BMW GROUP

BMW GROUP BATTERY CELL TECHNOLOGY.

WE ARE DOING **OUR PART.**

1.5°C

BEVs in the next 10 years

10 M

Use Phase

-50%

CO_2 per car 2030 vs. 2019

Lifecycle

-40%

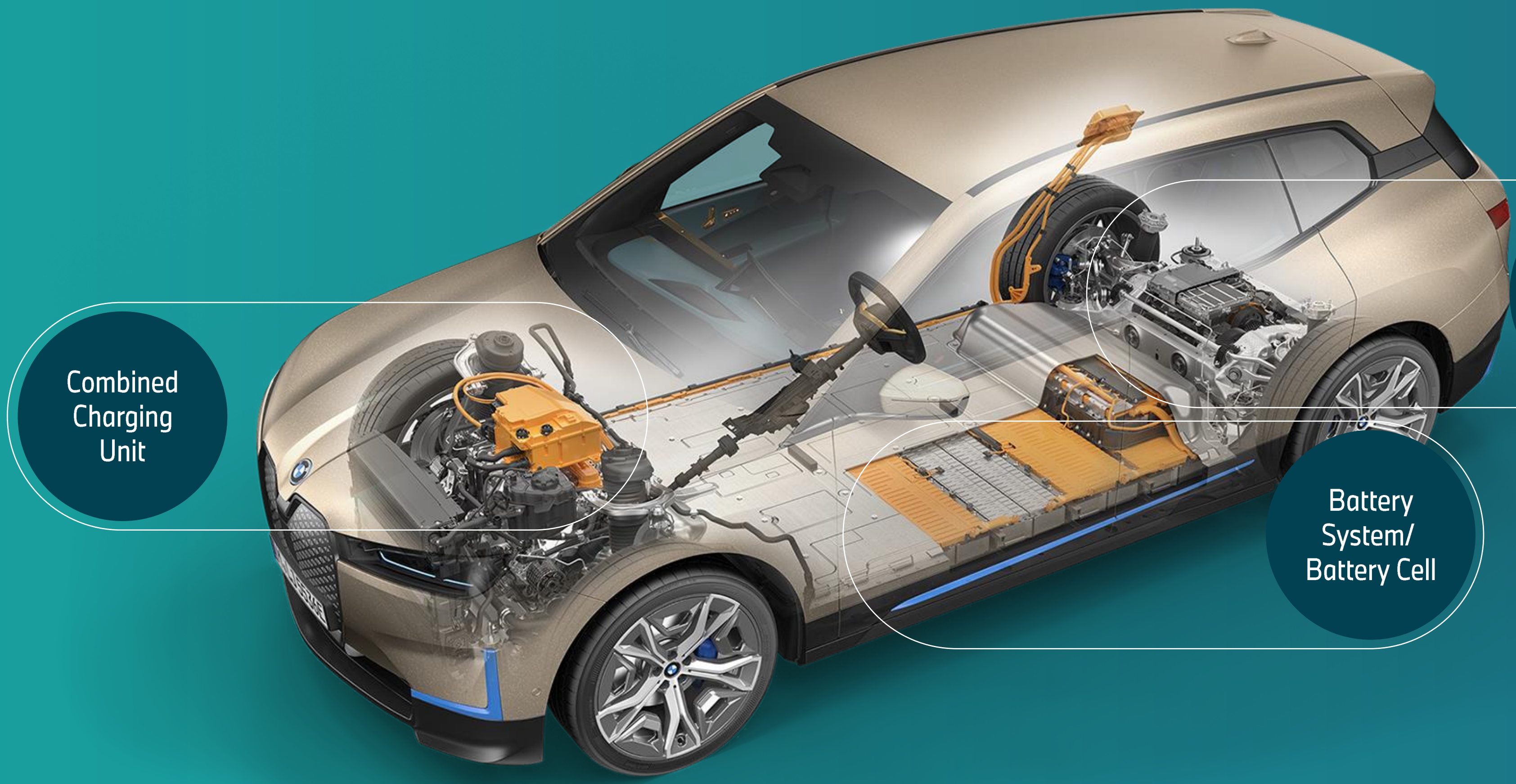
CO_2 per car 2030 vs. 2019

Share of secondary materials will increase to

50%

on average per car

IN-HOUSE DEVELOPMENT AND PRODUCTION OF KEY COMPONENTS.

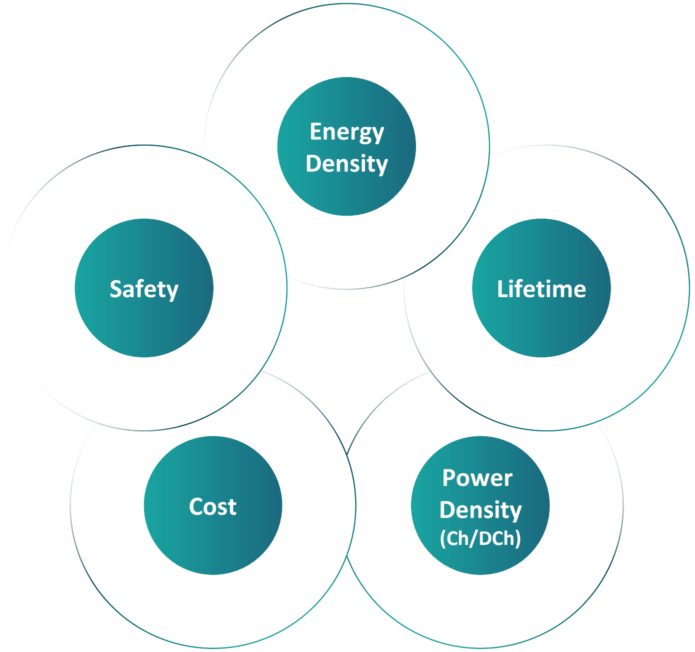


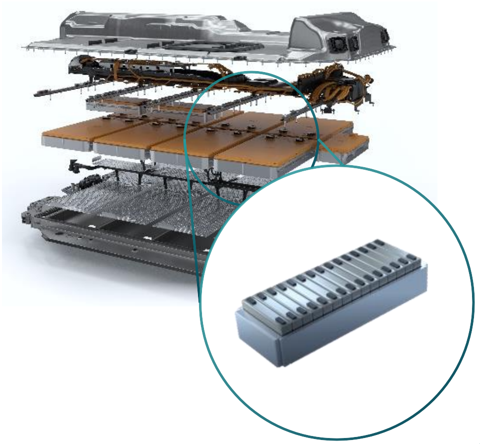
E-Motor, Power
Electronics
Gear Box

BATTERY CELL IS KEY COMPONENT **FOR FUTURE SUCCESS OF BMW.**

Battery KPI determine vehicle characteristics

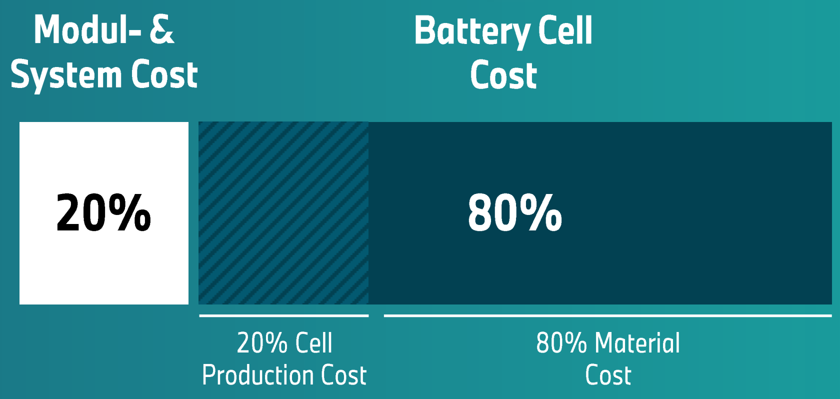
RANGE	CHARGE TIME	DRIVING POWER	COST





Ca. 40%

of total vehicle cost is cost for the battery pack (e.g. i4).



LONG TERM COMPETENCE FROM MOLECULES TO CELL **AND FROM BASIC RESEARCH TO APPLICATION.**

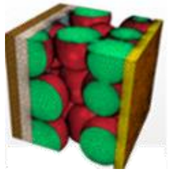
Start build-up of pilot line Parsdorf
Completion 2022
2020

Start build-up of BMW Group Battery Cell Competence Center
Completion 2019
2017

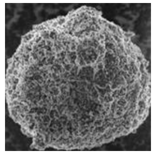
Start dedicated R&D project on battery cell technology
Deep dive, parallel top product development
2012

Start Li-ion development
In particular for i3/i8
2008

FUNDAMENTAL WORKING PRINCIPLES



MATERIALS



ELECTRODES/ SUBCOMPONENTS

CELLS

BMW DEVELOPMENT SPANS OVER EARLY R&D TO CONCEPT PROOF OF BOTH, PRODUCT AND PROCESS. INDUSTRIALIZATION IS DONE WITH PARTNERS.

R&D

> **300** contacts
43 running projects

- Institutes
- Academia
- Startups
- OEMs
- Industry

LAB

Material characterization

Chemistry development

Recipe development

Performance and safety test

Post mortem analysis

PROTOTYPE CELL BUILD

PILOT PRODUCTION

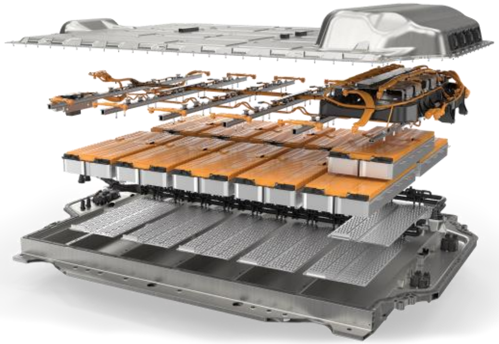
Industrialization with partners

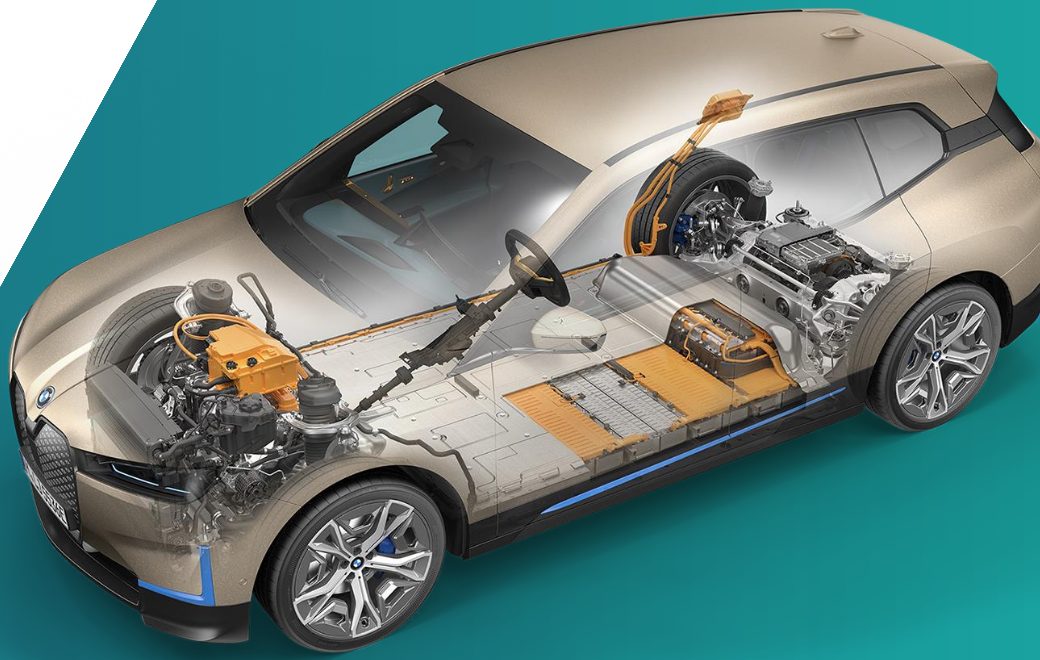
PRODUCT INNOVATIONS

PROCESS INNOVATIONS

COMPLETE VALUE CHAIN AND LIFE CYCLE HAS TO BE CONSIDERED. CLOSED MATERIAL CYCLE FOR BATTERY CELLS IS NECESSARY.

- Battery Material Production, Battery Quality Grade
- Battery Cell Development
- Battery Cell Production
- Battery Module & System Development & Production
- Production Launch (Use Phase)
- Second Use and/or Collection and Disassembly
- Recycling Recovery of Raw Materials
- Raw Materials (Mining, Refining)





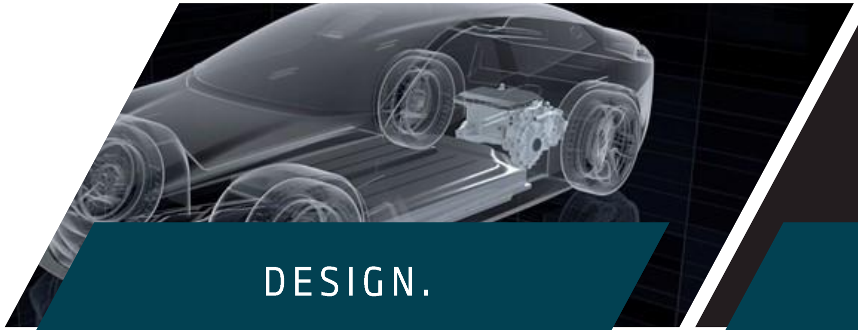
Cobalt and lithium from **certified mines** in Australia and Morocco. Usage of **secondary material.**

Production of battery cells with **100% power from renewable sources.**

Taking back batteries worldwide at the end of battery life. **Enabling second use e.g. in battery storage farms.**

Pushing the limits of material **recycling** and **returning materials efficiently into the production cycle.**

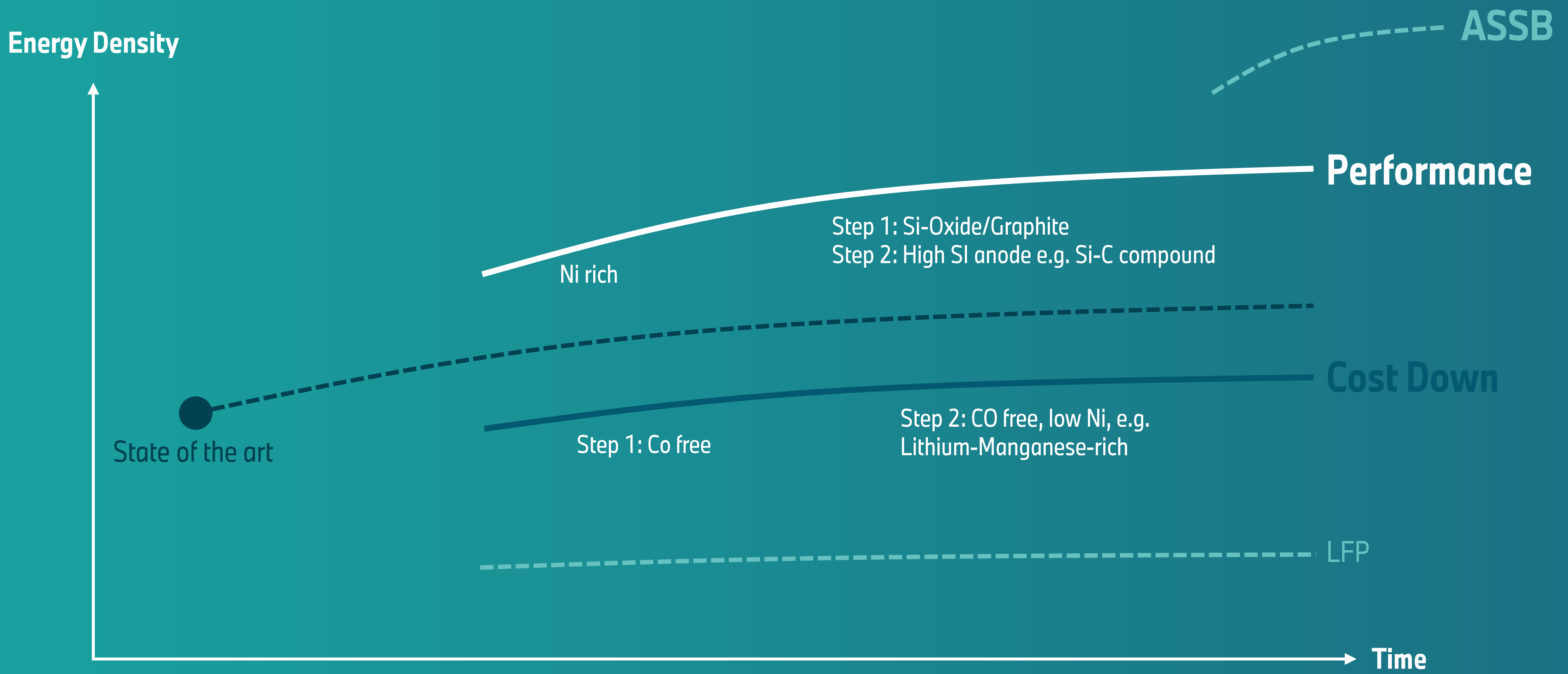
BATTERY SYSTEM DEVELOPMENT – TRENDS ARE BASED ON TECHNICAL NEEDS BUT ARE ALSO DRIVEN BY REGULATORY MEASURES.



	DESIGN.	SAFETY.	SUSTAINABILITY.
Present	Pack as individual component based on modules and with own structural capability and housing.	Mainly based on Chinese regulation: no propagation/battery integrity maintained for >5min in case of a thermal runaway of one cell.	Own responsibility but no mandatory requirement.
Trend	Higher integration to optimize filling factor/energy per volume e.g. cell-to-pack, cell-to-chassis.	Step-wise increase to 40min forecasted. Best solution: “propagation stop”.	Carbon footprint declaration 2024 on-wards (limit for CO_2 footprint in g/kWh expected); amount of recyclate used and recycling rates will become regulated for most relevant materials → **in particular driven by EU COM.**

Trends/changes in requirements will influence cell technology choice (pouch, cylindrical, prismatic hardcase).

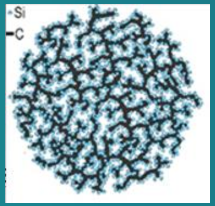
BATTERY TECHNOLOGY ROADMAP – TRANSITION FROM PERFORMANCE/RANGE MAXIMIZATION TOWARDS PORTFOLIO ORIENTED (PERFORMANCE VS. LOW COST).



TRENDS IN MATERIAL AND **CELL DEVELOPMENT.**

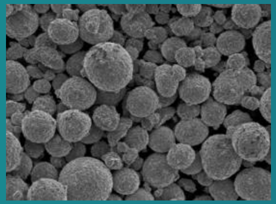
ANODE MATERIAL

Graphite	360 mAh/g
Graphite + SiOx	500 – 600 mAh/g
Si – C Composite	**1,200 mAh/g**



CATHODE MATERIAL

NMC 111	150 mAh/g
532, 622	180 mAh/g
811	210 mAh/g
>90% Ni	**230 mAh/g**

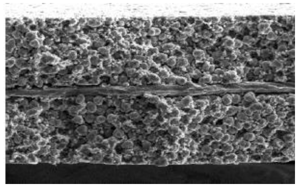


RISKS

- Stability (e.g. Ni-rich materials) and cost (e.g. Si-anodes) of "high performance materials".
- Materials have to be compatible with electrode and cell design trends.

ELECTRODE DESIGN

- Increased loading (limited by power requirement)
- Optimized coating (e.g. reduced uncoated area) (limited by manufacturing tolerances and safety issues)

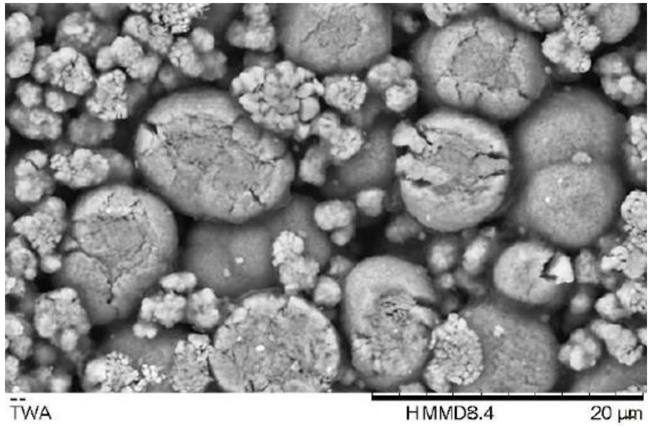


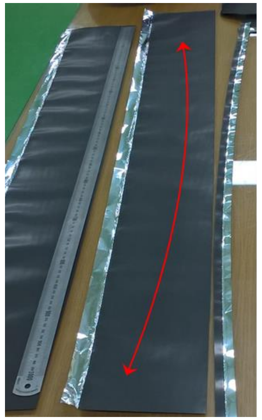
CELL DESIGN

- Increased volume utilization jelly roll to cell (e.g. stacking compared to winding → **risk: cost**)
- Increased packing density → **risk: swelling force**
- Reduced Al/Cu foil and separator thickness → **risk: handling, safety**
- Increased cell size with increased active-/inactive ratio →**risk: maintain safety level**

MATERIAL AND PROCESS DEVELOPMENT
HAVE TO BE DONE IN PARALLEL.

MIXING/COATING › PRESSING/CALENDERING › SLITTING





Typical Challenges/Risks

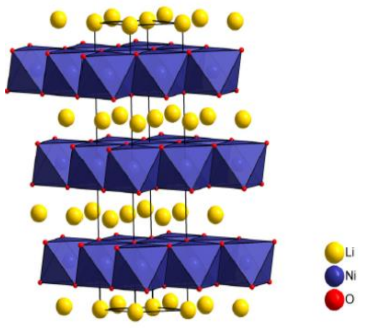
– Protective coatings and particle structures can be damaged.
– Final electrode density can not be reached.
– Requirements for cell assembly are not met (e.g. camber effect).

Counter Measures

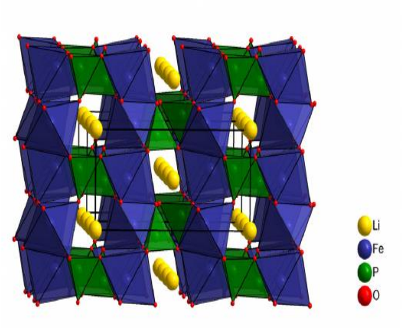
– Coating recipes have to be optimized, e.g. Cathode material powder densities have to be optimized, binder/conducting agents adjusted.
– Substrates foils have to be carefully selected.
– Calendaring processes have to be improved.

RENAISSANCE OF LITHIUM-IRON-PHOSPHATE (LFP) – MOTIVATION AND LIMITATION OF LFP FOR LOW-COST APPLICATIONS.

$LiMO_2$ Schichtoxid
e.g. $LiNi_xCo_yMn_{1-x-y}O_2$ – NCM

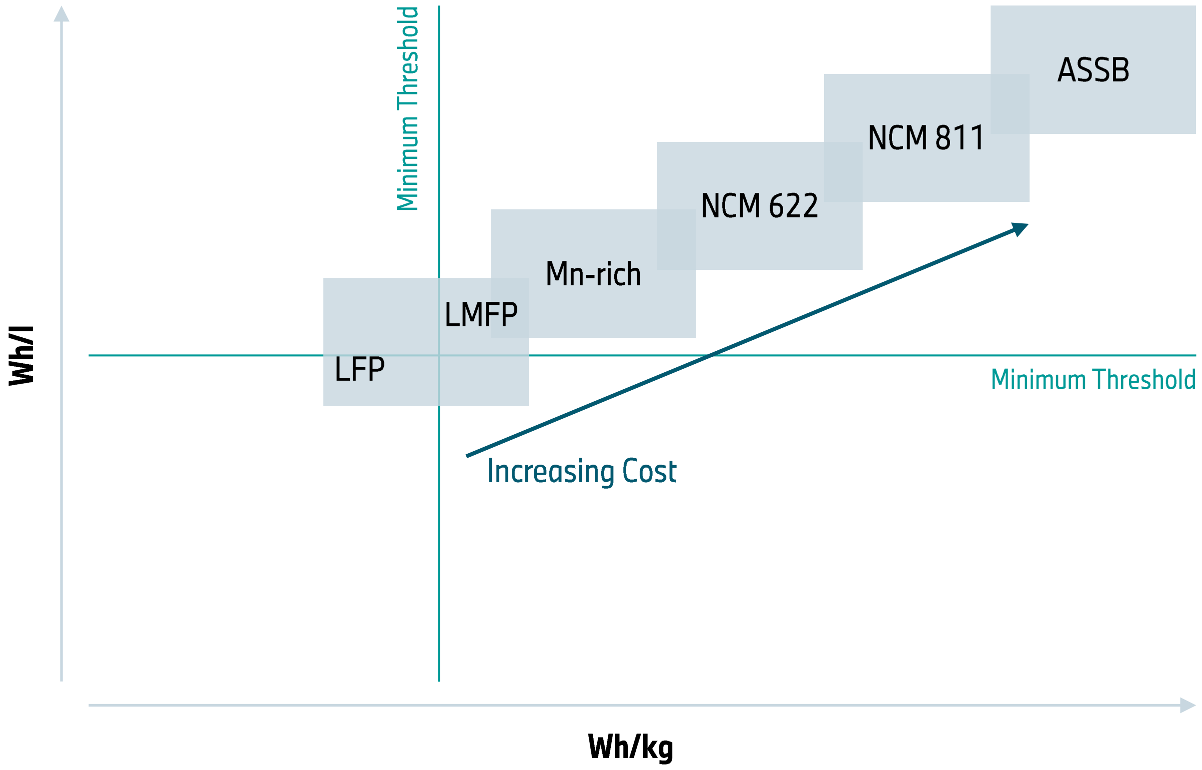


$LiMPO_4$ Olivin
e.g. $LiFePO_4$ – LFP



	NCM 811	LFP
Specific capacity	200 Ah/kg	158 Ah/kg
Mean cell voltage	3.68 V	3.22 V
Specific energy	**736 Wh/kg**	**509 Wh/kg**

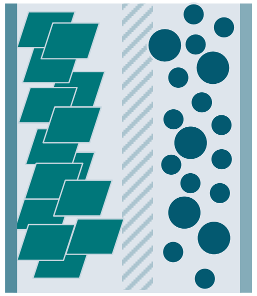
Volumetric/Gravimetric Energy Density



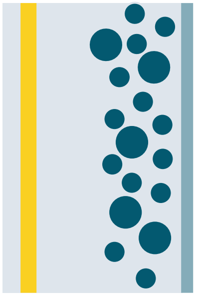
LFP material still the same. Optimization of cell and pack design made LFP attractive for entry segment.

ALL-SOLID-STATE BATTERY AS **THE NEXT GAME CHANGER.**

STATE OF THE ART
LI-ION CELL



NEXT-GEN
LI-METAL /SOLID ELECTROLYTE CELL (ASSB)



MAIN DIFFERENTIATION

Replace liquid electrolyte by Li-ion conducting solid electrlyte → **increase inherent safety**

Replace graphite or silicon-graphite anode by Li-metal anode → **increase energy density**

POTENTIAL.	CHALLENGES.

– Higher inherent safety level allows for
  – High performance materials
  – Large cell formats
  – Reduced secondary safety measures in the battery pack
– Solid electrolyte allows for innovative cell concepts (e.g. bipolar cells)
– Li-metal anode lead to energy density increase
	– Pressure necessary to stabilize interfaces and allow for good lifetime
	– Different thermal management needed (focus on heating instead of cooling)
	– Volume change during charge/discharge for Li-metal anode
	– Rate capability for Li-metal anodes
	– Robustness of material system in production and over lifetime

High potential in direction of safety and energy density. Cost still unclear but essential. Promises still need to be verified. Industrialization only reasonable after positive concept proof.

BMW GROUP

THANK YOU FOR YOUR ATTENTION!