Cell Technology, Overview and Trends

Jon Caine, Roman Zettl

Public

Redrawing the Lines of Electrification

AVL Battery Solutions

Leading the Charge in Battery Innovation for Sustainable Mobility.

20+ Years of Experience

5,700+ E-Mobility Experts

650+ Battery Engineers

45+ Global Tech Centers

1000+ Executed Battery Projects

266 Patents in Force*

AVL Global Battery Competence Team

Battery prototype build and test facilities


HQ Graz, **AUT**

Steyr, **AUT**

Reggio Emilia, **ITA**

Budapest, **HUN**

Neuenstadt, **DE**

Regensburg, **DE**

Remscheid, **DE**

Munich, **DE**

Södertälje,**SWE**

Istanbul, **TUR**

Basildon, **UK**

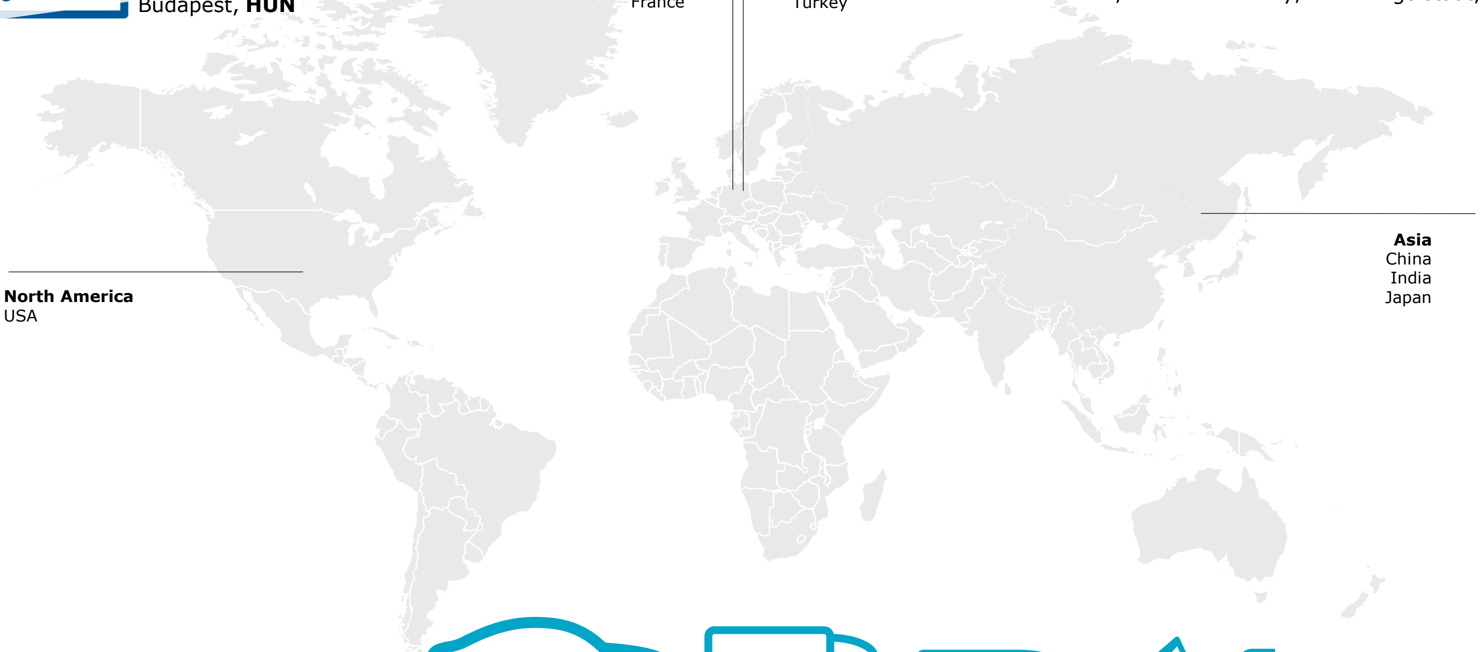
Coventry, **UK**

Ingolstadt, **DE**

Stuttgart, **DE**

Gothenburg, **SWE**

Massy, **FR**



Lake Forest, CA, **USA**

Ann Arbor, MI, **USA**

Plymouth, MI, **USA**

Delhi-Gurgaon, **IND**

Shanghai, **CHN**

Tokyo, **JPN**

Tianjin, **CHN**

Focus Areas:

Key Performance Targets for AVL Battery Development Services and Featured Competences

Technology & Innovation / Series Development Support

CO_{2e} Regulation

- Analysing, measuring and reporting of CO_{2e} footprint
- Life Cycle Analysis
- Reducing CO2e footprint

Energy Density

- Reduction of parts
- Light weighting
- Module2Chassis
- Integration of new electrodes Si-anodes
- Integration of ASSB

Efficiency

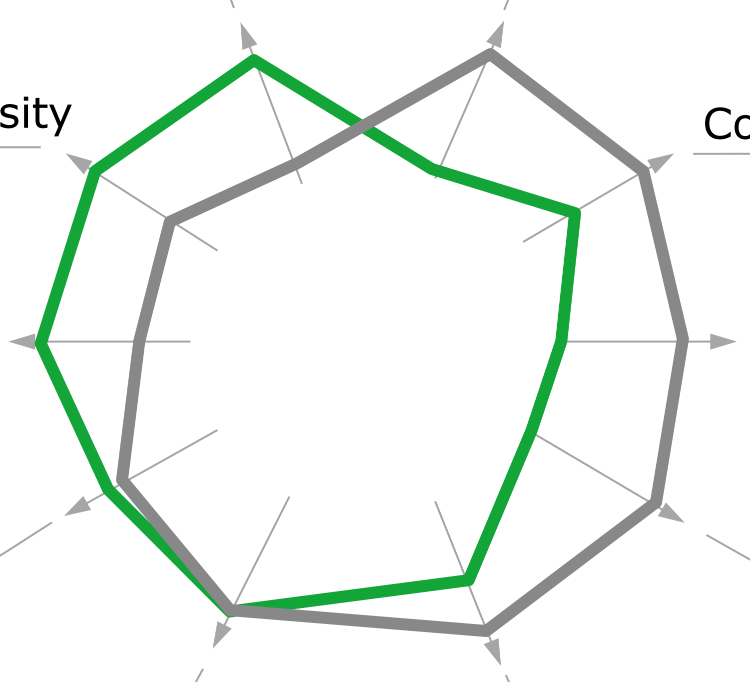
- Optimised cell designs
- Optimising thermal pathways
- Thermal syphon cooling
- >900V electric systems

Robustness

- Next Gen BMS systems
- AVL Load Matrix™ and generic battery validation planning
- EMC handling
- Robust EE integration and component development

Safety

- No Propagation design
- Battery Test & Validation
- Own testbeds and build of test equipment (with AVL ITS)



Time2SOP

- Model based Systems Engineering for battery
- Virtual validation capability

Cost

- LFP based systems
- Cost management for bottom-up target cost calculation and cost monitoring
- Innovation2cost
- Hand-in-hand functional design & process design

Supply Chain

- Cell supplier management for technical validation and delivery quality
- Scouting and building supply chains from raw material to finished product
- Enabling local or in-house supply chain for critical elements

In-Use & Recycling

- Cell & battery design for recycling & circularity
- Battery lifecycle management tools
- Cloud based battery fleet management
- Serviceability concepts for batteries (with AVL DiTest)

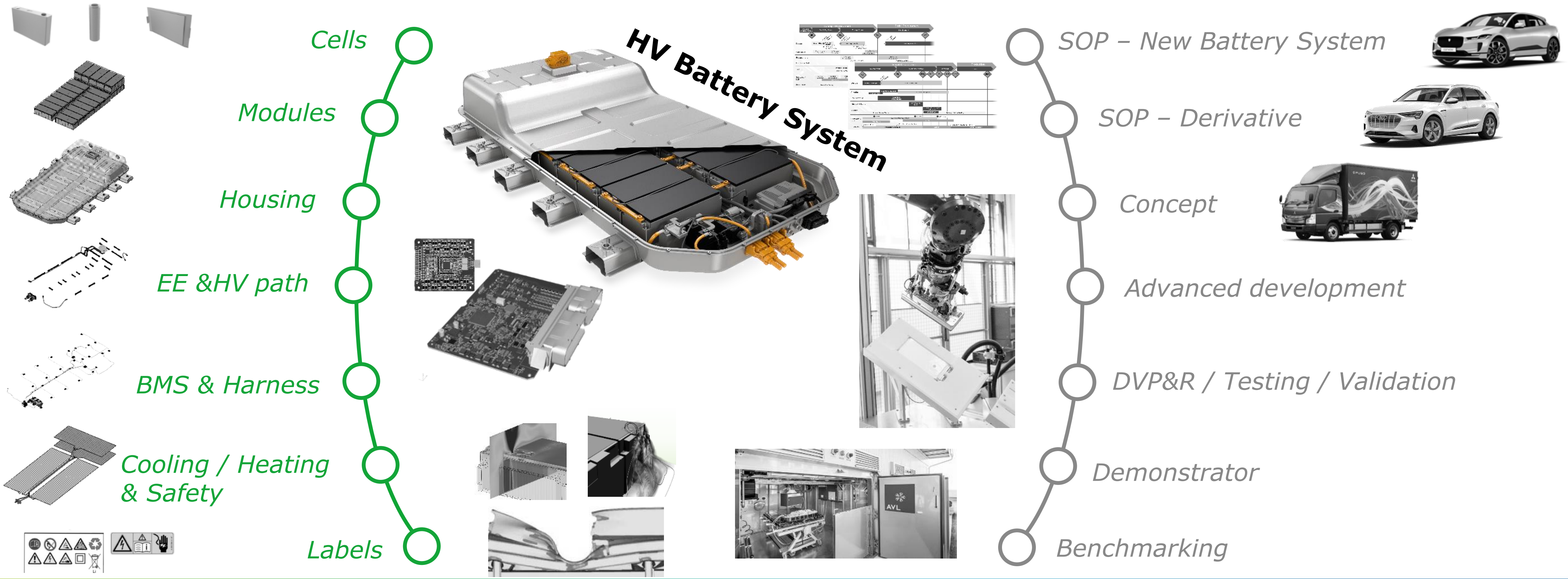
Production Ready

- Production process and quality system development
- Module and battery assembly automation (AVL BIC)
- Design2production

AVL Battery Development Competencies

Technology Competence
From electrode to pack integration

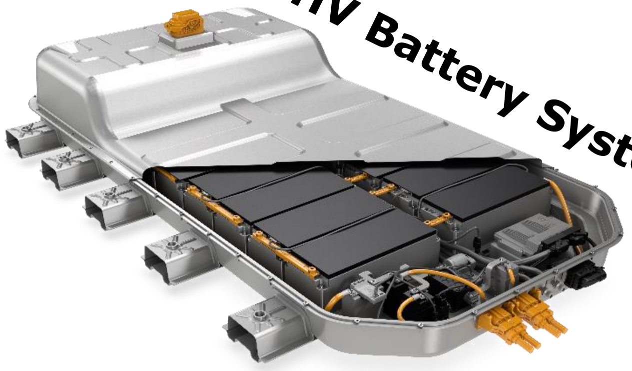
Project execution
from advanced development to SOP handover



AVL Battery Development Competencies

Technology Competence
From electrode to pack integration

Cells



Overview Cell Technology – Cathode & Electrolyte Today to 2030

Generic electrochemistry Roadmap - Spotlights

Technical

Road to 2025

Road to >2028

Cathode materials

LFP / LFMP

~190Wh/kg

Chinas patent restrictions fell 2022

Better safety and swelling behavior → drop-in derivative chemistry

BYD, Gotion, etc.

Safety
Cost
Trend

NMC /NCA

NMC-811, -89, -90, …

>250Wh/kg

Highest energy by pushing Ni-content to >95%.

NMC: CATL, LGC,…
NCA: Samsung, Panasonic, …

Safety
Cost
Trend

NMX

NMA-89 (contains Al)

Co-free alternative to NMC with very good long-term cycling stability and better thermal stability than e.g. NMC-89.

Safety
Cost
Trend

Semi-solid Electrolyte

Lower power density

Less gas evolution & higher electrode particle retention is expected by capturing the solvent in the semi-solid state

Drop-in to existing production line due to the flexibility of semi-solid state films.

SES, Factorial Energy, …

Safety, Durability
Cost
Trend

All-solid-state

>900 Wh/l
>400Wh/kg

No organic solvent – increase in safety

Manufacturing concerns: rigidity, brittleness, high temperatures or inert atmospheres.

QuantumScape, SolidPower, …

Safety
Cost
Trend

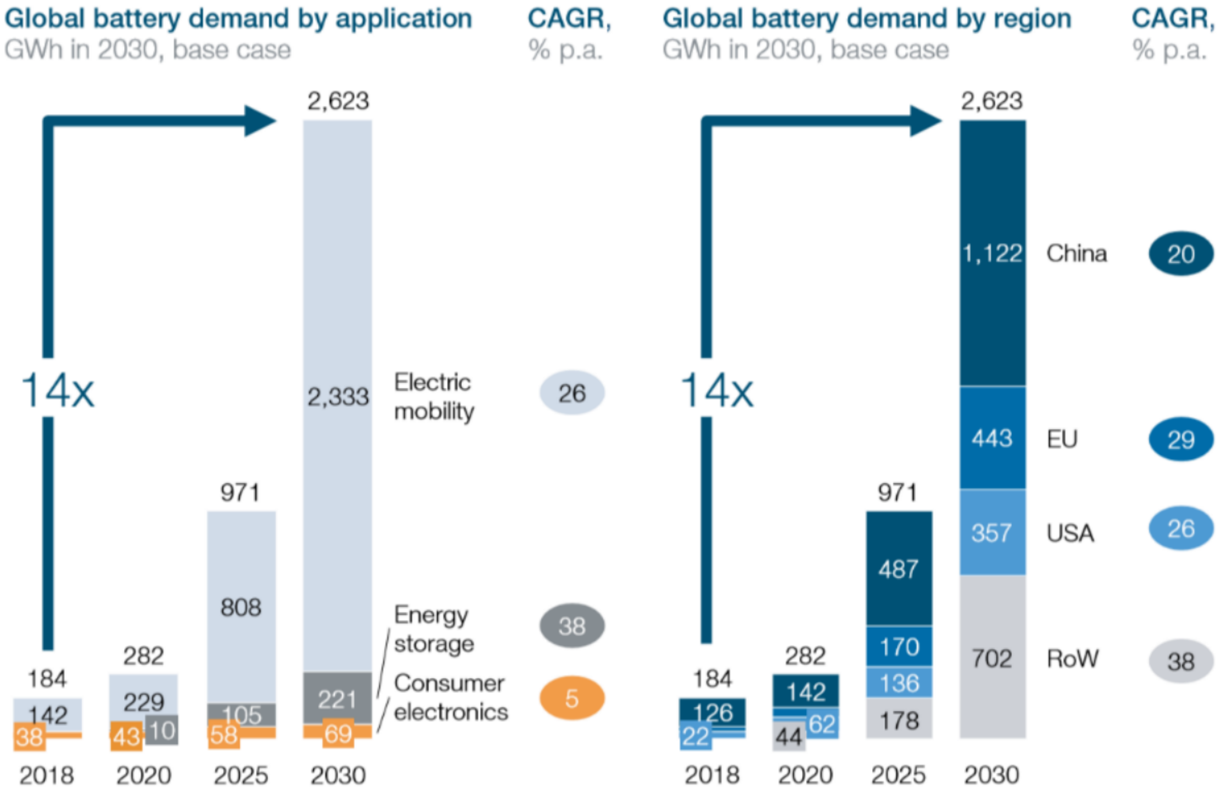
Rating

Overview Cell Technology

The globally increased demand of Li-ion battery (LIB) is expected to continue in the upcoming years.

The main driving factor for an increased demand is associated with the production of electric vehicles.

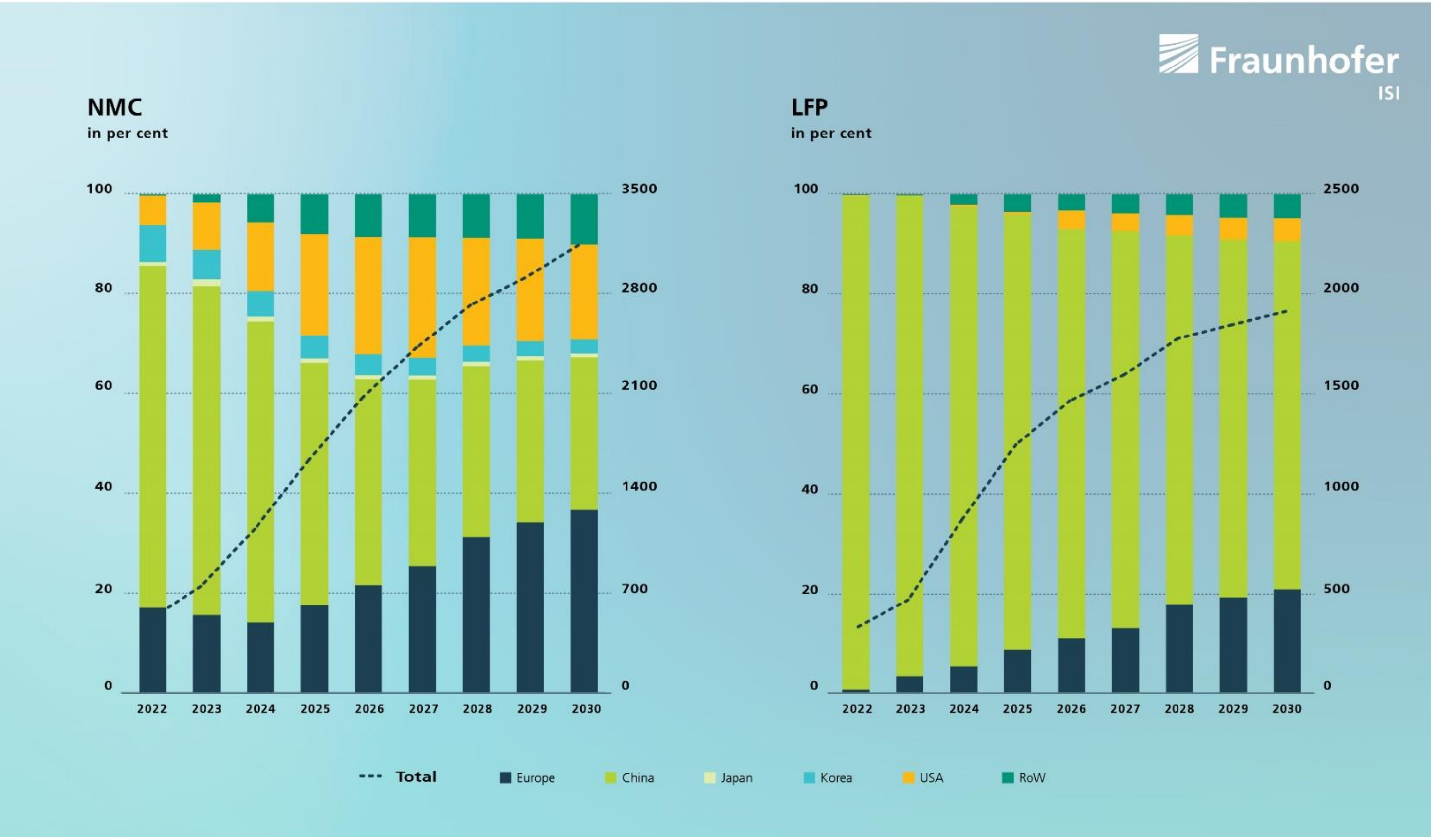
- Biggest demand expected to come from China, the EU and the USA.
- Due to a high demand in other major regions worldwide, the total share of China is expected to decrease from ~70% in 2018 to ~43% in 2030.
- The stationary sector is expected to gain a higher market share in the upcoming years.



AVL

Market specific share of NMC and LFP

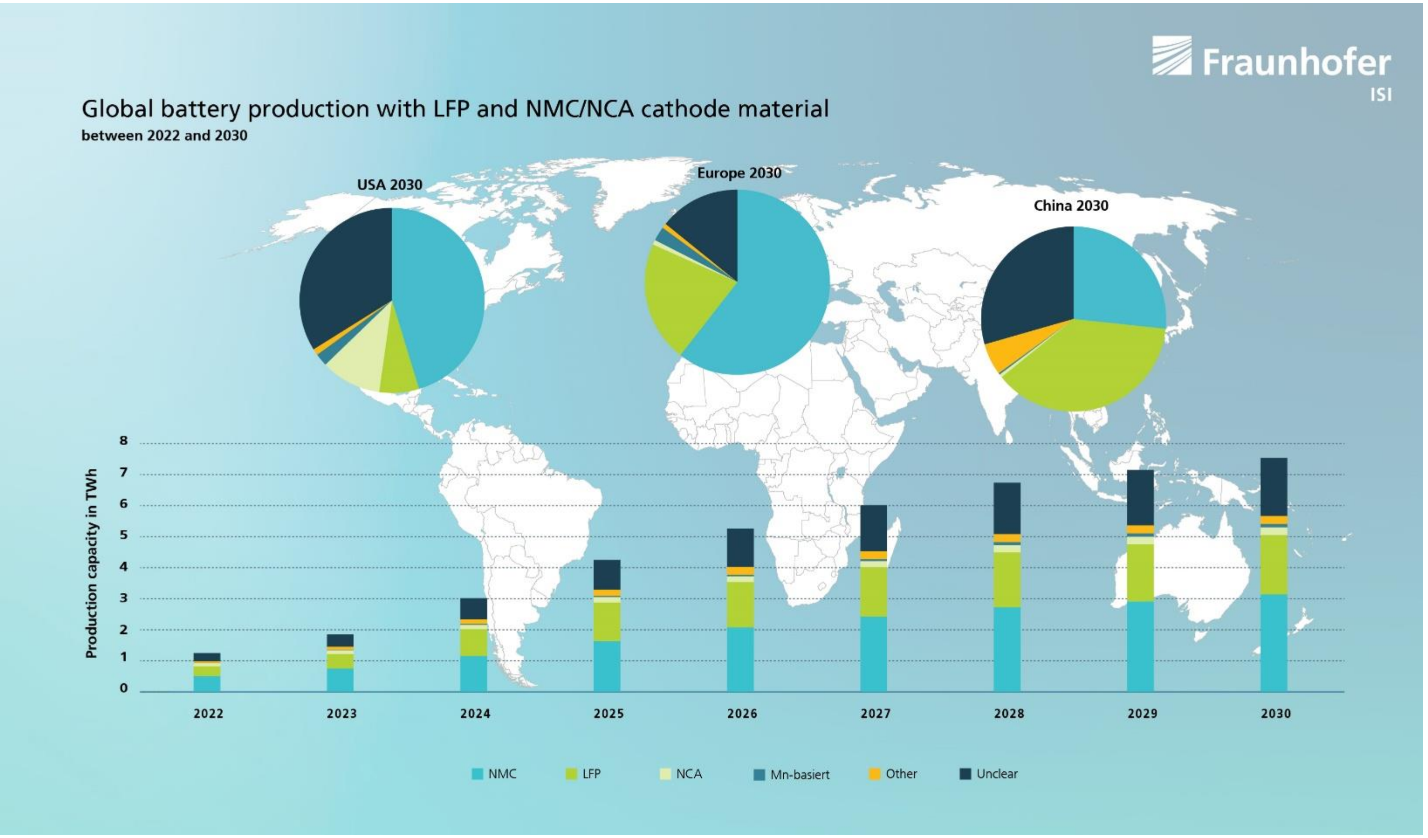
- The cell chemistry share in Europe and USA is driven by the presence of high-performance and more expensive luxury vehicles.
- The Chinese market is also represented by many smaller cars with LFP chemistry.
- Worldwide production of LFP battery cells takes mainly place in China.



[Analysis of global battery production: production locations and quantities of cells with LFP and NMC/NCA cathode material - Fraunhofer ISI]

Global battery cell production

- In the USA, the influence of Tesla and its widely used NCA material is reflected.
- LFP cell production in the U.S. accounts for only a small share of global production in 2030.
- Europe could produce more NMC cathodes than China in 2030.



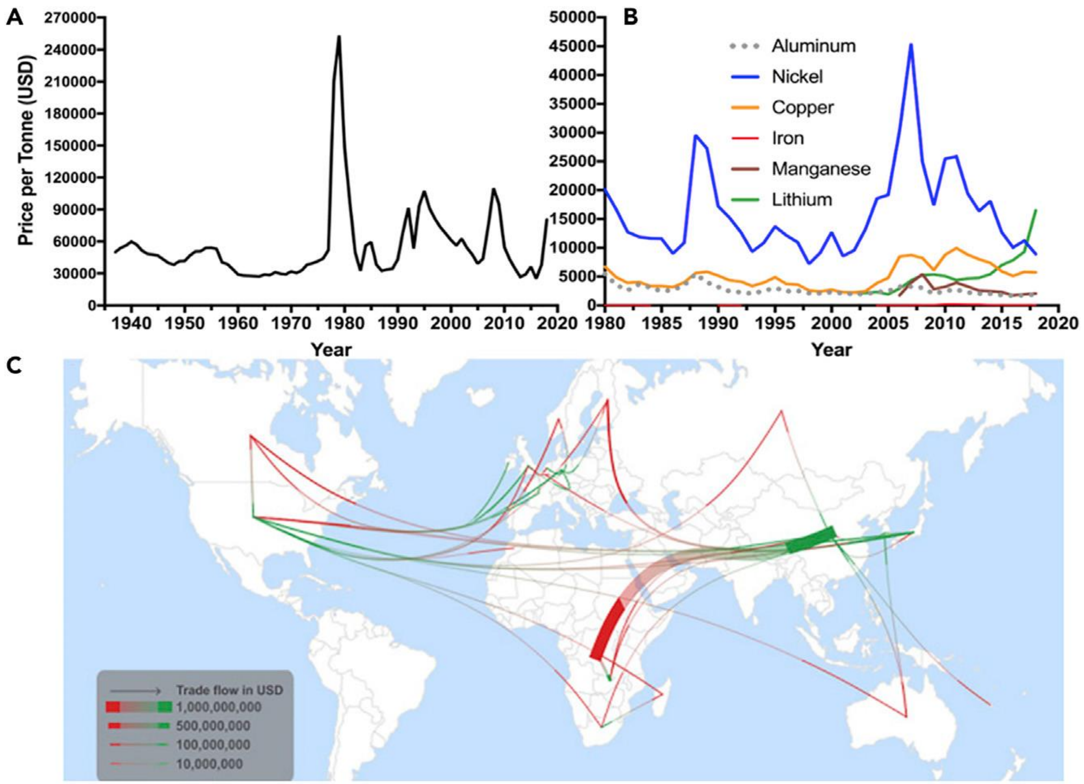
[Analysis of global battery production: production locations and quantities of cells with LFP and NMC/NCA cathode material - Fraunhofer ISI]

Cell Chemistry - LF(M)P Technology

Future trends – cathode materials (Co free)

Why strive for Cobalt-free cathode active material?

- Availability unsure
  - Scare, expensive and difficult to process (derived as by-product from Ni- and Cu- mining)
  - deficits in Co could already occur in 2030
- 65% of global Co mining comes from the Democratic Republic in Congo.
- Price of Co has seen wild swings in the recent years



Major LFP Cathode materials and battery producers in China

Major advantages of LFP

- very safe and secure technology
- very low toxicity for environment
- cycle life from 2000 to several thousands
- operational temperature up to 70 °C
- very low internal resistance; stable over the cycles
- high power capability
- ease of recycling; Recycled lithium iron phosphate (LFP) matches pristine LFP in performance

Drawbacks of LFP

- Energy density is only 60-70% that of NMC
- Different chemical potential → voltage range decreases 2.5 V to 3.6 V (compared NMC: 2.8 V - 4.25V)
- Low temperature performance
- Low profit recycling, limited value of recycled materials

Major Producers (Main IP for LFP in China):

LFP Cathode material producers	Dynanonic 德方纳米; 贵州安达科技能源股份有限公司 Guizhou Anda Energy Technology Co., Ltd; BTR Better our world; 升华科技; STL; 重庆特瑞 CHONGQING TERUI; Pulead 北大先行科技产业有限公司
LFP battery cell makers	acc AUTOMOTIVE CELLS Co; SUNWODA; EVE 亿纬锂能; BYD; 国轩高科 GUOXUAN HIGH-TECH; CATL; CALB

Cell Chemistry - LF**M**P Technology

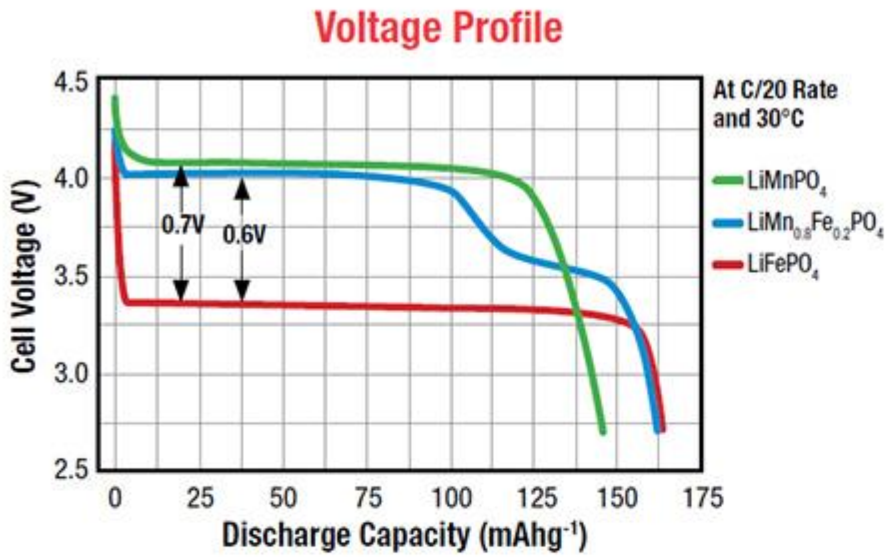
Advantages over LFP

- More energy (15-20 %) but maintaining
  - similar safety benefits
  - low cost (per kWh)
  - thermal stability
  - high discharge currents
- Can be blended with NMC due to similar voltage

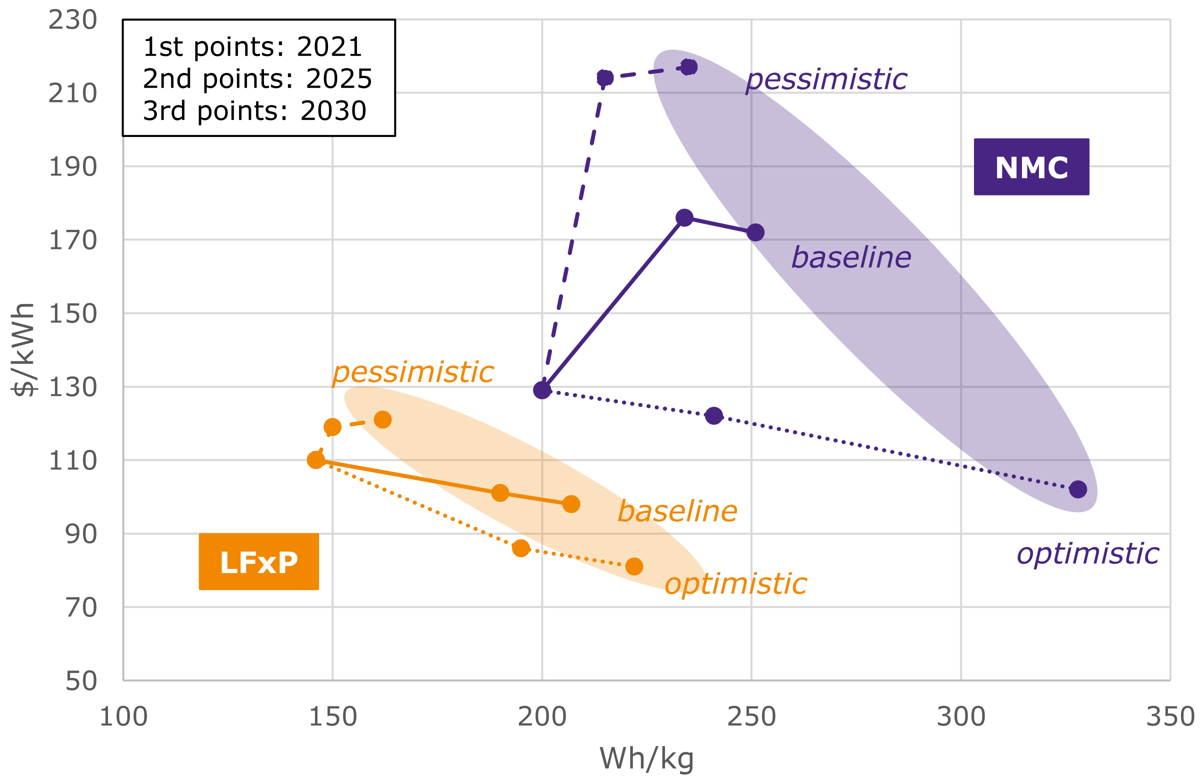
Disadvantages over LFP

- Immature technology (optimization of Mn content not finalised)
- Poor conductivity (nano scaling or C-coating necessary)
- Limited cycle life (Mn dissolution)

There is a trend towards **LMFP Li(Fe,Mn)PO_4.**
→ Substitution of Fe with Mn to increase energy density.
Currently the main production and application is mainly seen in China.



Cost sensitivity indicators



	NMC (Wh/kg (pack)			LFxP Wh/kg (pack)		
	Pessimistic	Baseline	Optimistic	Pessimistic	Baseline	Optimistic
2021	201	201	201	146	146	146
2025	215	234	240	150	190	194
2030	234	251	328	162	207	223

	Lithium hydroxide prices [$/kg]			Nickel sulphate prices [$/kg]		
	Pessimistic	Baseline	Optimistic	Pessimistic	Baseline	Optimistic
2021	17	17	17	10	10	10
2025	35	22	17	25	17	10
2030	35	22	17	25	17	10

	Lithium carbonate prices [$/kg]		
	Pessimistic	Baseline	Optimistic
2021	15	15	15
2025	33	20	15
2030	33	20	15

Advanced Propulsion Center UK – report March 2023

Due to their high safety and cycle life, C/LFP and C/LMFP become more and more relevant for automotive application

G/LFP & G/LMFP – Cell chemistry assessment

		Assessment	Comment
1	Energy density	★★★☆☆ (2.5)	Increased energy density by doping e.g. Mn; LMFP 30% lower than for NMC
2	Charging performance	★★★★☆	
3	Low temperature performance	★★★★★	
4	Cycle life	★★★★★	Cycle life around 7.000
5	Safety	★★★★★	
6	Cost	★★★★☆	

Main advantages

+ Very safe and secure technology
+ Very low toxicity for environment
+ Cycle life of several thousand cycles
+ Operational temperature up to 70°C
+ Low internal resistance
+ High power capability

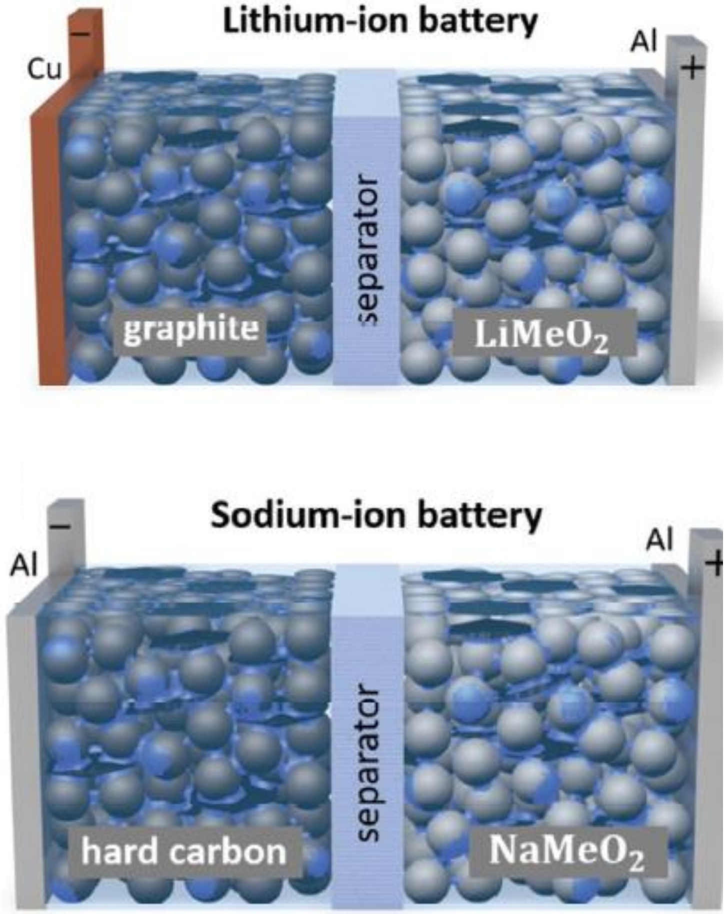
Main disadvantages

– Energy density only 60-70% that of NMC
– Different chemical potential; voltage range 2.5V to 3.6V (NMC: 2.8V-4.25V)

Recommended application field:
Heavy duty vehicles, passenger vehicles, stationary storages, hybrid and PHEV application

★★★★★ Highest rating   Lowest rating   ★ Half star rating

Fast Facts about Na-ion batteries



Facts about SIB (=sodium ion batteries)

- Pouch, cylindrical and prismatic cells
- SIB have energy densities in the lower range of LIB (reduced by ~30%)
- SIBs have ignited interest because of their low-cost potential
- HC | 1M $NaPF_6$ in EC:DMC | NVPF
  - Good electrochemical performance (e.g. > 4000 cycles 90% DOD)
  - Mediocre performance at 55°C in terms of self-discharge and capacity retention
  - Poor stability of protecting the SEI layer on the anode side
- The anode current collector can be Al instead of Cu*
  → lighter and cheaper

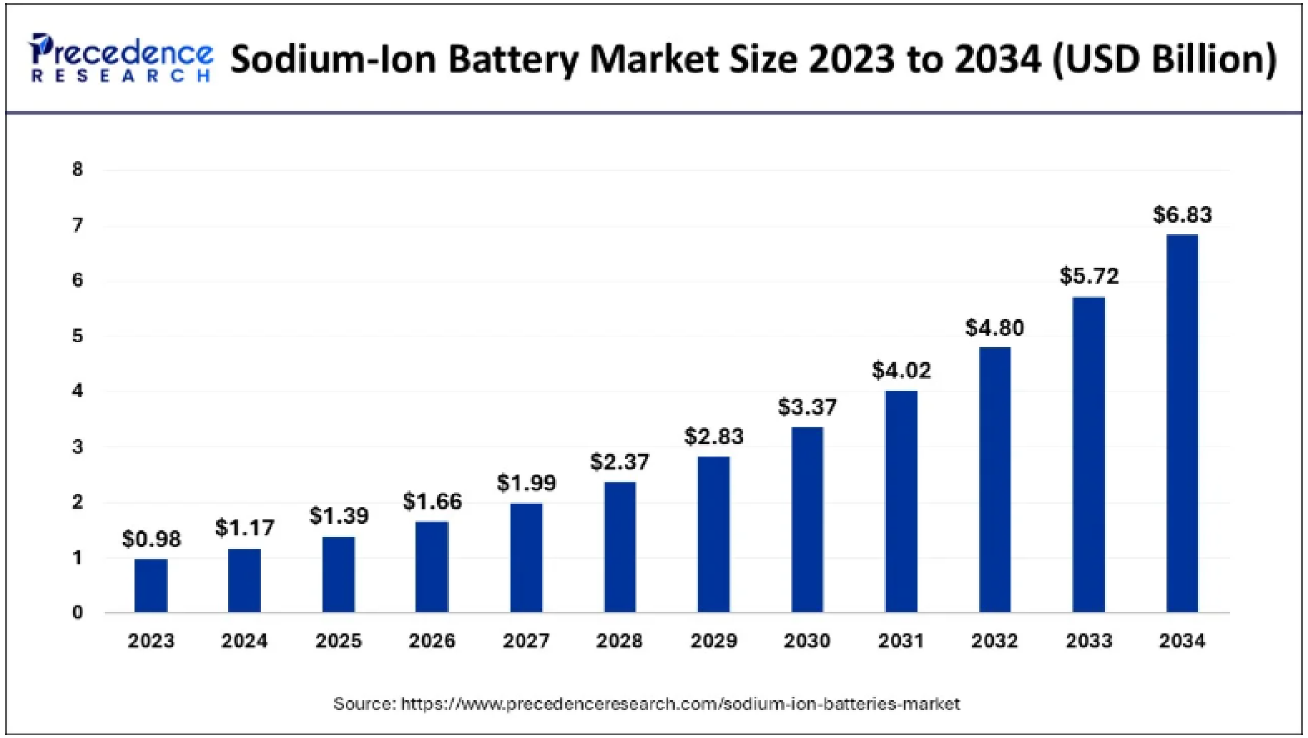
* Li builds an alloy with Al at low potentials

Global demand for Na-ion Batteries

- Similarities in the production of Li-ion and Na-ion batteries lead to enhanced technological progress and faster adaption to market demands

- Market growth expected, however there is considerable market uncertainty as it is emerging technology

- Key driving factors for increased demand:
  - Transportation: electric vehicles using Na-ion or Na-ion and Li-ion hybrid technology
  - Stationary: storage batteries for renewable energy

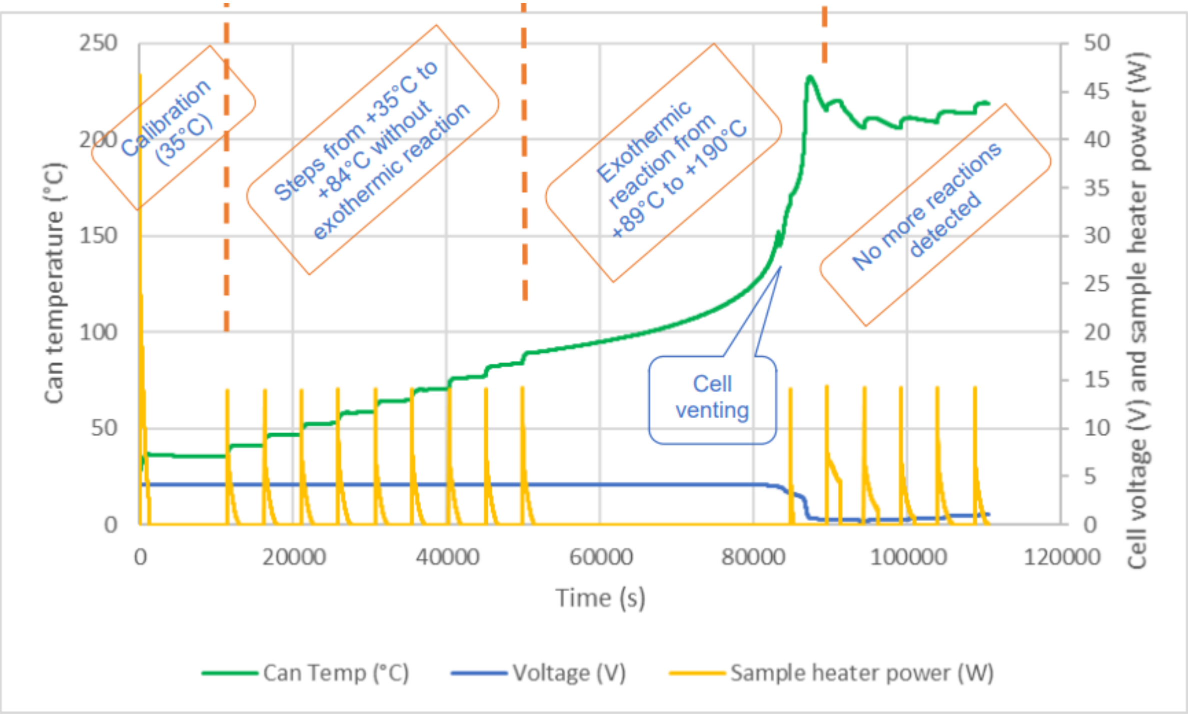


Heat Release of Na-Ion Cells

- Heat-Wait-Seek (HWS) test of 15 Ah prismatic cell with polyanion cathode (NVPF) performed

- Lower maximal temperature in Na-ion cells (233 °C) compared to conventional Li-ion cells (~800 °C) indicate a much less energetic heat release during thermal runaway.

Na-ion cell 15 Ah	Cell temperature [°C]
First exothermic reaction	89
Voltage drop temperature	151
Onset temperature	89
Venting temperature	151
Maximum temperature	233



[1] CATL announcement as reference

Performance indication of layered oxide Na-ion cells

HC/Layered Oxide [1] (sodium-ion) – Cell chemistry assessment

	Assessment	Comment
1 Energy density	★★★☆☆	
2 Charging performance	★★★★☆	
3 Low temperature performance	★★★★☆	
4 Cycle life	★★★★☆	
5 Safety	★★★★☆	
6 Cost	★★★☆☆	Between LFP and NMC chemistry of Li-ion technology

Main advantages

+ Low costs: high abundance of Na, unlimited and inexhaustible resources
+ High safety
+ High cycling stability (negligible self discharge)

Main disadvantages

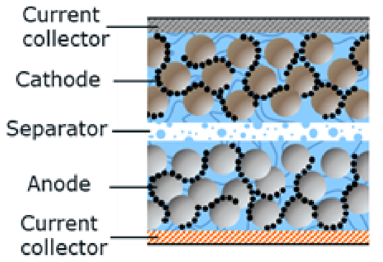
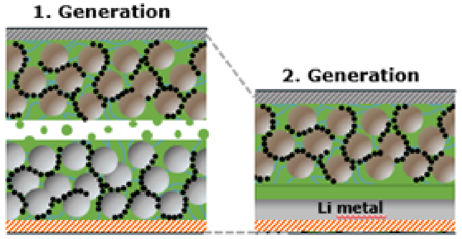
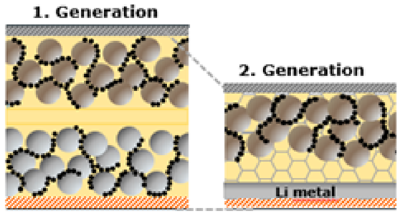
– Limited choice of anode materials (graphite cannot be used – radii of the Na-ion)
– Moderate energy density and specific capacity

Recommended application field:
Stationary storages, electrified automotive field are a potential niche field application for NIBs (high power)

★★★★★ Highest rating   Lowest rating   ★ Half star rating

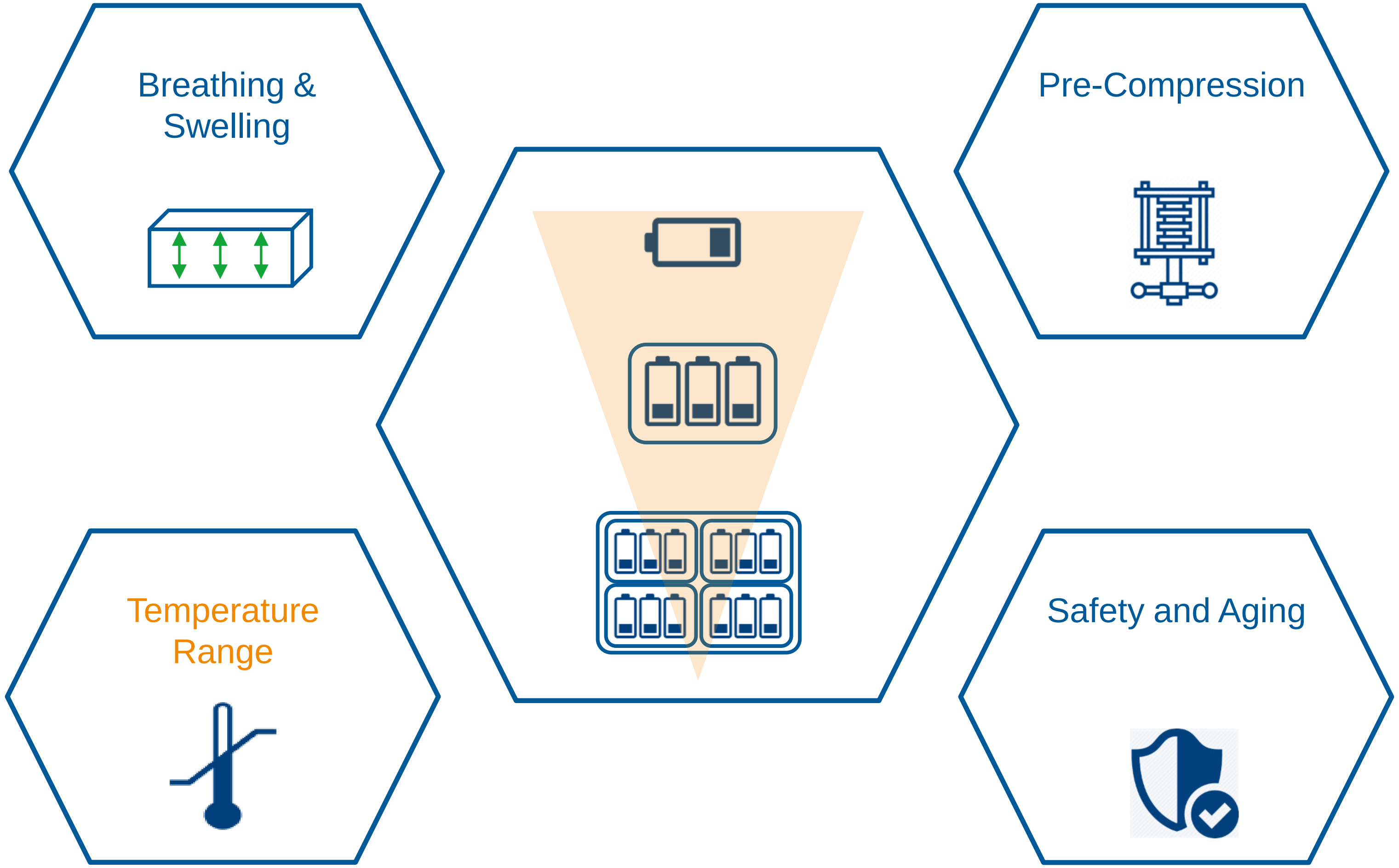
Three types of cell systems are in discussion for automotive application

However, SSSB and ASSB are not ready yet for large scale industrialization

	State of the art battery cell (LIB)	Semi-solid state battery (SSSB)	All-solid state battery (ASSB)
Illustration			
Description	• Anode: G, G-Si, LTO • Cathode: NMC, NCA, LFP, LMNO, NMx • Electrolyte: Salt + Solvents + Additives (e.g. $LiPF_6$ + EC + DEC)	• Anode: G, G-Si (1st generation), Li-metal (2nd generation) • Cathode: NMC, LFP • Electrolyte: Gel, Polymer	• Anode: G, G-Si (1st generation), Li-metal (2nd generation) • Cathode: NMC, LFP • Electrolyte: Oxide, Sulphide, Phosphates,…
Advantages	+ Safety for G/LFP and LTO/NMC + LFP: Environmental friendly + NMC: Proven technology and highly ordered structure	+ "Drop-in" to established LIB production + Mechanical compliance	+ No organic solvent (increased safety) + Increasing energy density + (Bipolar stacking)
Disadvantages / challenges	- High Ni-content → thermal stability (safety) - High Mn content: Stability – Jahn-Teller distortion - High Si content in the anode causes higher breathing/swelling	- High Ni-content → thermal stability (safety) - Low ionic conductivity at room temperature - Limited oxidation stability with HV-cathodes [1)] - Challenges: Conductivity, separator anode ASR, Li-metal stability, interface resistance, dendrite resistance	- Increased breathing with Li metal - High pressure (>2 MPa) - Challenges: Scale up, conductivity, separator anode ASR, Li-metal stability, interface resistance, dendrite resistance

The change from conventional LIB to ASSB technology has a major impact on operation, production and safety

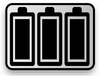
Battery system view – main changes due to cell technology change

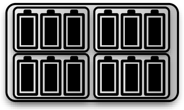


There are major changes on the different systems inside a battery due to the change from LIB to ASSB cells

Classification of the changes on module and pack level

*For systems with no changes, there are no extra slides generated (e.g. influence of ageing on electrical system)





	System	Temperature range	Breathing & Swelling	Pre-compression	Safety
Module	Mechanical system	◕	●	●	◕
	Electrical system	◕	◕	○	○
	Thermal system	◔	○	○	○
	Control system (BMU - System)	◕	◔	◔	○
Pack	Mechanical system	◑	◕	◕	◕
	Electrical system	●	◔	○	○
	Thermal system	◕	○	○	○
	Control system (BMS - System)	◑	◑	◔	○

○ No changes found	◔ Minor changes and adaptions necessary	◑ Small impact and rework of system necessary	◕ Major impact of technology and rework on system level	● Complete rework and assessment of system

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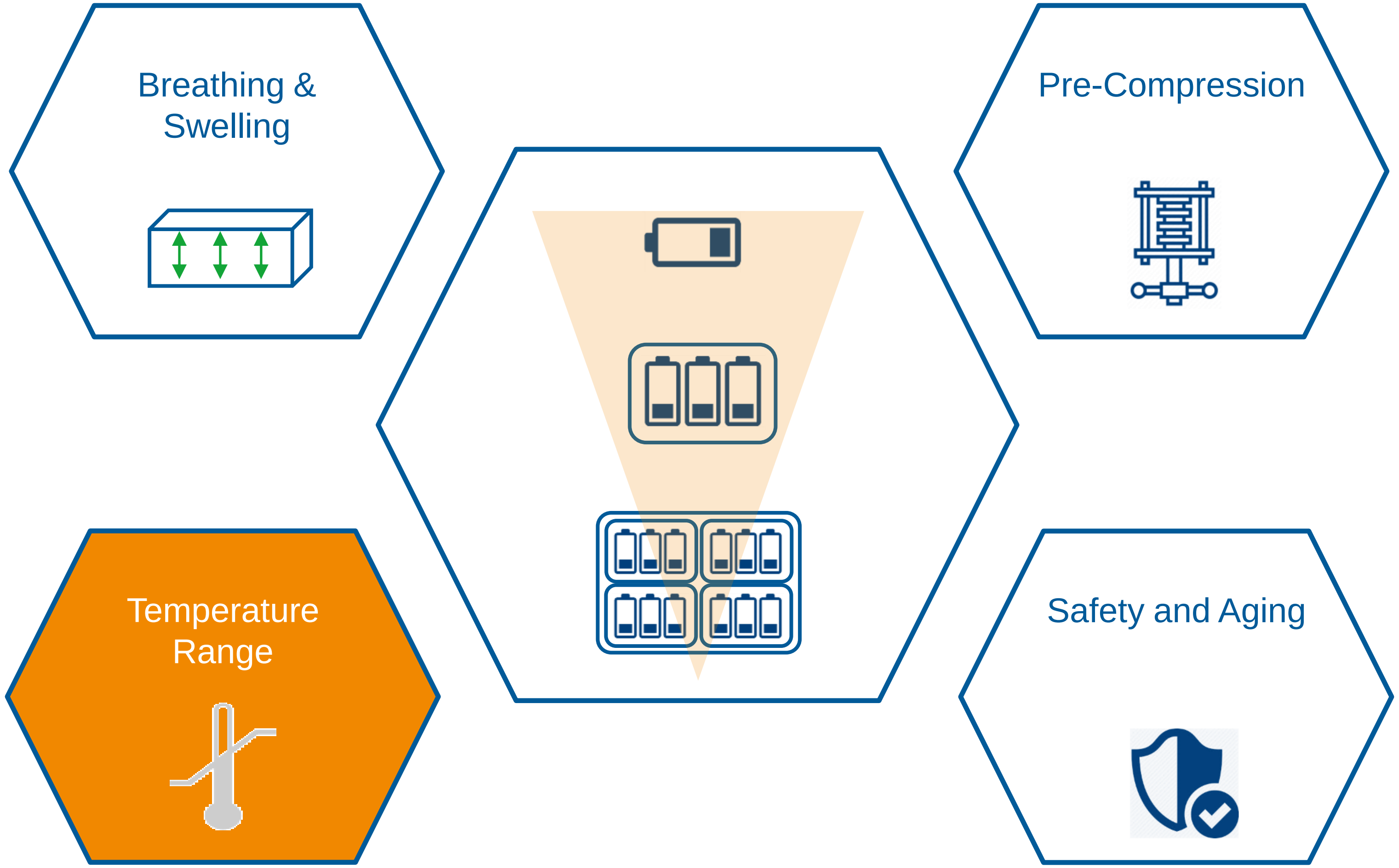
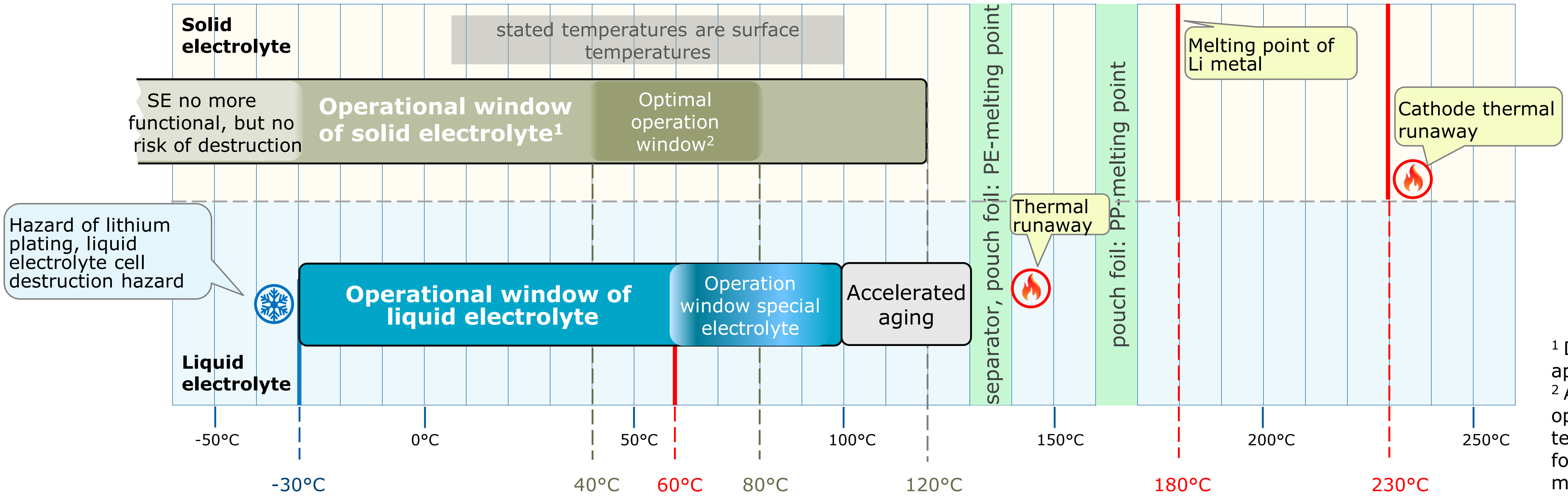


The operational temperature window for ASSB cells is significant superior compared to liquid-electrolyte based cell technology

Temperature ranges SE-based & liquid electrolyte-based cells



[1] Depending on the applied SE-material
[2] Average optimal operating temperature range for diverse SE-materials

- **Inorganic solid electrolytes allow operation in low and high temperatures** without safety or degradation hazard – the range is **-30°C up to 120 °C**
- Liquid electrolyte could boil, decompose, and freeze in the window where **solid electrolyte is performing without safety issues**
- The **conductivity** of **solid electrolyte increases** with **higher temperatures**

Influences of a Larger Temperature Range

Module **mechanical:** ◕ **thermal:** ◔ **electrical:** ◕ **control:** ◕

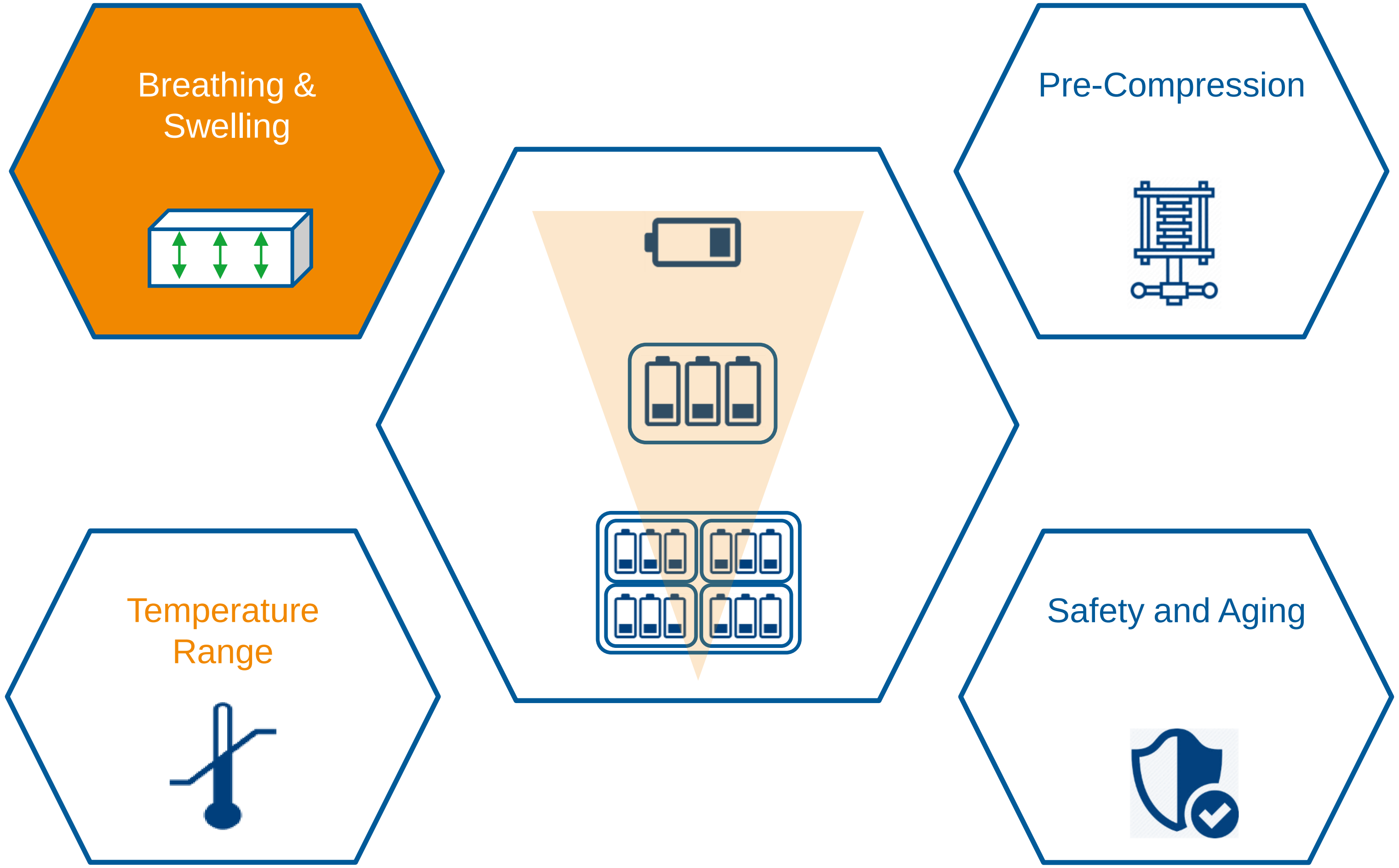
- ❑ Busbar carrier materials and cell holders → thermal and chemical stability needed up to 120 °C
- ❑ Faster ageing and fatigue of plastics and adhesives
- ❑ Thermal expansion of supporting frames or housing → thermal stress need to be compensated
- ❑ Thermal insulation against ambience to faster reach optimum *T* window → influence on module design depends on cell chemistry and operational *T* range
- ❑ All terminals and busbars with isolation must withstand higher *T* (e.g. different isolation material classes)
- ❑ Busbars between modules must be designed for mechanical compensation

Pack **mechanical:** ◑ **thermal:** ◕ **electrical:** ● **control:** ◑

- ❑ Mechanical stiffness and material properties (thermally, ageing, chemical stability etc.) stable up to 120°C or more
- ❑ Mechanical tolerances due to thermal expansion of modules and busbars must be incorporated
- ❑ Breathing device inside the battery pack: Designed for higher *T* levels and higher volume flows
- ❑ Cooling fluid must be stable > 100 °C → no evaporation and no significant ageing over lifetime
- ❑ All HV-components: fulfillment of end-of-life criteria
- ❑ Influence of higher operation temperatures:
    - Cooling circuits for electronics must be redesigned

The change from conventional LIB to ASSB technology has a major impact on operation, production and safety

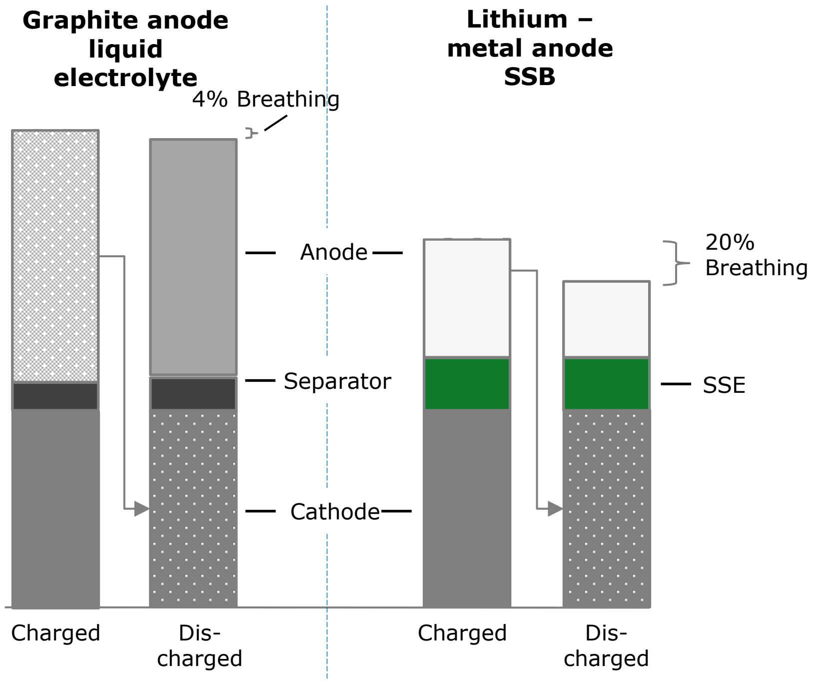
Battery system view – main changes due to cell technology change



Significant breathing[1] during operation must be considered for ASSB

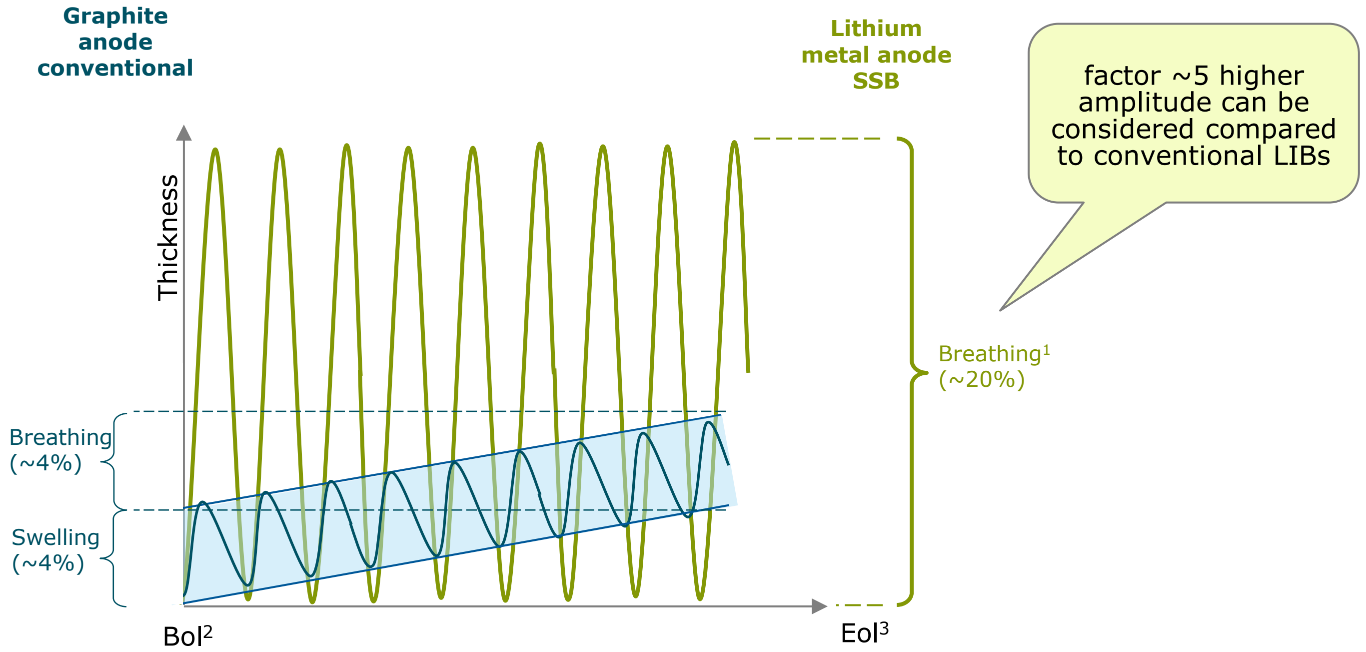
Breathing & Swelling: comparison of ASSBs to conventional Li-Ion batteries

Breathing



assumption: energy density per cm² is the same

Lifetime and swelling



[1] according to current AVL projects, breathing values of ASSB can be derived between 15-25% in comparison to conventional LIB cells with approx. 4% swelling and breathing (swelling = irreversible formation of the SEI layer over battery lifetime; breathing = reversible intercalation of ions in the anode material

[2] BOL = Begin of lifetime; [3] EOL = End of lifetime

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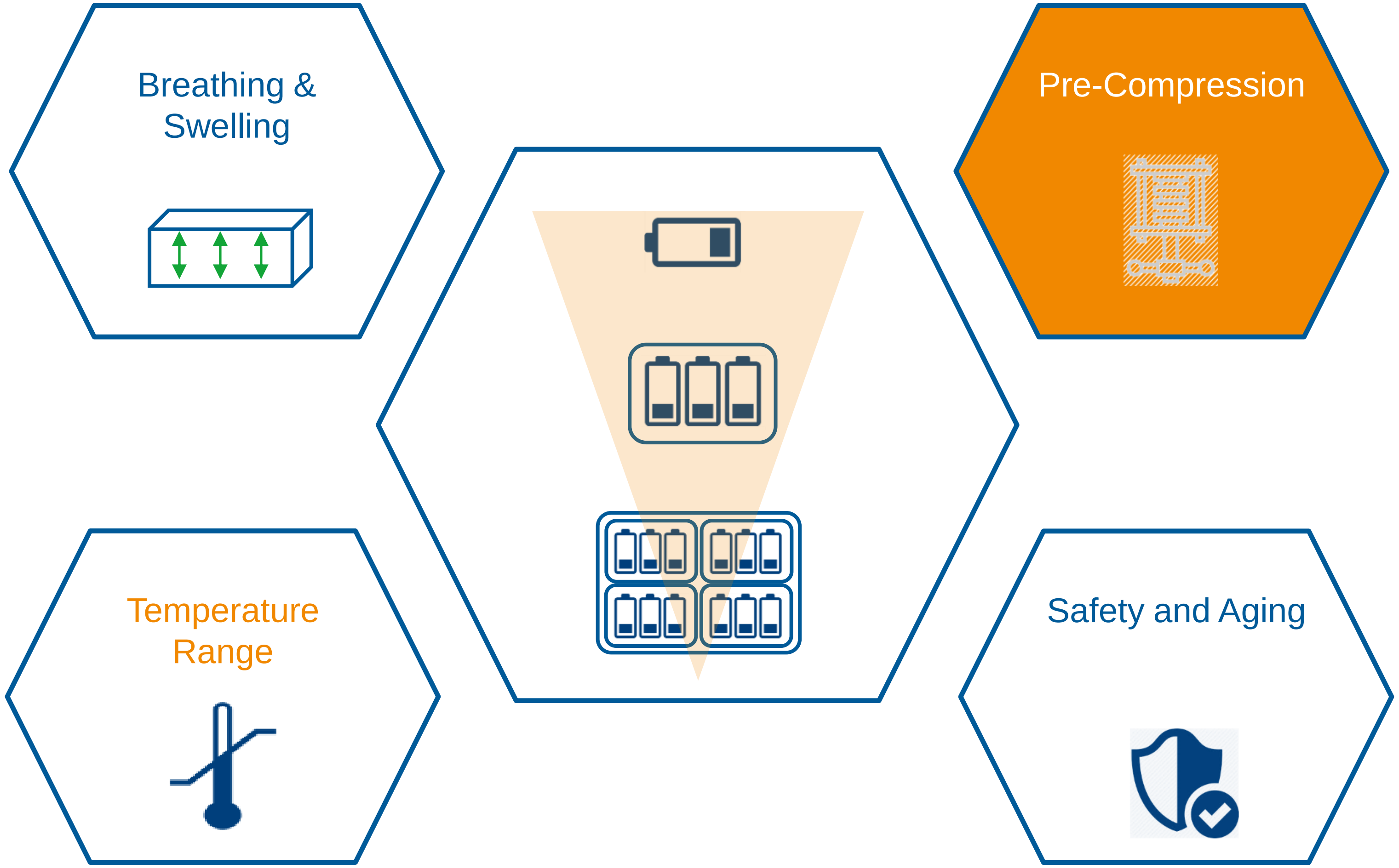

Influence of Breathing, Swelling and Pre-compression

Module **mechanical:** ● **thermal:** ○
electrical: ◕ **control:** ◔

- ❑ Compression pads typically used between liquid-based cells → not feasible for 20 % swelling
- ❑ Active systems for compensation must be investigated regarding:
  - Risk of microcracks due to overload
  - Fully functional under all temperature influences
  - Uniform pressure distribution on whole cell area
- ❑ Housing structure thickness and brackets (positions and stiffnesses), depending on module concept, must be increased to meet mech. requirements (>5MPa)
- ❑ Electrical connection between cells must ensure, that breathing and swelling will be either compensated on cell level (e.g. flexible tabs) or on busbar level

Pack **mechanical:** ◕ **thermal:** ○
electrical: ◔ **control:** ◑

- ❑ Housing structure dimensioning and brackets (positions and stiffnesses) may need to be increased to meet mechanical requirements (>5MPa)
- ❑ Active systems for compensation methods and pre-compression must be investigated
  - Longitudinal, transversal and side beams may have to be slightly increase
- ❑ Higher weight for ASSB cells for the same installation volume
- ❑ Usage of flexible busbars between modules to compensate terminal movement
- ❑ If active systems are applied, additional routing and an adapted control and drive strategy which must be incorporated into the battery pack

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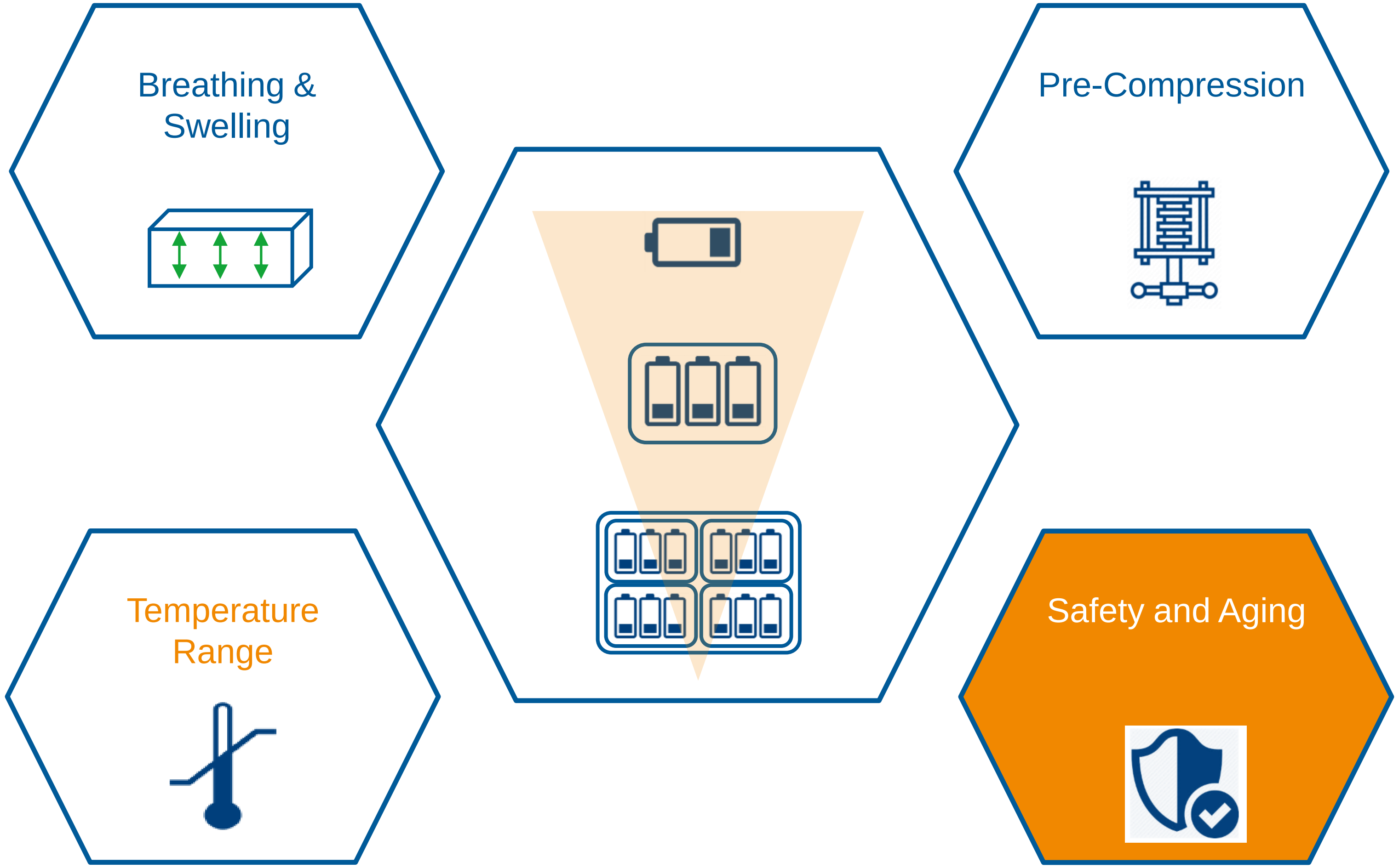


The risk profile for ASSB cells is relatively low for all four risk categories

Categorized safety risks for ASSB cells

Chemical hazard

Active principle: hazards linked to

- ❑ **spillage** (flammable electrolyte) &
- ❑ **gas emission** (flammable volatile organic substances)

Assessment for ASSB cells

- ❑ **spillage:** electrolyte is solid: no spillage; (SSE flammable at > 450°C) ➔ **no risk**
- ❑ **gas emission** (only when cell is ruptured) ➔ **low risk** generation of …
  - .. H_2S (in case sulfide electrolyte reacts with moisture)
  - .. SO_2 (O_2 generated by overcharge, reacting to SO_2 in the cell, only with sulfide electrolyte)
  - .. H_2: Li metal reacts with water producing H_2 (>4% H_2 in air is flammable (low probability))

Electrical hazard

Active principle:

- ❑ Joule effect: current flow in conductor is creating heat & needs to be managed by a thermal management system
- ❑ Overcharge and over discharge create unwanted reactions with more exothermic reactions

Assessment for ASSB cells

- ❑ Thermal runaway of cathode material (NMC) starts at temperature of > 230°C
- ❑ Solid electrolyte autoignition temperature is at > 450°C

➔ **low risk**

Active principle:

- ❑ cumulative effects of chemical & electrical hazards may lead to thermal runaway
- ❑ short circuit will increase cell temperature based on the Joule effect which may lead to thermal runaway

Assessment for ASSB cells

- ❑ Thermal runaway of cathode material (NMC) starts at temperature of > 230°C
- ❑ Solid electrolyte autoignition temperature is at > 450°C

➔ **low risk**

Thermal hazard

Active principle:

- ❑ Active destruction of a cell / battery pack by accident or abuse

Assessment for ASSB cells

- ❑ Generation of toxic H_2S or flammable H_2 in case of contamination of cell e.g. following an accident (only with sulfide electrolyte material)
- ❑ ➔ cell is opened, and water/air gets into the battery
- ❑ No additional sensors required, since functional safety measures are not helpful, as the control over the system is lost

Mechanical / destruction hazard

Influence of Ageing and Safety

Module **mechanical:** ◕ **thermal:** ○ **electrical:** ○ **control:** ○

- ❑ Minimal thermal propagation:
  - No necessity of thermal propagation materials → reduces costs
  - No chance of venting of the cell anymore → no venting spaces needed anymore
- ❑ The increased wall thickness of the module housing generally increases the stiffness and robustness of the module
  - Lower deformation during crash → less probability of short circuit and increased safety
  - Stiffer modules lower constrained and unconstrained eigenfrequency

Pack **mechanical:** ◕ **thermal:** ○ **electrical:** ○ **control:** ○

- ❑ Thicker module housings and beam structure → overall stiffness and safety of the battery pack increased & better vibrational behavior
- ❑ No venting on cell level leads to:
  - No venting device (e.g. butyl plugs) necessary → cheaper
  - No cutout on beam level → more stiffness
- ❑ No flame out on cell level leads to:
  - No need of fire-retardant materials (mica-sheet etc.) → less manufacturing effort, packaging & costs
- ❑ Additional effort may be necessary for:
  - SoX estimation algorithms: additional support points due to temperature range necessary → increased testing effort
  - Possibility of development of microcrack detection algorithm and integration into ageing model

Summary
Impact on battery module and pack technology

Compensation of breathing ↓
→ SSBs show a high thickness change during cycling (breathing)

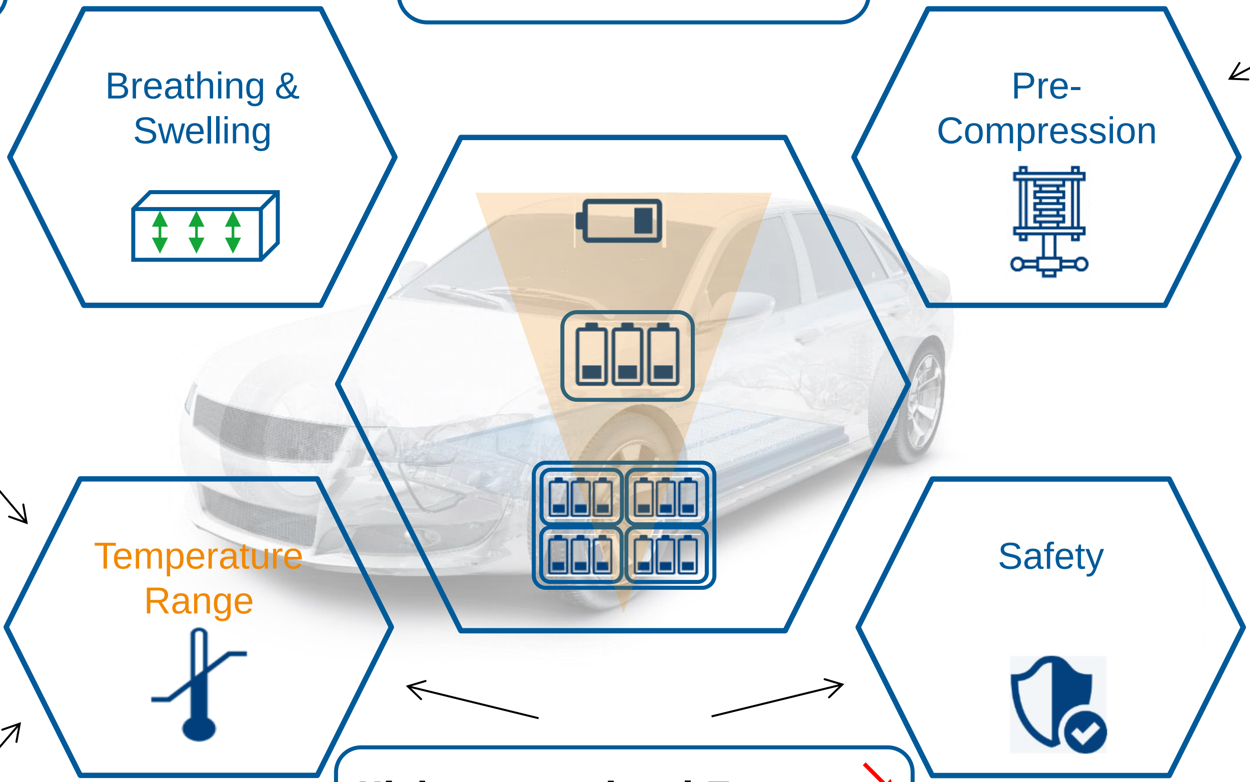
New cell formats & Less cell housing →

Pressure application ↓
→ higher pressure required for solid-state system

Heating concept ↘
→ depending on material of ASSB, heating required

Less protection (safety) ↑
→ no flammable liquid electrolytes

Less cooling ↑
→ SSBs are not that sensitive to higher temperatures

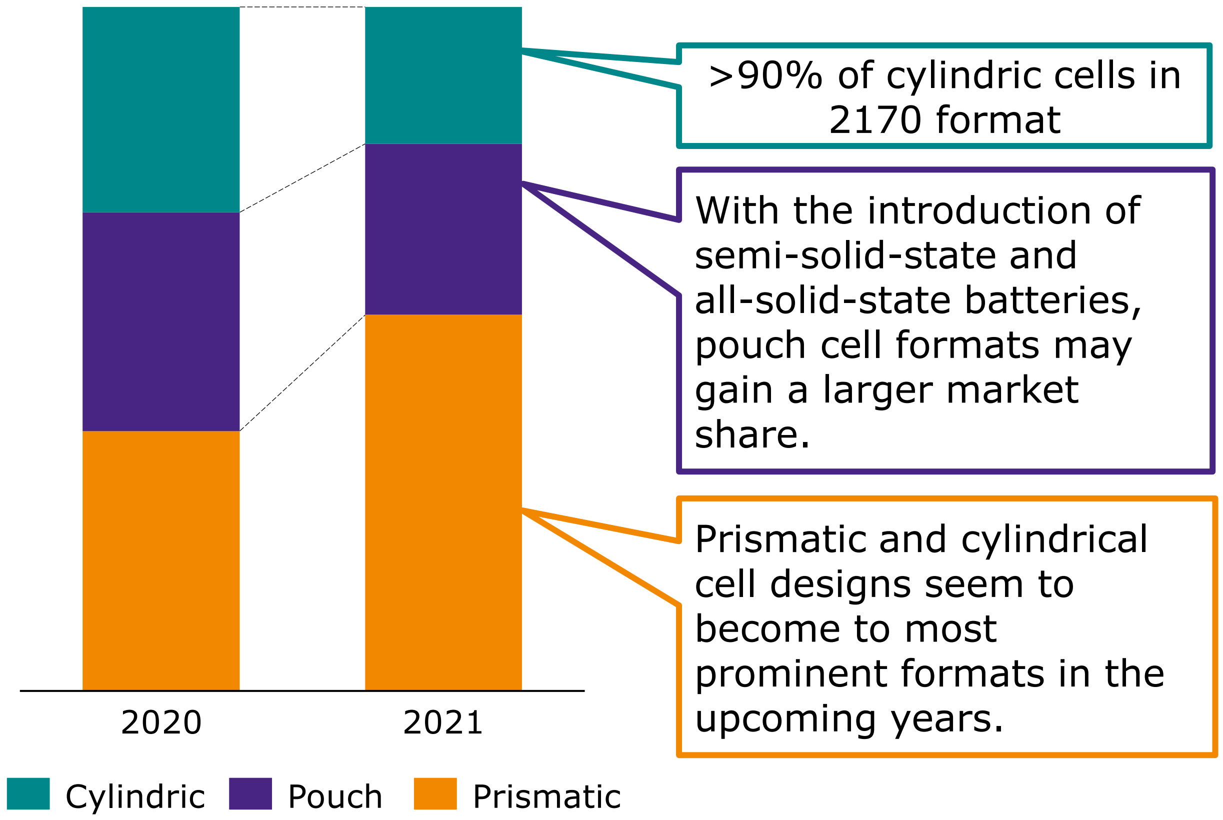


Higher operational *T* range ↘
- stability of structural plastics, sealings etc. need to be evaluated

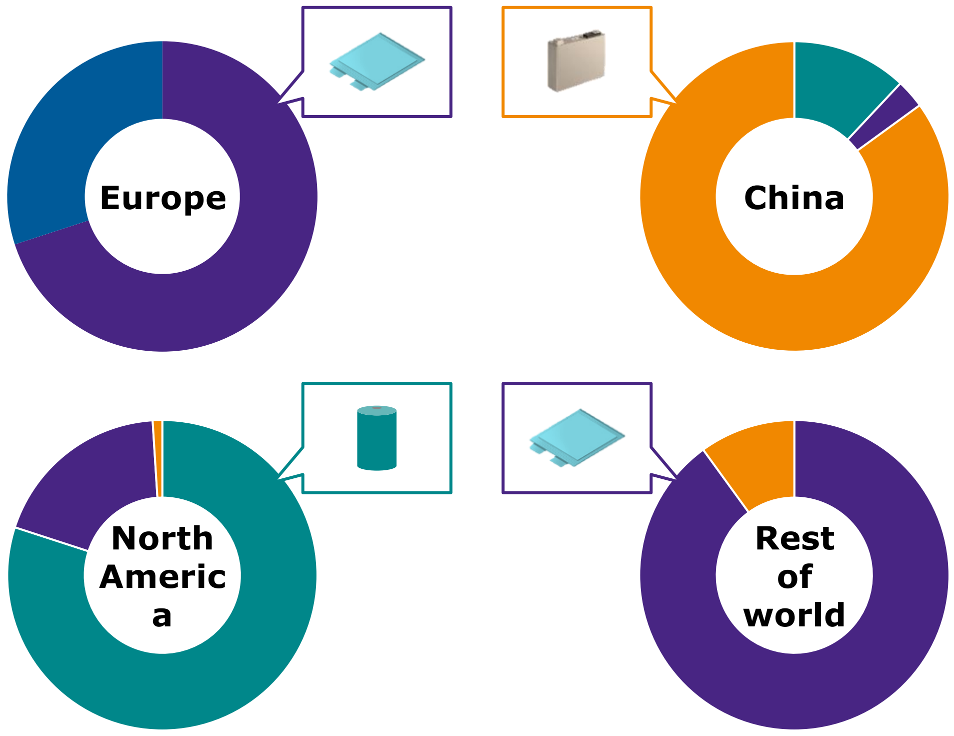
Overview Cell Technology

Globally, prismatic cell shares grew significantly between 2020 and 2021 with strong market-specific differences. Further focus on prismatic cells is expected, especially versus pouch cell, due to the increasing interest in C2P and heavy-duty applications.

Global development of applied cell formats [1)]



Market-specific application of cell formats [1)]



Source: LMC Automotive Limited

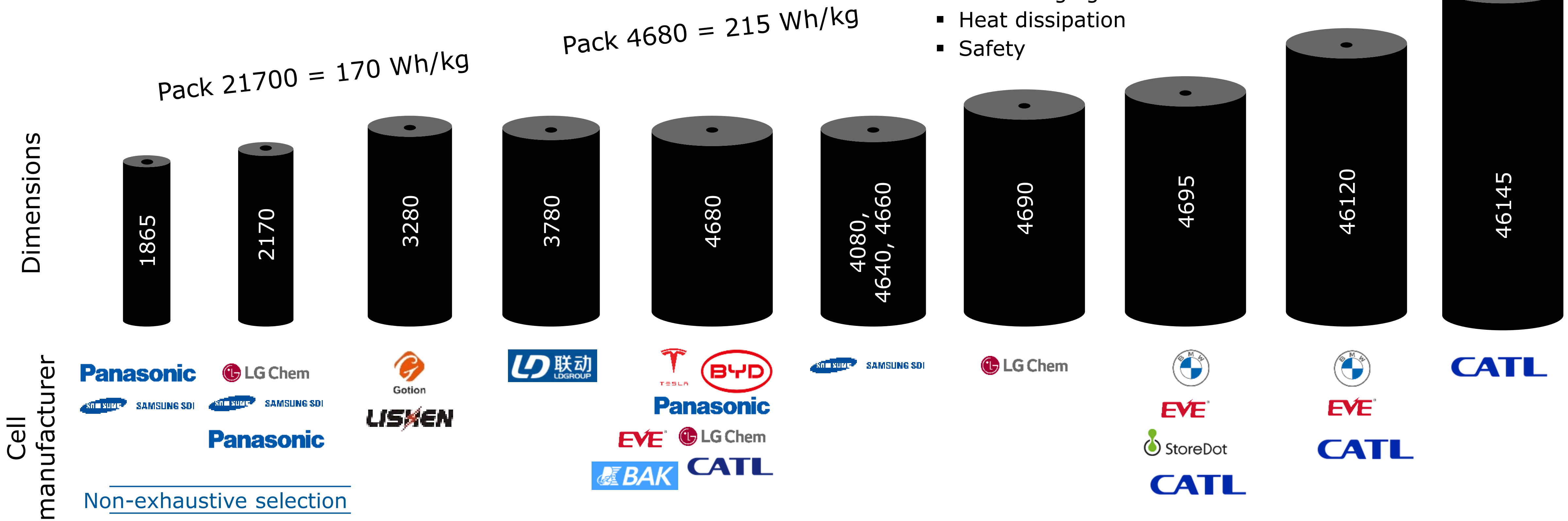
[1)] Only battery electric light-duty vehicles considered (< 6t)

Cylindric cells with increased dimensions were announced by several manufacturers

Main advantages: cost reduction and energy density increase.

Evolution of cylindric cells:

Improvement of:
- Costs
- Energy density
- Fast charging
- Heat dissipation
- Safety



Sources: http://electrios.com, 46xx Cylindrical Cells - Battery Design

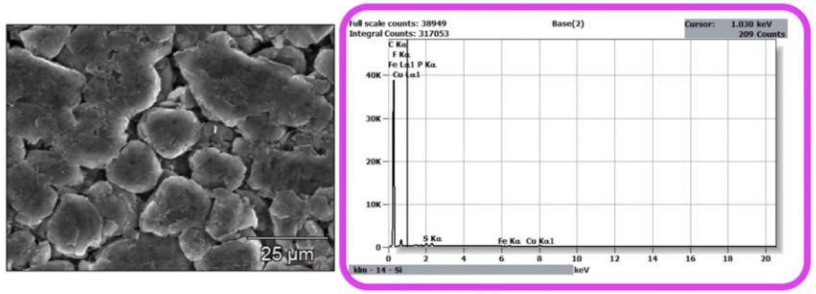
Tesla 4680 cylindrical cell

- 4680 (Model Y) vs. 2170 (Model 3)
  - 5x higher energy
  - 6x higher power
  - +16% range
  - Cell chemistry: Si-free graphite / NMC811
    → change in geometry does not mean innovations in cell chemistry.
  - A thicker cell can shall guarantee a „structural cell" to increase the stiffness of the battery pack

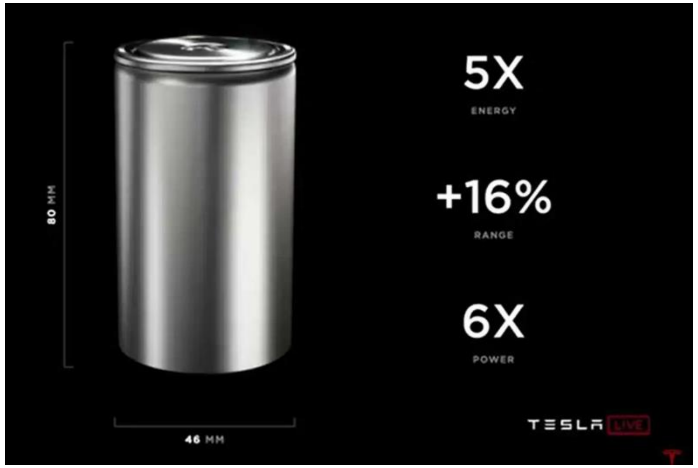
Anode - Chemistry

EDS area

Spectra (transition metal range)



- Anode active material does not contain Silicon, only carbon can be detected with some P/S, possibly from electrolyte salt and additives.



Teslas 4680-Zellen haben NCM811-Chemie und reine Graphit-Anode (insideevs.de)

For the prismatic cells, a trend towards larger cell dimensions can be observed

Prismatic cells – Common dimensions

Energy content, dimensions are increasing as well change in chemistry (high Ni, no cobalt,…)

- Length
- Thickness: increasing number of jellyrolls inside the cell

Applied cell chemistries:

- G/NMC
- G/NCA
- G/LFP
- LTO/NMC

Examples for large-format cells

- **BYD** Blade (905 x 118 x 13,5 mm)

- **SVOLT**
  - 226 Ah (574 x 118 x 21,5 mm)

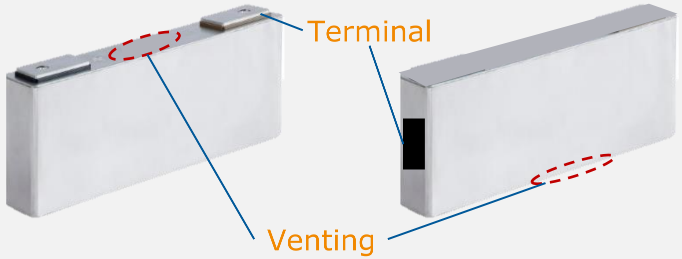
  - 115 Ah (220 x 102,5 x 33,4 mm)

Apart from the current standard of venting as part of the cell cap, venting is integrated in the bottom of the cell having safety benefits

Venting positioning industry standard

Illustrated shape	Characteristics
 *CALB 72 Ah*	Small round venting: small, low-capacity cells
 *Samsung SDI 94 Ah*	Venting in parallel to cell length: thinner cells with one jelly roll
 *CATL 180 Ah*	Venting perpendicular to the length: thicker cells with >1 jelly rolls
 *BYD 138 Ah*	Venting on one side: blade cells

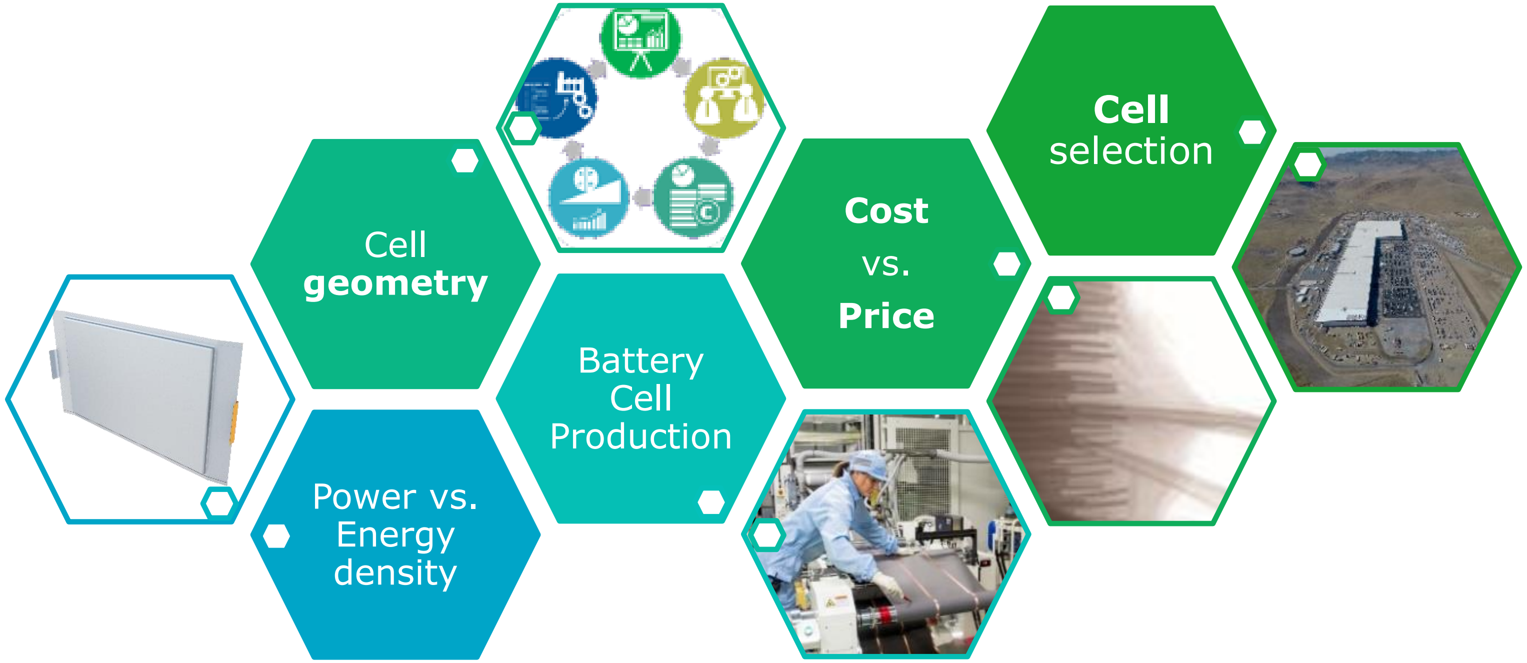
Positioning trends



- Separation of terminals and vent to different sides offer safety potentials:
  - Venting gas release towards bottom away from the passenger cabin
  - Overcome challenge due to thermal propagation:
- Impact: venting are not necessarily part of the cell cap anymore

Battery Cell Selection and Development

AVL Expertise: **Battery cell Research, Analysis and Selection, Consulting in Future Battery Cell Technologies**



Battery cell expertise from raw material to cell integration

Ongoing joint research to **influence future cell chemistry**

NDAs with cell supplier in place to enable **technical cell selection support**

Thank you

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