POTENTIALS FOR ALL-SOLID-STATE CELL MANUFACTURING IN EUROPE

EVS32

Entering Mass Market & Demand Issues

20th May 2019

Lyon, France

P3 automotive

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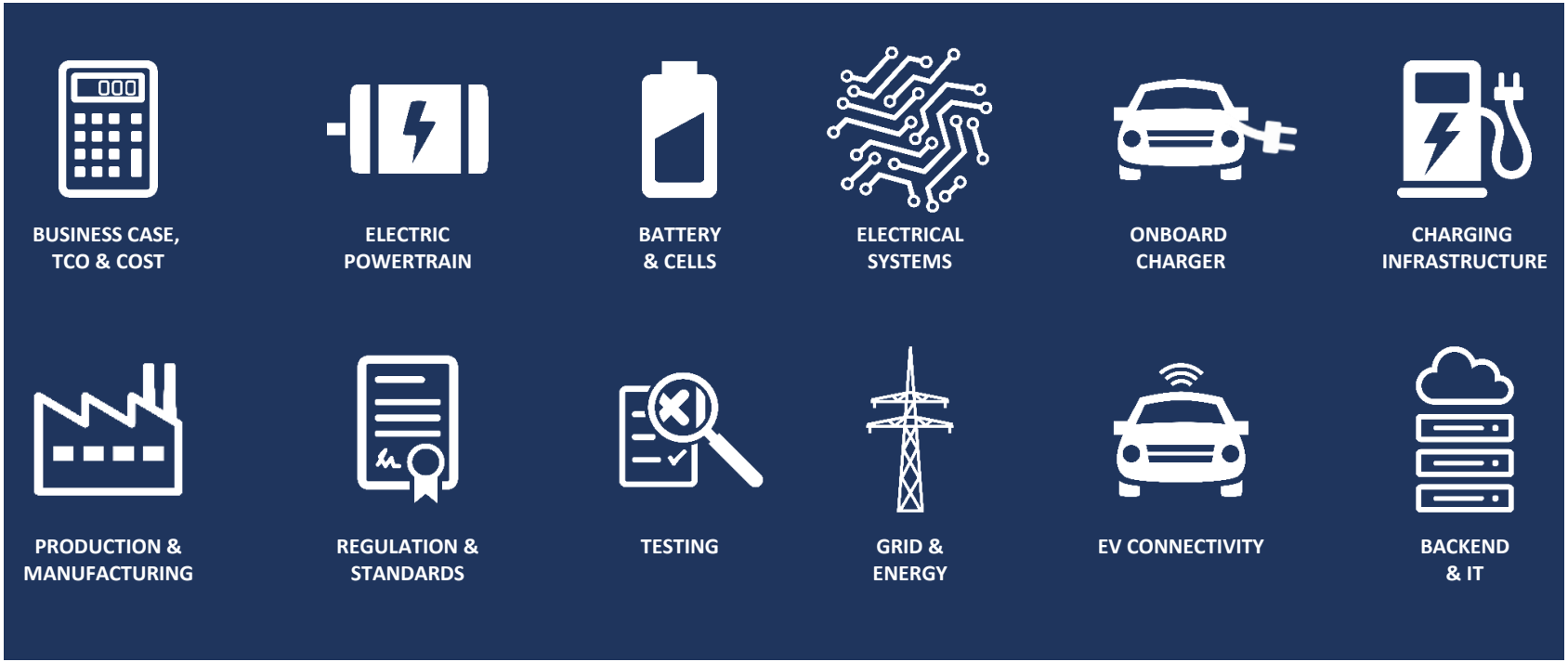
Our P3 electrify portfolio – from the first business case up until rollout of the vehicle including charging infrastructure – we enable the industry with our team



Three years after the clear view on that electromobility will come to the market inevitably, it is finally time to act for the automotive industry.

Safety

- Intrinsic cell safety is paramount
- Intervention on module or system level shall not be required
- System must be operative at any time -> Redundancy
- Trade-off between energy and safety

Battery Weight

- Cell, module and system design should be as light as possible
- System has to be redundant due to safety requirements
- Light-weight material to be used, preferably also for conductivity and EMV protection

High C-Rates require intensive cooling solution.

Energy and Power

- High peak power during take-off and landing required
- Aircraft on the ground (AoG) does not make money – high energy (and/or fast charging) required for longer operational time

Classic Trade-offs

Lifetime

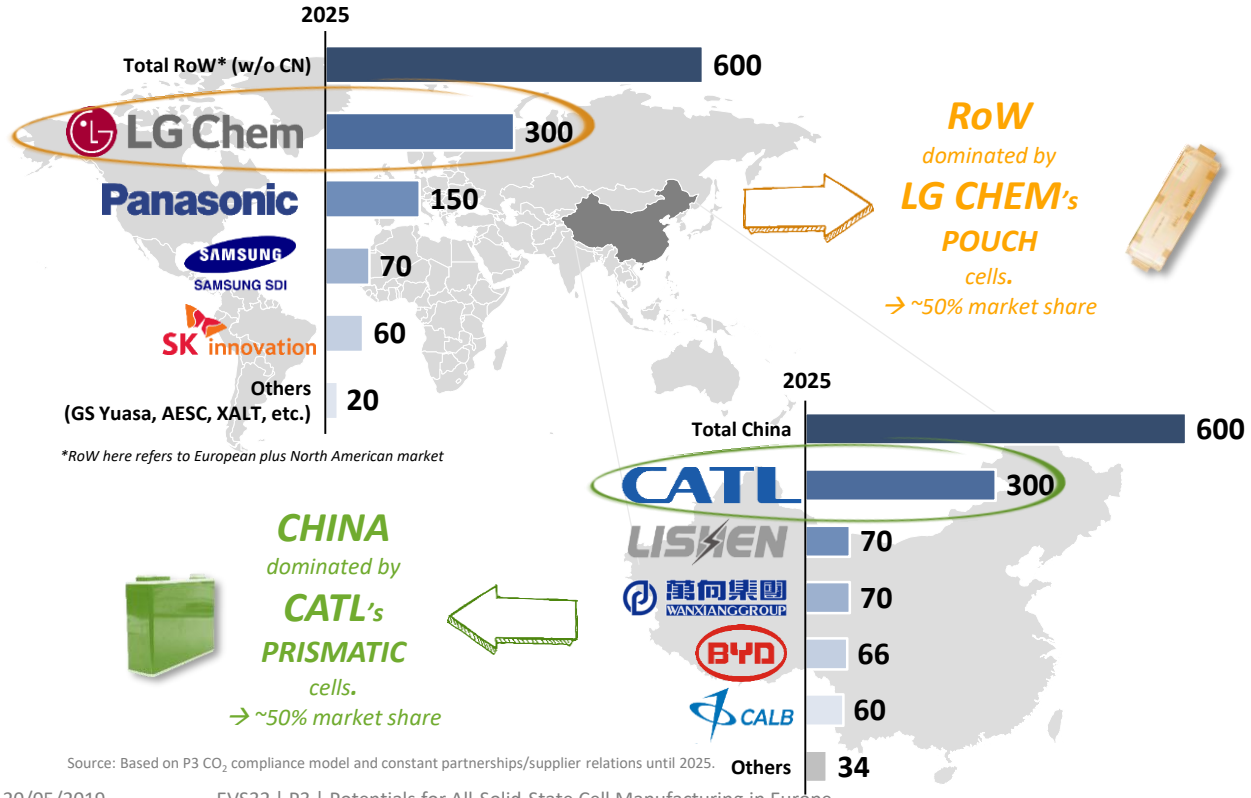
- Cycle stability is a ‘should’, not a must
- Loss in capacity leads to loss in flight time
- Increase internal resistance leads to loss in power
- Fast charging required to reduce AoG time will effect lifetime

Potential for parallel charging with parallel connected batteries with multiple charger inlets

Battery Costs

- High Safety requirements also lead to high costs
- Light weight requirement leads to higher costs

The Li-ion cell market for automotive applications will grow to >1.200 GWh in 2025, with dominance of CATL in China and LG Chem in the rest of the world.



Source: Based on P3 CO_2 compliance model and constant partnerships/supplier relations until 2025.

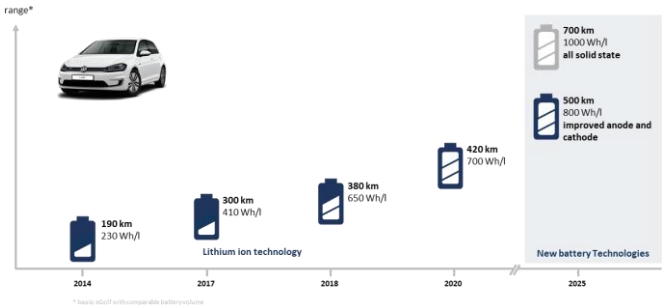
FINDINGS

- According to the P3 CO_2 compliance evaluation a rapid market growth of the lithium ion cell market is expected until 2025 (CAGR: 35%).
- The Chinese market will be dominated by CATL, whereas LG Chem is expected to dominate the remaining global market.
- Panasonic reaches a strong position through its close collaboration with Tesla.
- LG Chem is expected to stick with pouch cells, while CATL and SDI follow their strength in prismatic cells; Panasonic focusses further on cylindrical cells for Tesla.

Solid-State-battery cells have the future potential for a stable and safe high-energy storagesystem

Motivation for Solid-State-Elektrolyte

- Key motivation for solid-state technology is the potential for higher specific energy densities by the usage of lithium-metal as anode material instead of graphite compositions
- In liquid electrolyte cells the generation of dendrites and strong side-reactions lead to insufficient life time and safety performance
- Solid electrolyte supports the potential to stop both mechanisms and enable the usage of lithium-metal as a conductor
- By the exchange of the liquid and flammable electrolyte the safety features can be strongly enhanced



Higher Energy densities by usage of lithium-metal anode designs

Janek, J., & Zeier, W. G. (2016). A solid future for battery development. Energy, 500(400), 300.

Exemplary size comparison

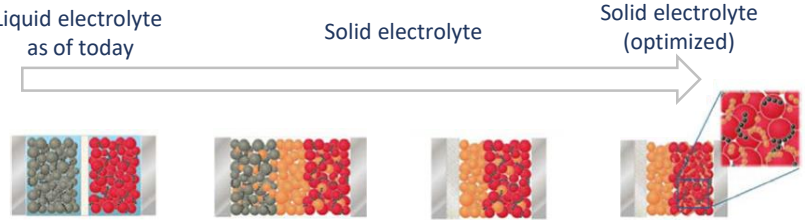
All Solid State

Increase of energy density on cell level up 50-70% feasible

Quelle: Solid Energy, The Battery Show NA, Novi Michigan 2017

To achieve higher energy densities the pure lithium-metal needs to be combined with NMC or NCA. Intermediate solutions do not offer sufficient advantages as of today.

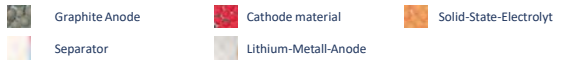
Evolutionary development of solid state technology



	Liquid electrolyte as of today	Solid electrolyte		Solid electrolyte (optimized)
Cell Chemistry	Graphit/NMC	Graphit/NMC	Lithium/NMC	Lithium/NMC (optimiert)
Electrolyte	liquid	solid	solid	solid (optimized)
Energy density (grav.) (Estimation P3)	-	↘ -8%	↗ +40%	↗ +70%
	LG Chem, CATL, Samsung SDI, Panasonic	ProLogium, Solid Power	ProLogium, Solid Power, Sion Power	

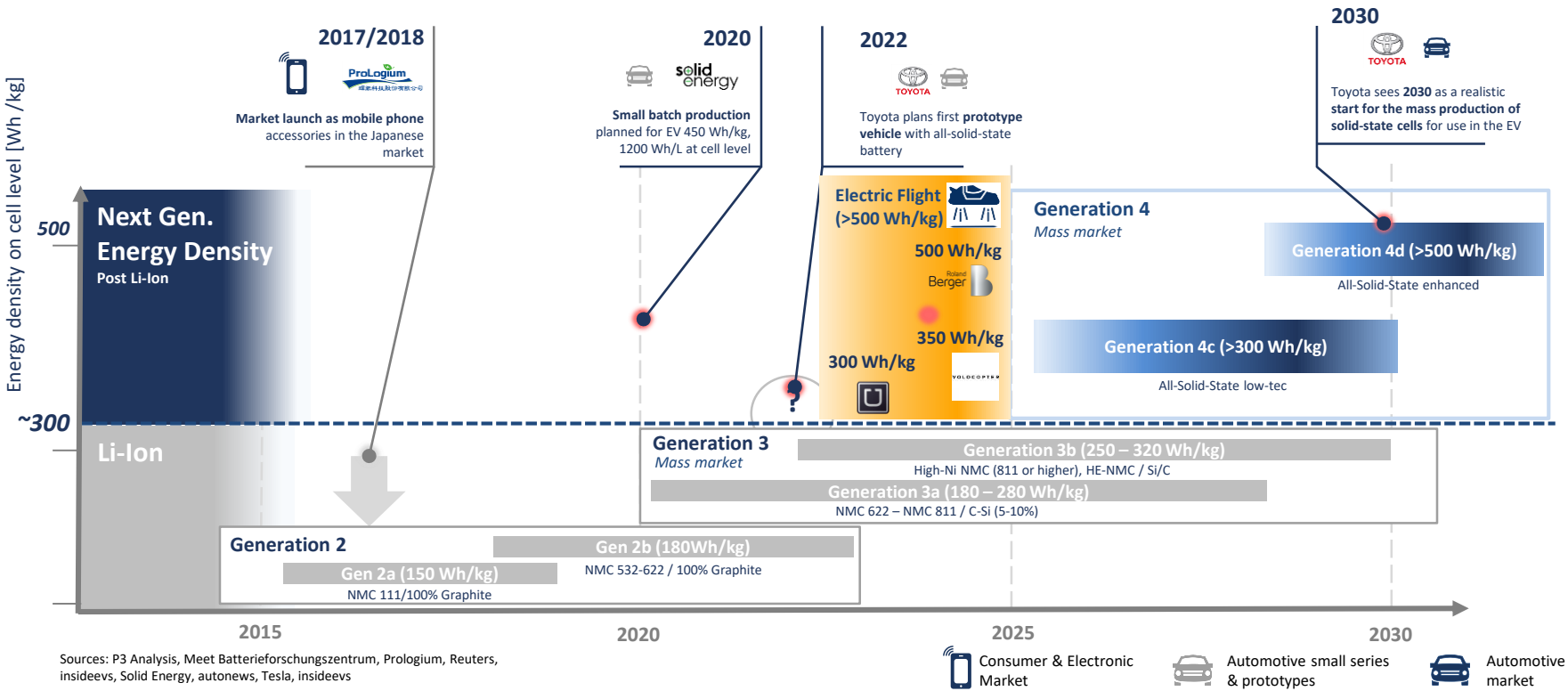
Key Findings

- The sole substition of liquid electrolyte by a solid state electrolyte resolves in a decreasing energy density
- By the usage of lithium metal (if < 20 µm) resolves in a volume optmization on the anode side and higher energy densities.
- Due to the insufficient compatibilty of the solid electrolyte, lithium, NMC and NCA multiple intermediate solutions exist:
  - Graphite (with silicone particles) as anode material
  - LFP als cathode material
  - These typically resolve in lower energy densities
- The usage of a optimized all-solid-state cell with lithium-metal anode and NMC/NCA cathode an increase of the energy density up to 70% is possible.



Placke et al.; Journal of Solid State Electrochemistry, 2017, 21. Jg., Nr. 7, S. 1939-1964.

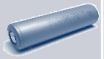
First all-solid-state batteries are already available in the consumer market or as prototypes. The introduction into the EV mass market and specifically electric flight is not expected until 2025.



Sources: P3 Analysis, Meet Batterieforschungszentrum, Prologium, Reuters, insideevs, Solid Energy, autonews, Tesla, insideevs

All solid state batteries require cell formats that support a stacked battery design as basic setup if further advantages in comparison to e.g. convential coiled cells shall be implemented

OVERVIEW POTENTIAL MATERIAL & MANUFACTURING COMBINATIONS

Cell type	Electrode design/setup	Polymeric Setup	Ceramic Setup (sulfide)	Ceramic Setup (oxide)
Cylindric 	coil			
Prismatic 	coil			
	stack			
Pouch 	coil			
	Stack			

possible | potential solution | not possible

BOSCH SEEO 

Production of stacked cell design

ProLogium 

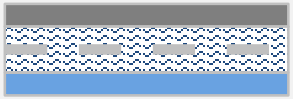
Experience in stacked thin film batteries, scale up in size without changing proven cell format

KEY FINDINGS

- **Ceramic electrolytes are only usable in stacked cells**
  - sulfide and especially oxide based ceramic ion conductors are brittle and break when bent or winded
- **Polymeric electrolyte can be used in cell coils**, but shows the same disadvantages as coiled cells today (lower energy density)
- **Only stacked prismatic and pouch cells are usable for all possible variants of solid electrolyte** with higher energy densities

» Pouch cell format seems to be the preferred cell design for All-Solid State batterie

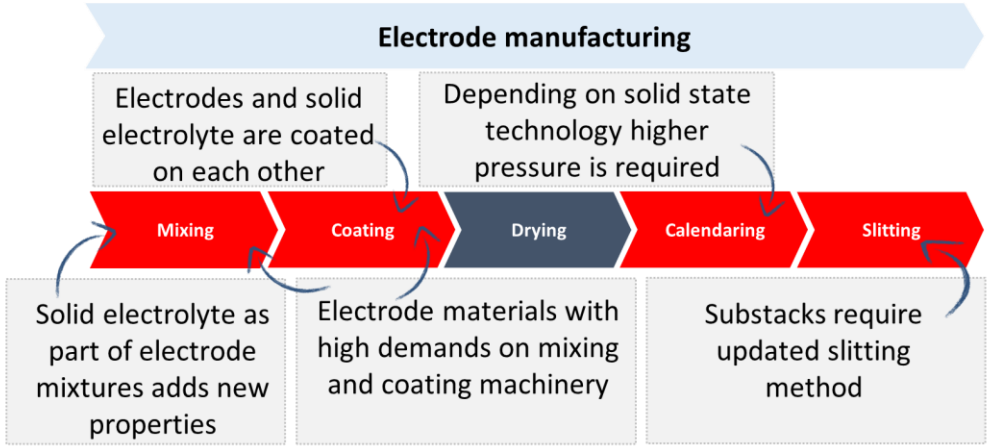
The comparison of safety failures in Li-Ion and All Solid State technologies shows the advantages given by the all solid-state design, but also identifies the same base materials for the Cathode side

	Conventional Li-Ion (NMC)		All Solid State Technology
	Cathode Separator / Electrolyte Anode		Cathode Electrolyte Anode
Cathode	▪ NMC setups with increased Nickel & Lithium content ▪ Porous structure filled with liquid electrolyte	→	▪ Coatings required to ensure cathode/electrolyte contact ▪ **Usage of state of the art cathode materials (NMC) currently expected**
Electrolyte	▪ Liquid organic Electrolyte ▪ Evaporation under high pressure and **thermal runaway will lead to ignition**	↘	▪ Solid electrolyte ▪ **No evaporation** is possible. ▪ The use of solid electrolytes enhances **high temperature stability.**
Separator	▪ PE **separator melts** at elevated temperatures. ▪ **Dendrites** can grow through the separator and will form a short circuit.	→	▪ **No separator** is needed. ▪ Possibility of suppressing partial dendrite formation
Anode	▪ Graphite provides a **host structure for Lithium**. ▪ Graphite **participates in a thermal runaway**.	→	▪ Elementary lithium is used as anode material. ▪ In case of contact to oxygen or water a **hardly extinguishable lithium metal fire** can occur.

FINDINGS

- **Eliminating the liquid, flammable electrolyte gives all-solid state batteries a safety advantage** as a basic feature.
- Safety issues for conventional Li-Ion batteries will only increase with energy density or reactive materials
- **Future all solid state technologies promise high energy densities** with acceptable safety properties
- To ensure safety in the all solid state battery **handling the lithium metal anode is essential**

For a longterm European battery manufacturing facility it may be more suitable to prepare for next generation technologies, due to strong and established competition for state-of-the-art technologies as Lithium-Ion out of Asia

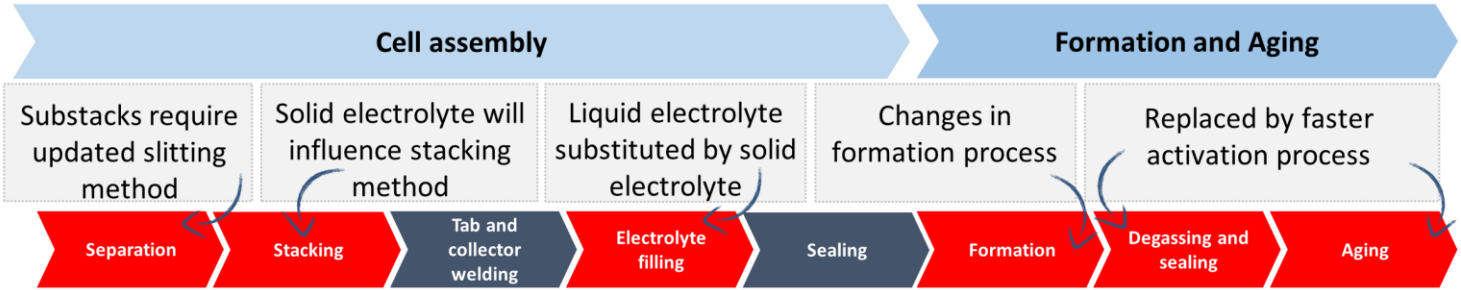


Mayor process adaptions

- Controlled atmosphere for entire process needed
- Fully automated process required
- Thin layer technologies needed

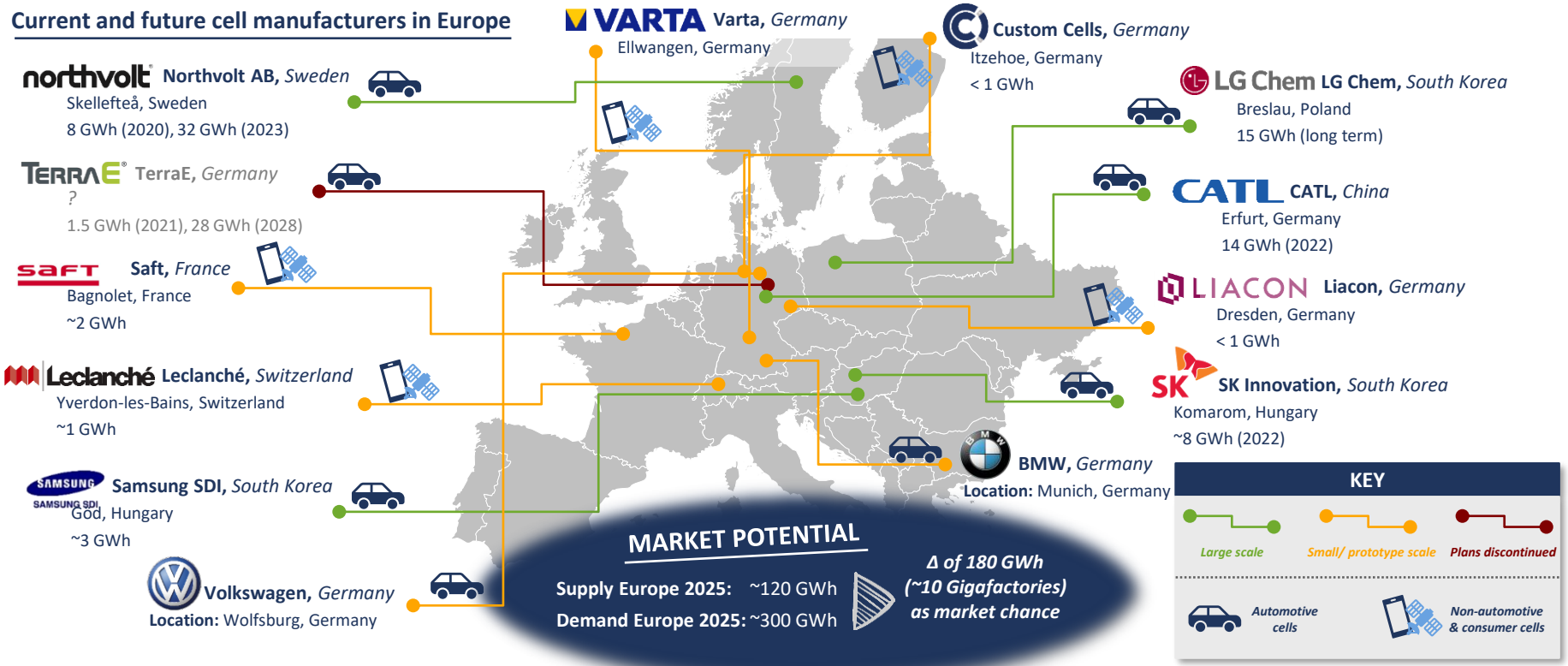
Single step adaption

Changed production step



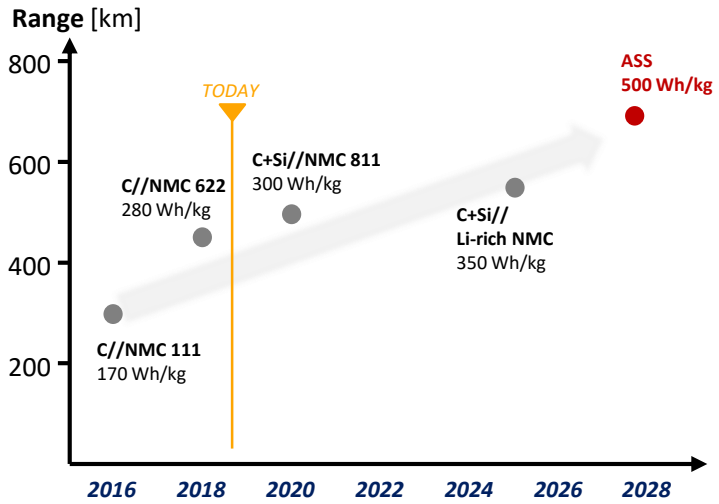
Established battery cell manufacturers are moving to Europe due to customer requirements for large scale supply; delta between estimated demand and supply in 2025 offer great market potential.

Current and future cell manufacturers in Europe



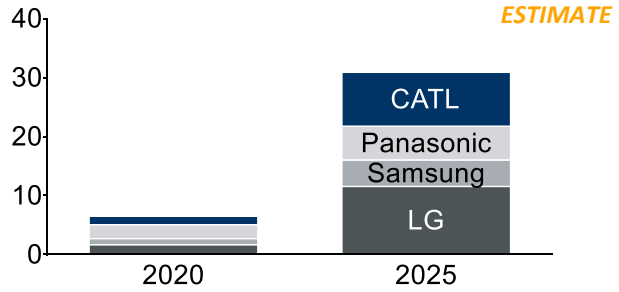
Leading cell manufacturers will be able to transfer their advance in knowledge for conventional Li-ion cells to future technologies such as All-Solid-State (ASSB).

ASSB is the natural sequel of conventional Li-ion cell technology: cell manufacturers will defend their edge...



… and they have the necessary financial and technological means to do so.

Cumulated investment in processes and machines
(in bn EUR)



*"Even if a new battery technology will win the race: **80% of** the **knowledge for a cost competitive mass production** will be **exactly the same as for conventional Li-ion batteries** as of today."*

Prof. Dr. D.-U. Sauer
Chair for power generation and storage systems, RWTH Aachen

Extensive market ramp-up for electromobility, threat of dependency on Asian players and technological as well as economical importance of Li-ion cells call for an European cell manufacturing.

- **Electromobility** will come to the market **inevitably** and in **extensive volumes**. **Cell demand** will increase to **1.200 GWh** until 2025.
- The **Li-ion cell** will become the **differentiating element** of EVs – both from **economical (~30% of value share)** and **technological** viewpoints.
- **Performance** of traction battery **cells** has a **significant influence on vehicle performance**, **quality** and **cost**. Automotive OEMs have limited options regarding the setup of their value chains which leads to a **dependency** on **Korean**, **Japanese** and **Chinese cell manufacturers**.
- Major **disruptive cell technologies** are **not expected before 2025 (conventional Li-ion will stay until >2030)**. Other than commonly believed, everyone has to **gather experience with state-of-the-art cell technologies** before producing e.g. All-Solid-State cells.
- The **automotive technology path will also provide the basic technology for electric flight**, e.g. air taxis, as these are cell and battery systems with comparable quality and safety levels as well as cost targets. We therefore expect a hybrid approach of the automotive and aviation industry on this.

THANK YOU FOR YOUR ATTENTION

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