCM
- Tailored portfolio to meet various requirements, e.g. broad/narrow span and small/large particle types yielding high electrode densities > 3 g/cm^3
- Custom coating for lower Mn-dissolution, excellent high voltage cycling stability at 45 °C

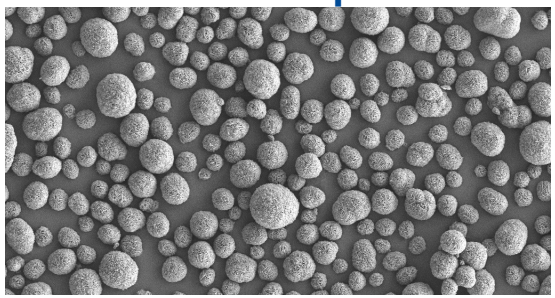
Gen 1 Morphology



Narrow Span



Broad Span



LCO: CE applications (high rate & high ED)

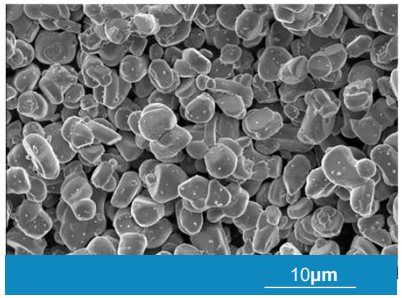
High voltage & high rate

4.5V

Application: E-cig, drone

- 0.2C Cap.：High
- 45℃ life cycle (10C Pulse DCH.) : High

High rate & long cycle



BASF not only develops and produces xEV market materials

LCO for consumer electronics application

LCO provides unique learnings also for xEV type of materials such as NCM and NCA

High performance needed by LCO:

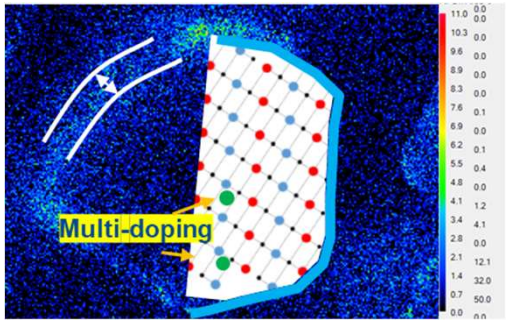
Learnings for

Morphologies

High-voltage applications

Gassing

Max. electrode densities



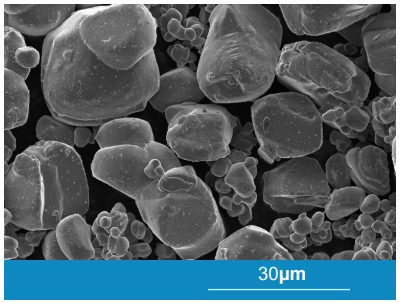
High capacity & ED

4.55V

Application: smartphone, laptop, tablets

- 0.2C Cap.：Highest
- 45℃ 3C fast charge cycle life : High

High capacity, low impedance & long cycle



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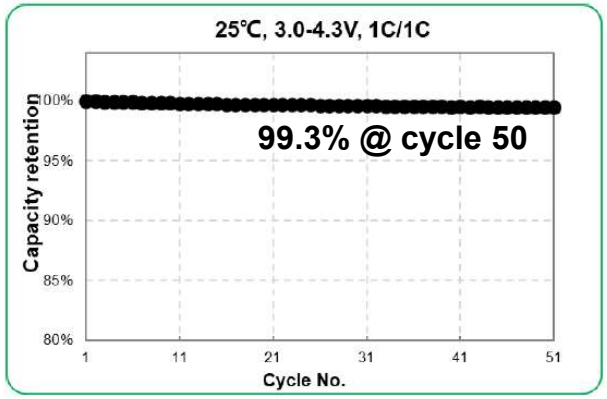
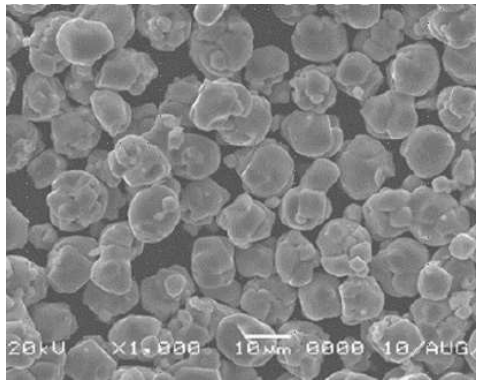
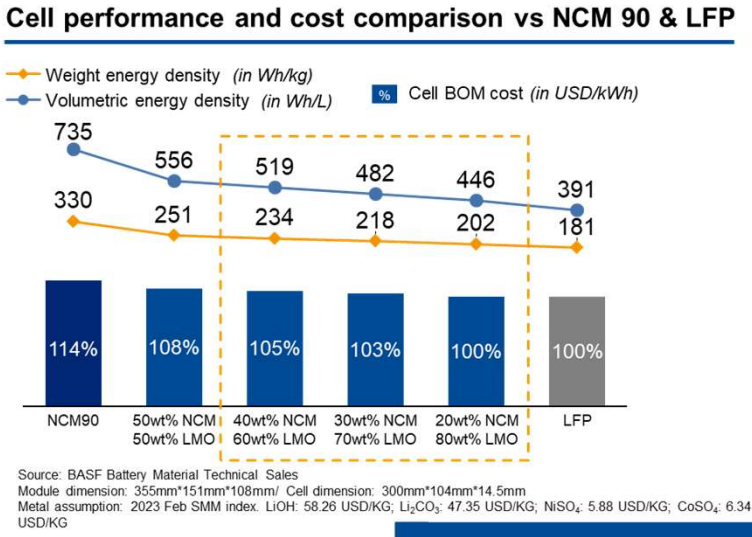
New developments for old chemistry: LMO

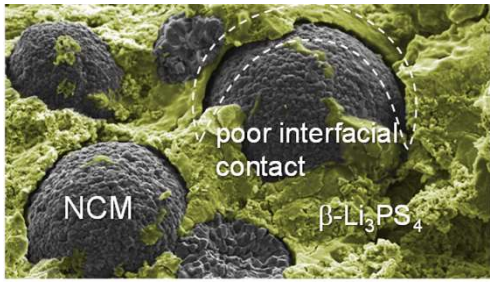
- LMO was used in early mass market EVs, due to its low cost and ease of manufacturing in cells
- LMO traditionally has poor capacity retention due to manganese dissolution
- Our R&D achieved recent breakthroughs in form of state-of-the-art coatings and dopings and new single crystal morphologies
- LMO with similar capacity retention of NCMs → this opens up an avenue to blend NCM with LMO for adjustable low-cost / high-performance chemistries







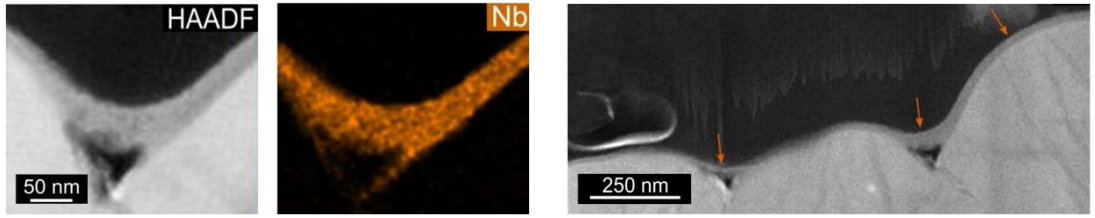
The problem:

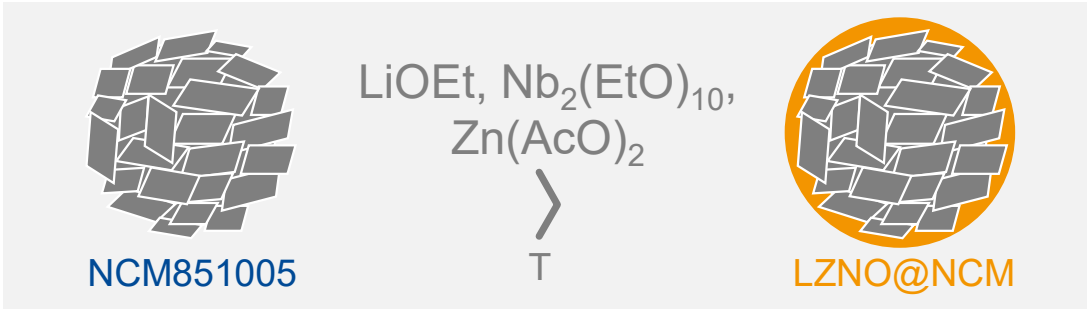


Stabilizing interfacial reactions and gassing

One potential solution: LZNO sol gel coating

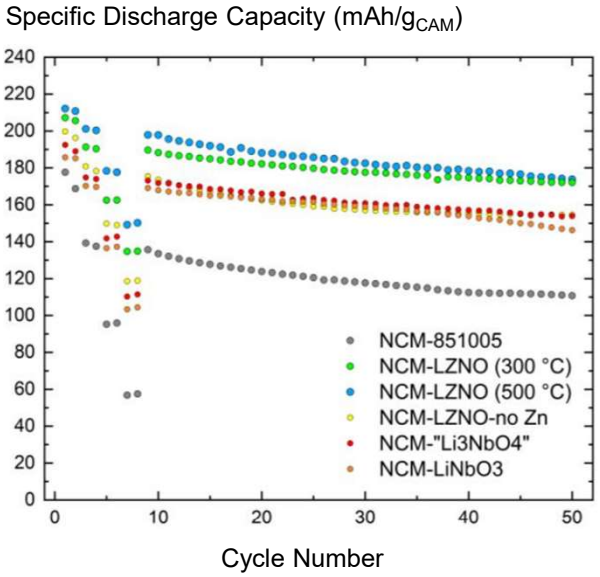
Sol gel process and coating morphology





- Targeting $Li_6ZnNb_4O_{14}$ (LZNO) to increase conductivity
- Resulted coating is a rock salt Li_3NbO_4 nanolayer with Zn inclusion

Electrochemical performance



Despite high (>10 nm) thickness, coating has sufficient ionic conductivity
Zn-containing rock salt Li_3NbO_4 coating outperforms Li_3NbO_4 and $LiNbO_3$ – Zn is essential

Kitsche et al, Batteries& Supercaps2022,5, e202100397(6 of 7)

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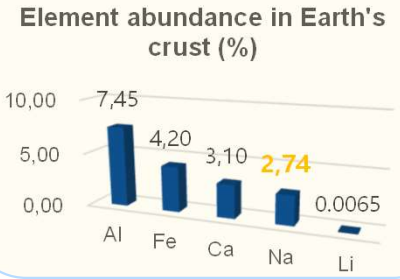
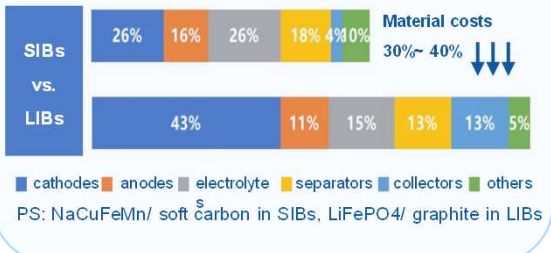
Sodium-ion battery claims in a nut-shell

Characteristics

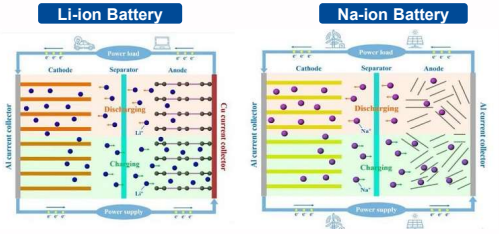
☑ **abundant resources**



☑ **competitive low costs**



☑ **similar work principles**



☑ high safety performance ☑ excellent high- and low-temperature performance

Applications

Electrochemical energy storage (ESS)

entry level EV

E-Scooter

household ESS

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Pu, Xiangjun, et al. Small, **2019**, *15(32): 1805427.*

BASF develops tailored CAM for each car segment with a strong intellectual property (IP) portfolio

Entry Segment	Volume Segment	Performance Segment
Lower range, lowest cost	Balanced cost-performance	Maximum range and power
		
Manganese-rich CAM	NCM[1] with 60-80% nickel	NCM[1] with > 80% nickel
Manganese-rich CAM	CAM with less or no cobalt	Ultra-high nickel CAM
CAM for sodium-ion batteries	Single crystal CAMs	CAM for solid-state batteries

New R&D trends

With customized cathode active materials, we are able to optimize cost and performance for every segment

Each car segment offers different opportunities to drive sustainability

[1] Nickel, cobalt, manganese

When research becomes reality: New CAM plant in Schwarzheide operational since June 2023

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