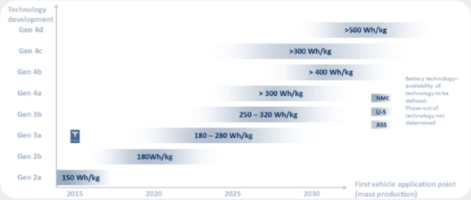

BATTERY TECHNOLOGY FOR THE MOBILITY OF THE FUTURE

Raumfahrt bewegt
Mobilität und Raumfahrt – Chancen für die Zukunft

Bonn, March 27th, 2017

P3

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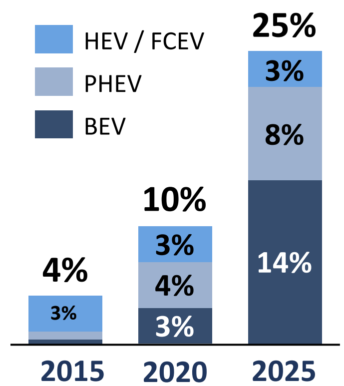
Robert Stanek

Market Development and Resolving Challenges in Battery and Cell Market

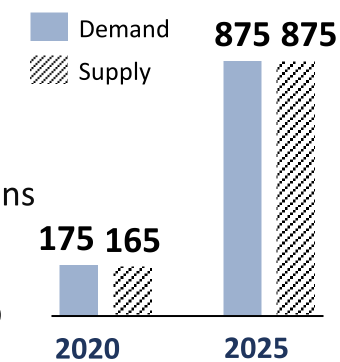
Vehicle & Battery Application Markets

- Global xEV penetration [25% @ 2025]* with more than 20 MM vehicles globally
- Full supplier responsibility necessary as system providers with worldwide production locations set up



Manufacturing Capacity Development

- Currently 30GWh installed capacity in the market (equals 20% of 2020 capacity)
- Steep rising demand due to CO_2 regulations with peak demand of 875 GWh in 2025
- Biggest Players: Panasonic, LG Chem, BYD



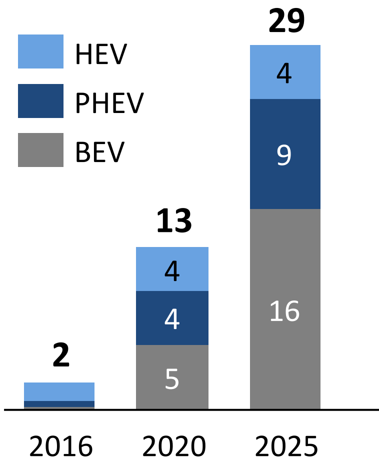
Challenges and Opportunities

- High automation grade necessary to fulfil customer feed rates in facilities
- Dedicated manufacturing lines for high runner cell designs and high flexible assembly lines for niche cells
- Strong push of Tier1 suppliers to become powertrain system suppliers
- Automotive OEMs pushing for higher value add on batteries towards cell manufacturing and pack assembly
- Strong competition towards raw material access, e.g. Cobalt, Lithium

*Assumption: All OEMs full fill CO2 Compliance targets in all regions

The legal requirement of CO_2 fleet compliance (especially on highly regulated markets) leads to a strong increase of global xEV sales , reaching 29 mil. electric vehicles in 2025

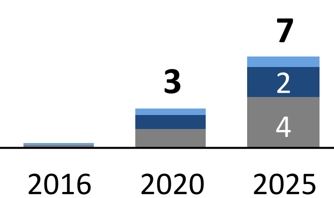
xEV Volume in M Units



World Wide

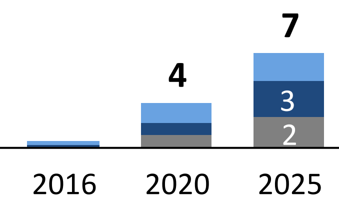
xEV global Penetration

2020	**~10 %**
2025	**~25 %**



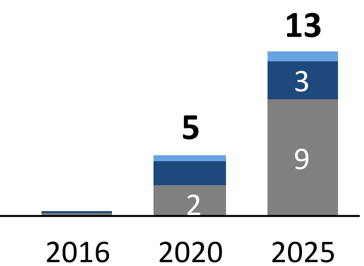
Europe

Average Fleet Target	
2020	95 g CO_2/km
2025	75 g CO_2/km



North America

Av. Fleet Emission Target	
2020	132 g CO_2/km
2025	102 g CO_2/km



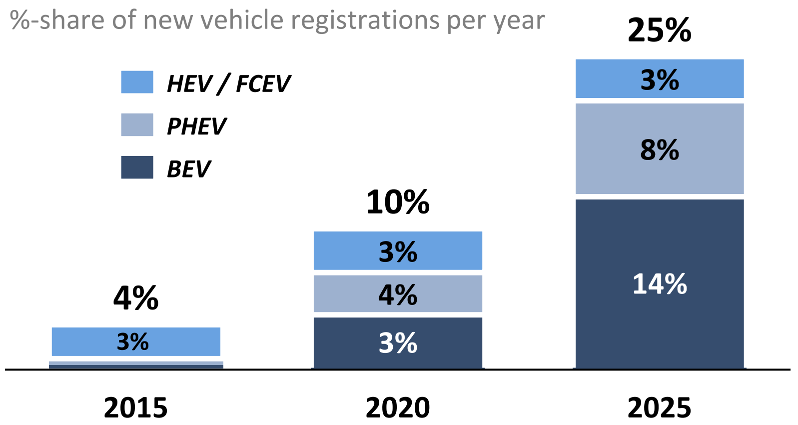
China

Av. Fleet Emission Target	
2020	117 g CO_2/km
2025	94 g CO_2/km

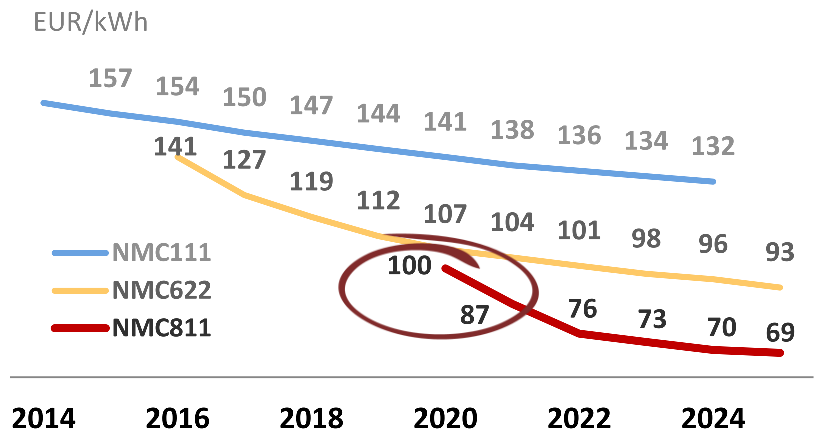
CO_2 compliance, decreasing battery cost and resulting positive TCO for xEVs as well as the expansion of charging infrastructure will lead to a global xEV penetration of approx. 25% in 2025 worldwide.

Automotive market development and derived battery system costs

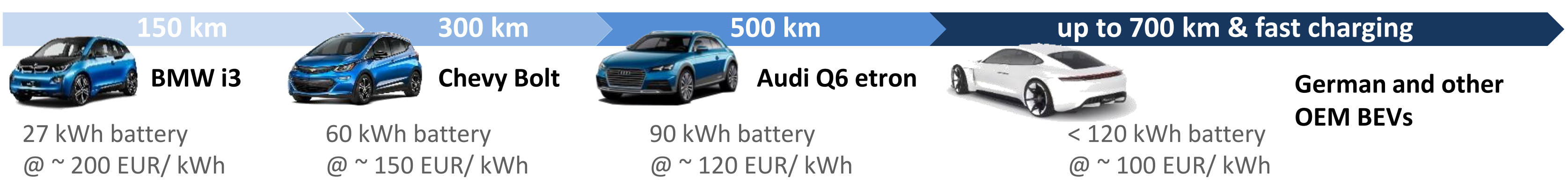
Market development



Cost development of battery systems[1]



BEV development



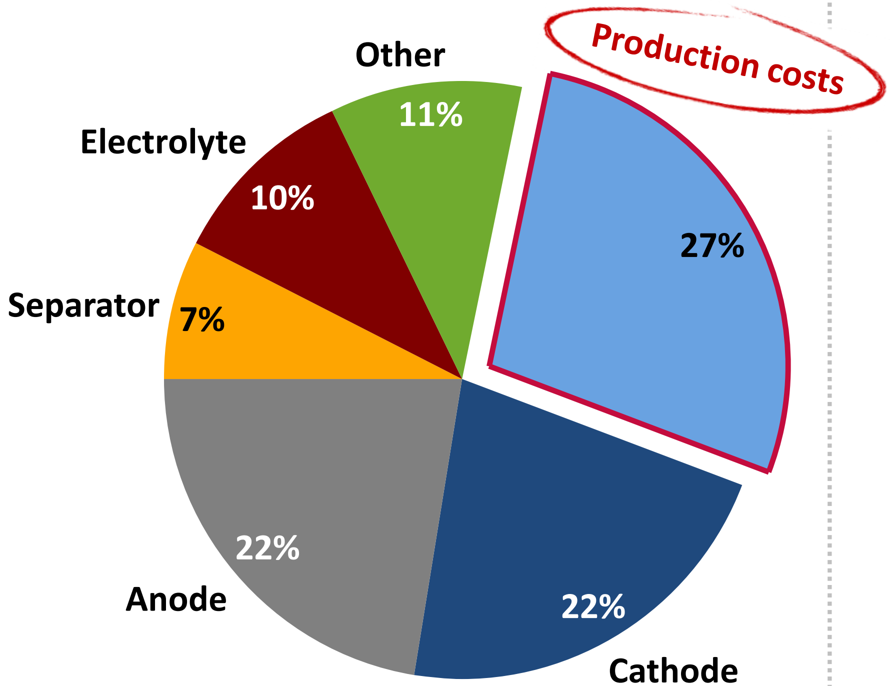
As of 2018, battery cost reduction due to a higher energy density materials (e.g. NMC 622), leads to competitive prices of xEVs. By 2020, system costs of 100 EUR/kWh will be met.

1) Assumption: Long-range BEV with 90kWh battery, automotive system cost structure: ~80% cell, ~20% system components

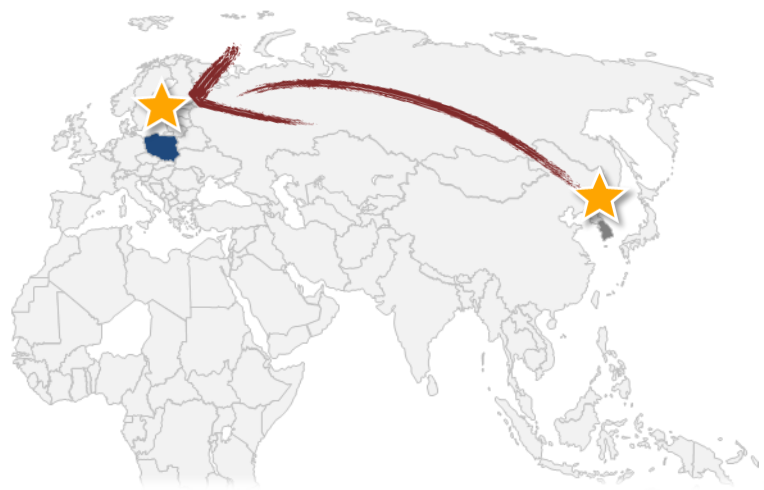
Source: P3 cell cost analysis

Current cost structures will be transferred from Asia to Europe and further improved

Cost structure: BEV Lithium-ion cell, 2016



Cost effect: Relocation of production



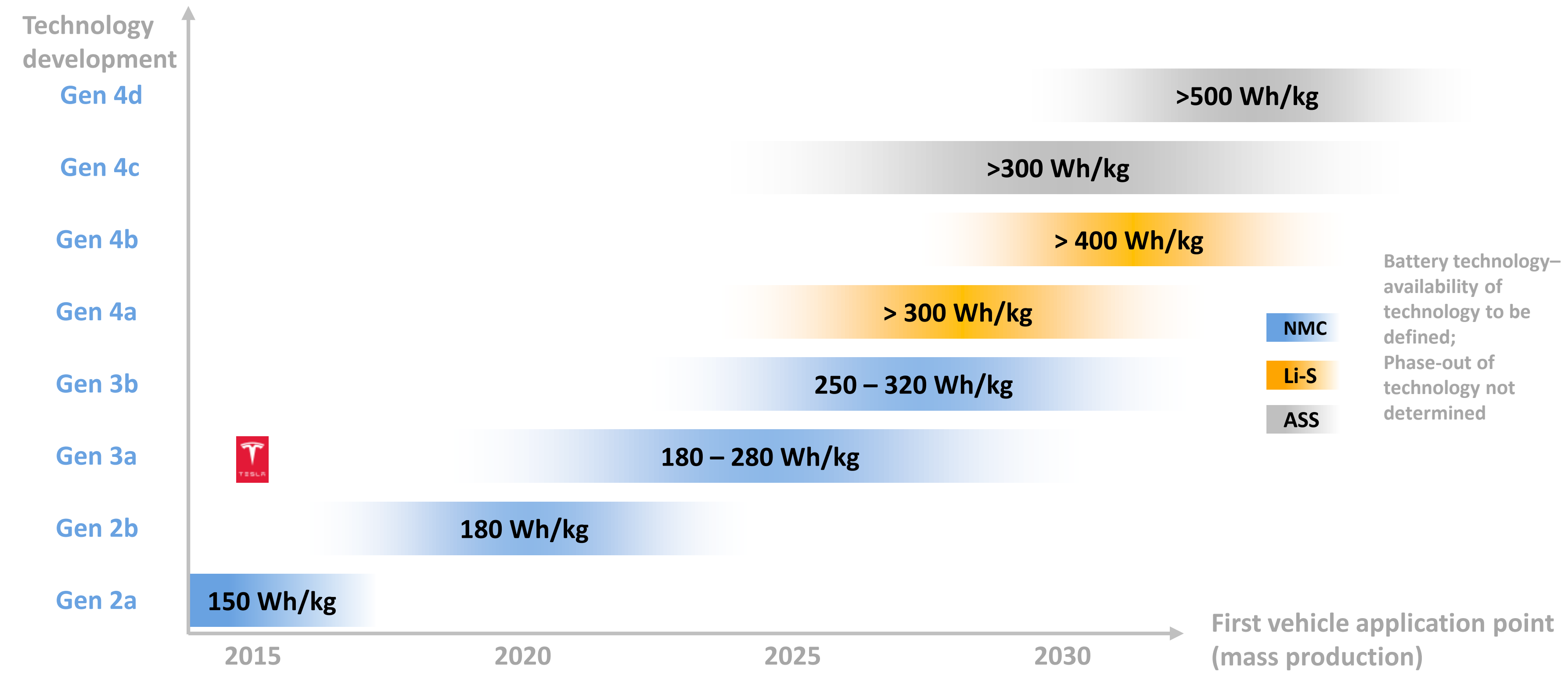
For European OEMs and markets, Asian key players transfer their production sites to Eastern Europe.

First learning curve effects and constant production improvements will be transferred to new sites in Eastern Europe with ongoing cost reduction. (Labor, energy and space costs, etc.)

Source: P3 cell cost analysis

TECHNOLOGY ROADMAP LITHIUM ION AND BEYOND

Current and future battery technologies



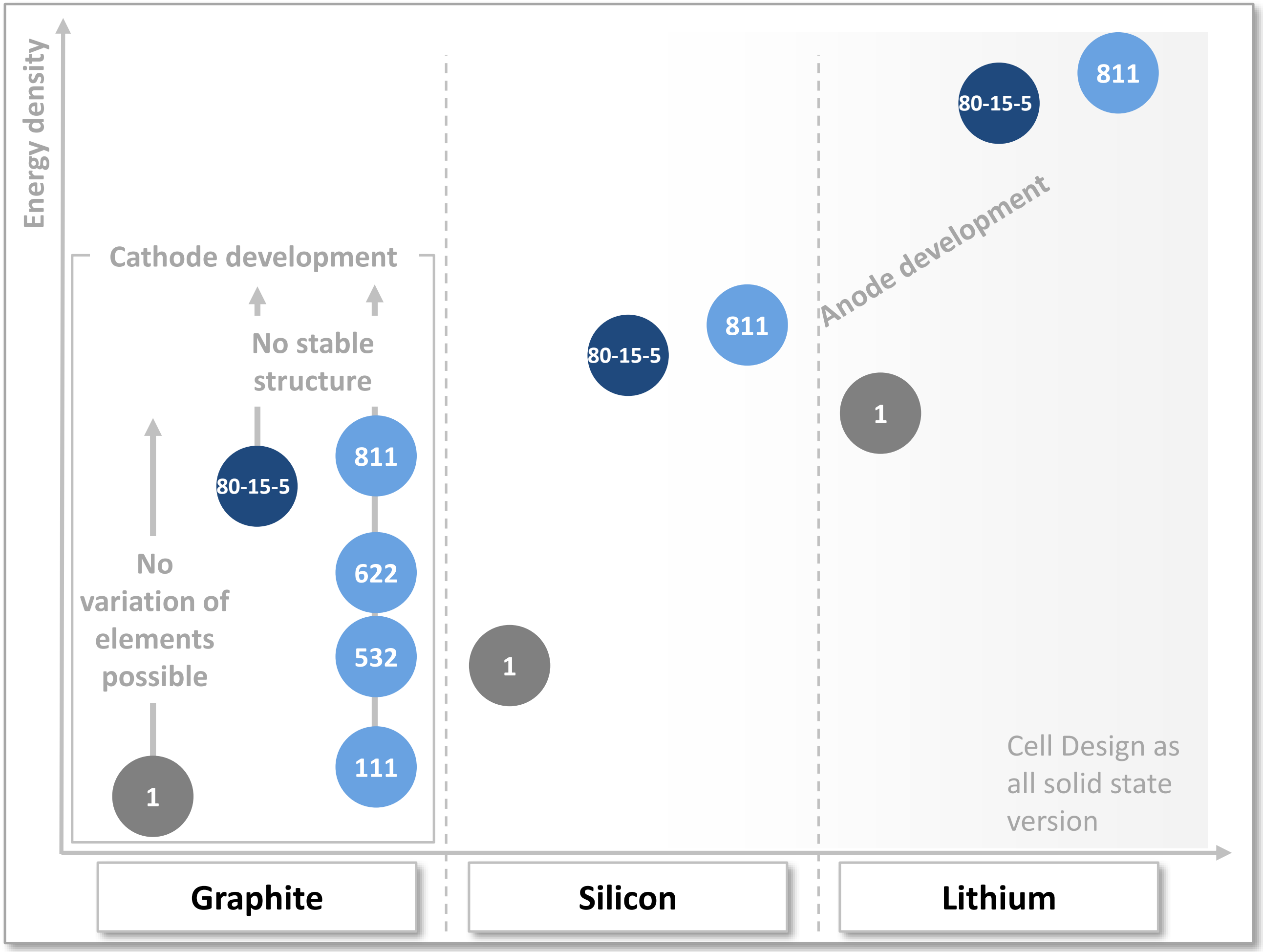
- Gen. 2a: NMC 111 / 100% Graphite
- Gen. 2b: NMC 532-622 / 100% Graphite
- Gen. 3a: NMC 622 – NMC 811 / C-Si (5-10%)
- Gen. 3b: NMC 811, HE-NMC / Si/C
- Gen. 4a: Li-S conventional
- Gen. 4b: Li-S enhanced
- Gen. 4c: All-Solid-State low-tec
- Gen. 4d: All-Solid-State enhanced

Tesla 2015: NCA / 100% Graphite
NCA is not assigned to a specific generation. The data point is given for comparison only. With NCA Tesla is able to have the same energy density as a Gen. 3a NMC technology.

- 258 Wh/kg on cell level / 140 Wh/kg pack level

Source: P3 group / MEET Muenster

Increasing energy densities: from state-of-the-art to lithium metal anodes



NMC $Li(NiMnCo)_1O_2$

NCA $Li(NiCoAl)_1O_2$

LFP $LiFePO_4$

- The LFP cathode is not suitable for a chemical development to reach a higher energy density.
- A higher nickel share would destabilize NMC-811 und NCA`s chemical structure.
- An advanced anode made of silicon or elementary lithium could increase the energy density.

Bubbles are representing cathode materials

C Boxes are representing anode materials

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Change of cell technology: from liquid to solid

Cell type	Anode		Electrolyte	Separator	Cathode	
	Current collector	Material			Current collector	Material
Gen 3a NMC 622	Copper 6 µm	Graphite (+Silicon)	EC / DC with $LiPF_6$	PE/PP	Aluminum 9 µm	NMC 622
Gen 4b Li-S enhanced	Copper 6 µm	Lithium metal	Polymer electrolyte 10 µm e.g. Block-Copolymer +Ionic Liquid		Aluminum 9 µm	Sulfur / Graphite-composite 80% sulfur
Gen 4d All Solid State	Carbon structure	Lithium metal	Solid electrolytes (e.g. ceramics, polymers)		Aluminum 2 µm by deposition	NMC(811) by deposition

- The cell technologies are adopted from literature and industrial cell concepts. The assessment of the manufacturing process base on the presented cell technologies.
- The all solid state technology represents a concept in an enhanced state of development. Therefore, the manufacturing process is essentially different from the common Li-Ion technology.

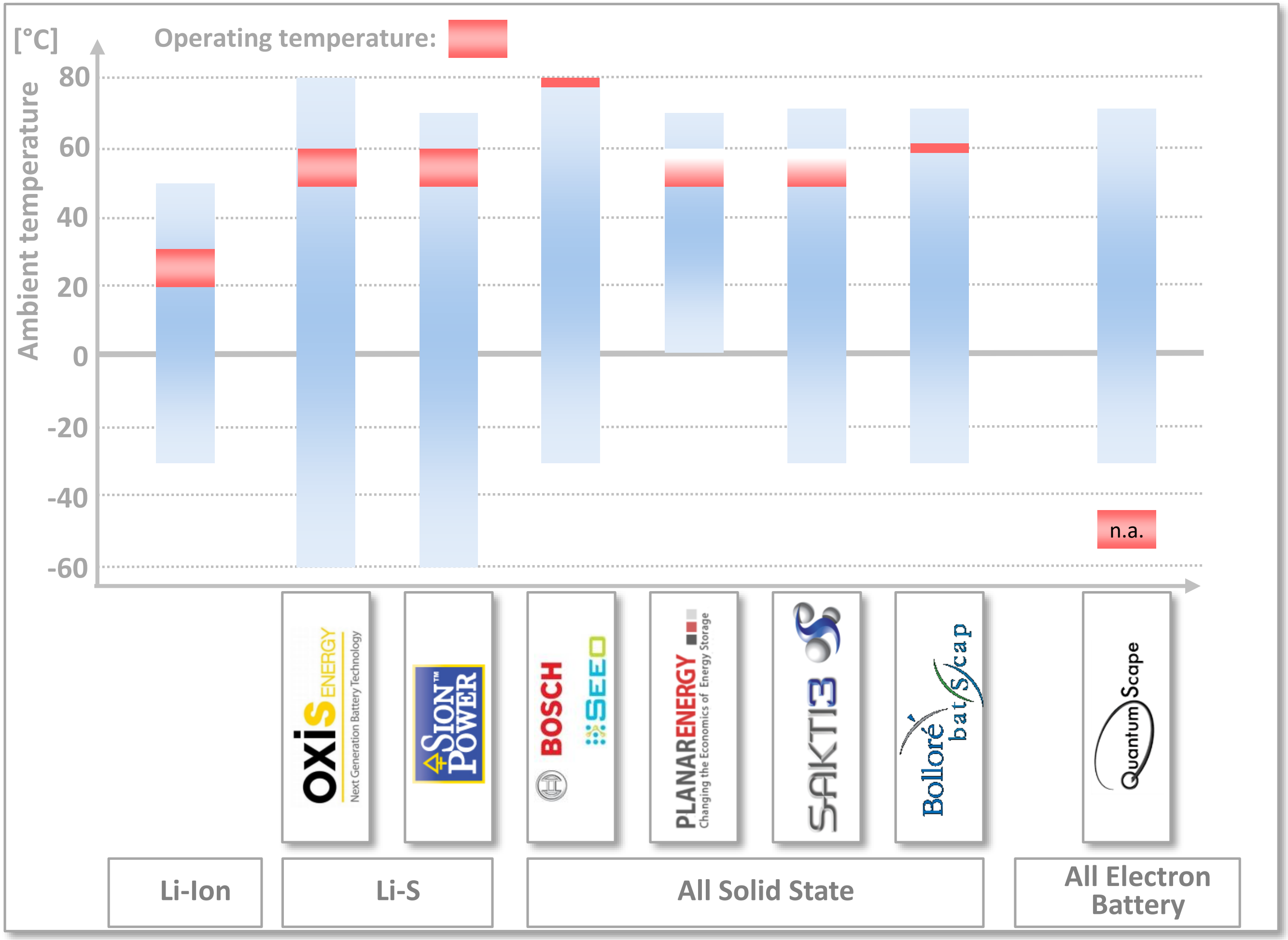
COMPARISON OF CELL GENERATIONS (2015-2030)

Technical feasibility and usage probability

	Technical feasibility		Probability / Market opportunities	
NMC-622 **as of 2015**	**Standard product** ▪ Materials are largely studied and commercially available. ▪ Production on existing Li-ion battery production lines.	🟢	**High competitive pressure** ▪ Established cell manufacturers have already big market shares. ▪ There is a strong market situation with high pressure on prices.	🔴
NMC-811 **as of 2017***	**Evolutionary approach** ▪ Materials are largely studied and commercially available. ▪ Production from existing Li-ion battery production can be taken over.	🟢	**High competitive pressure** ▪ Established cell manufacturers have already first products on offer. ▪ There is a strong market situation with high pressure on prices.	🔴
Li-Sulfur **as of 2026**	**Prototype status** ▪ Research and development for materials needed. ▪ Conventional production methods can be reused partially.	🟡	**Restricted application** ▪ Application in the automotive sector due to volumetric energy density questionable. ▪ Performance for the automobile sector problematic.	🟡
All Solid State **as of 2028**	**Research intensive** ▪ Intensive research effort on materials and production necessary. ▪ Manufacturing methods from other fields of technology partially transferable.	🟡	**High compatibility** ▪ Purchase of start-ups by suppliers and OEMs takes place reinforced. ▪ The cell technology is fully compatible with existing battery structures.	🟡

* earliest large-scale production

Operating temperatures for Li-S and all solid state technologies



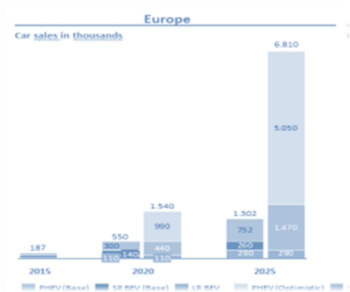
- Sion Power and Oxis Energy claim that the Li-S technology is operational at ambient temperatures of -70°C.
- The addition of ionic liquids to the polymer electrolyte of all solid state cells enables the operation at room temperature.
- The different technology of Quantum Energy cells results in a broad operation temperature window.

Operating Temperature

Indicates the optimum operating temperature of the cell

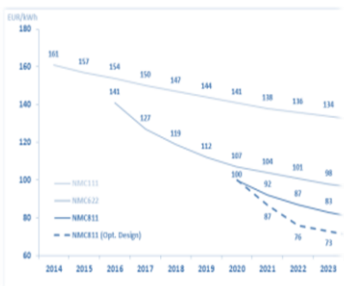
Source: P3 group / MEET Muenster

Significant influences on Li-based batteries



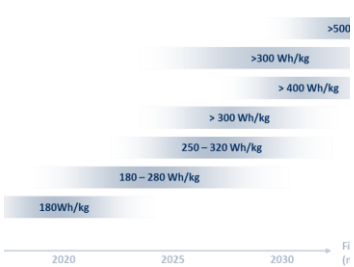
Market

- Battery market is driven by **automotive companies** (CO_2 regulations) and **Chinese demands**
- **Supply safety** due to the booming global demand is **highly critical**



Costs

- Battery system cost reduction due to **economies of scale** and **technological advances** of battery materials
- Additional logistics cost minimize by **relocation of production**



Technology

- **NMC development** predominant for the next 10 years
- Implementation of innovative improvements in **Li-S** and **all solid state batteries**

Thank you for your attention!

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