BATTERIES FOR ELECTRIC VEHICLES – CURRENT STATUS AND NEW DEVELOPMENTS

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Fraunhofer Institute for Solar Energy Systems ISE

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AGENDA

- Introduction to battery research, development and services at Fraunhofer ISE
- Battery storage – Mission
- Electromobility – Market developments and trends
- Battery storage – Market segments and market developments
- Battery storage – Cell technologies
- Battery life cycle
- Conclusions

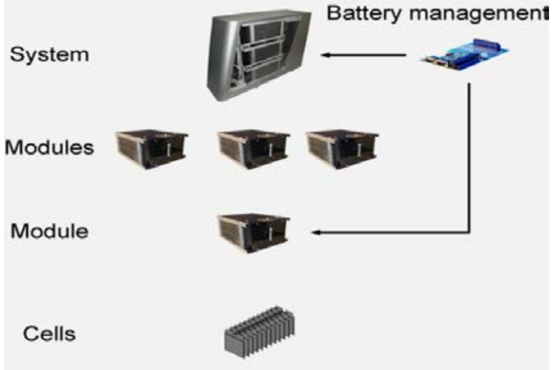
Department Electrical Energy Storage

Overview – Research, Development and Services

Battery Cell Technology
materials, architecture, production

- Development and characterization of materials and battery cells
- Development of process technologies
- Aqueous systems for stationary energy storage
- Lithium ion battery cells
- Solid state battery cells
- Technical and economical analysis
- Life cycle analysis

Battery Engineering
from cells to systems



- Cell formation
- Cell and system characterization
- Ageing and performance scrutiny
- System design and engineering
- Thermal management
- Battery management
- Algorithms for state estimation and life time prediction
- Optimized charging and operating control strategies

Applied Storage Systems
system design, integration and quality assurance

- Realization of lighthouse projects
- Business case development
- Consulting during complete life cycle of storage projects
- System modelling, analysis and optimized system design
- Simulation based storage sizing
- Energy management systems
- Technical due diligence: Site inspection, testing and monitoring

TestLab Batteries
electrical, thermal, mechanical testing

- Ageing: calendric and cyclic
- Safety: components and systems including functional safety
- Reliability: consideration of operating conditions and system behavior with aged components
- Performance: efficiency and effectiveness
- End-of-line quality control for cell production

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New location “Haidhaus” – End of 2021

- Existing building
- 5500 m² for labs
- Battery cell technology
- Battery engineering
- Storage applications
- Testing

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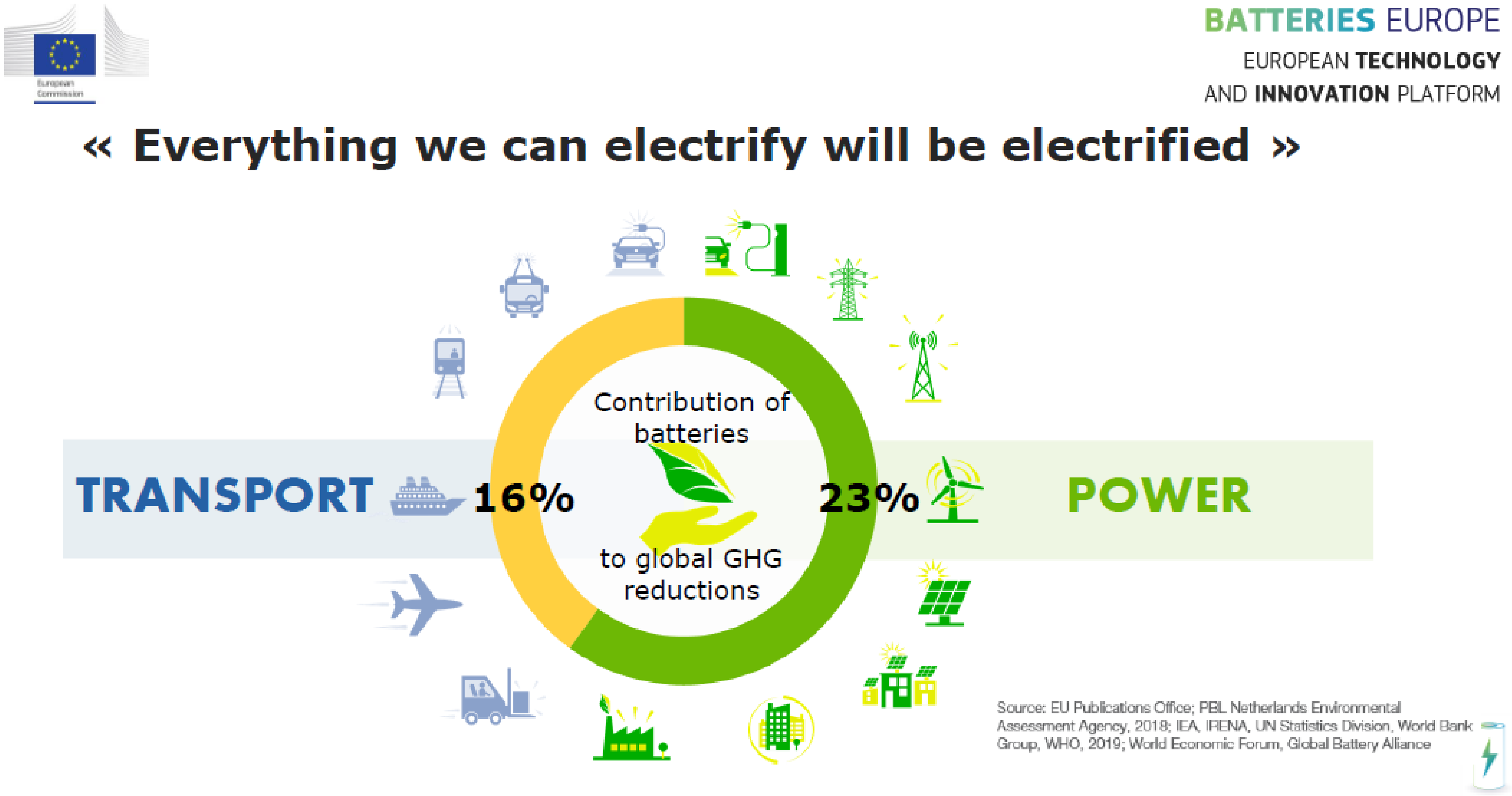
Battery storage – Mission
Batteries Europe: Strategic Research Agenda – Extract



Source: E. Sheridan: Batteries Europe, European Technology and Innovation Platform – Overview of Strategic Research Agenda, Batteries Europe Webinar, 28th of October 2020.

Electromobility – Market developments
Global xEV market

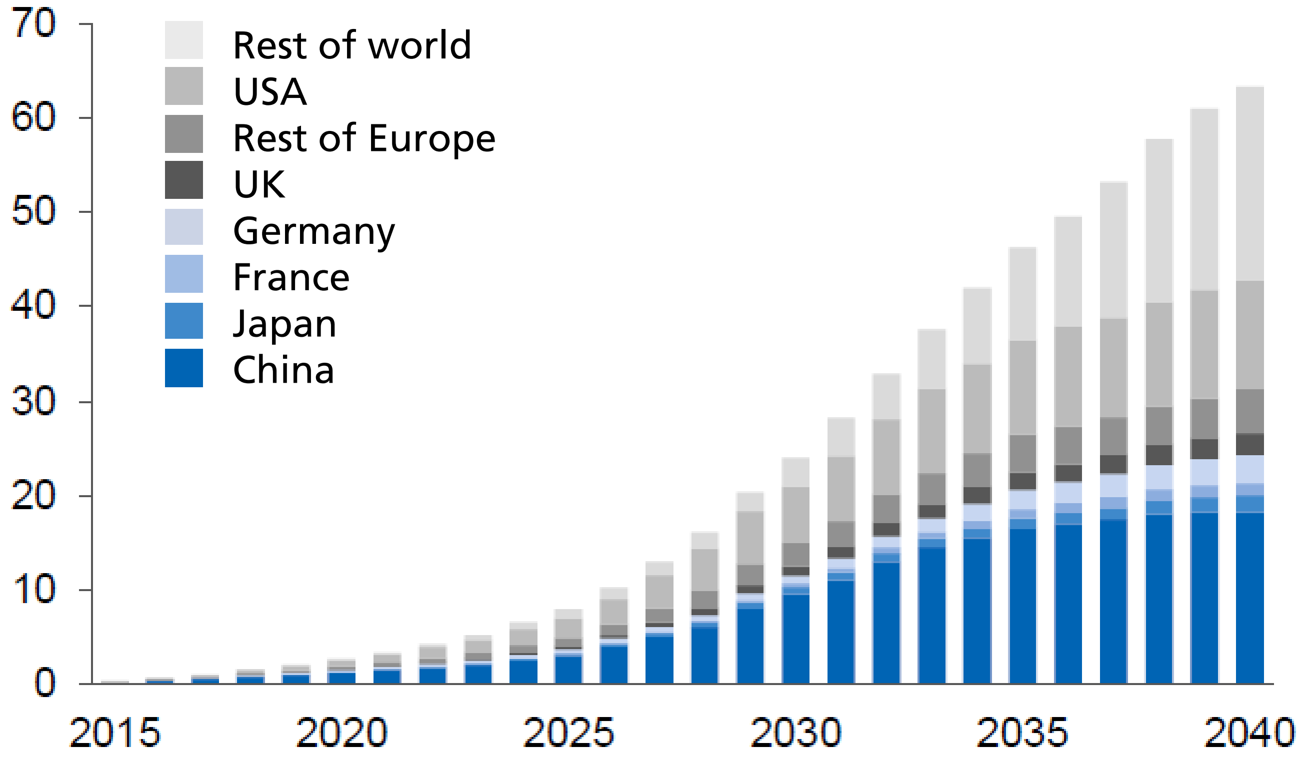
Global xEV market in 2019:

- ~ 2 209 832 (74 % BEVs)

Global xEV battery market in 2019:

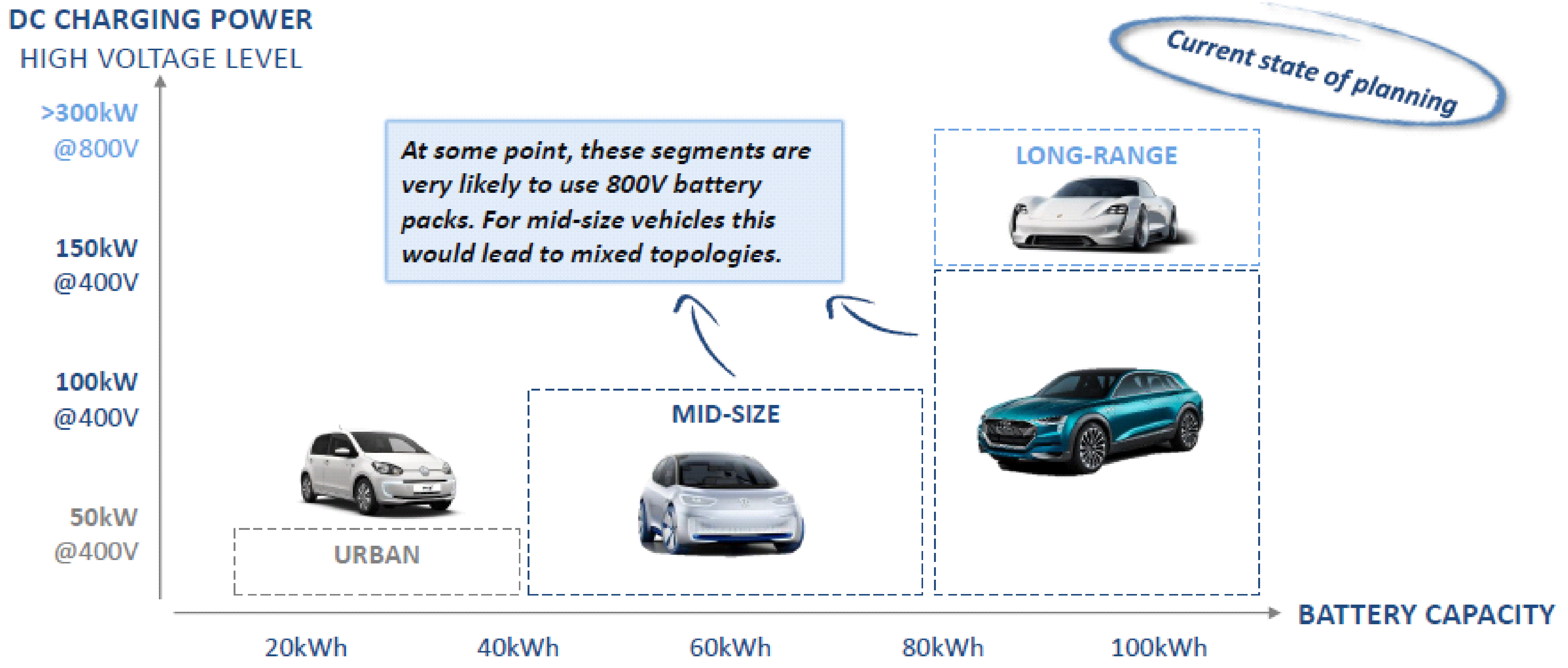
- ~ US$ 27.2 billions
- ~ 112 GWh
- Average battery capacity / EV: ~ 50.5 kWh
- Average battery price / EV: ~ US$ 7877
- Average battery price / kWh: ~ US$ 156

Annual xEV sales in millions



Sources: J. Mähliß: Trends im Lithium-Ionen Batteriemarkt, 2020; BloombergNEF; InsideEVs; statista; EV Volumes; McKinsey, 2020; Citi Research, 2018; Avicienne Energy, 2018.

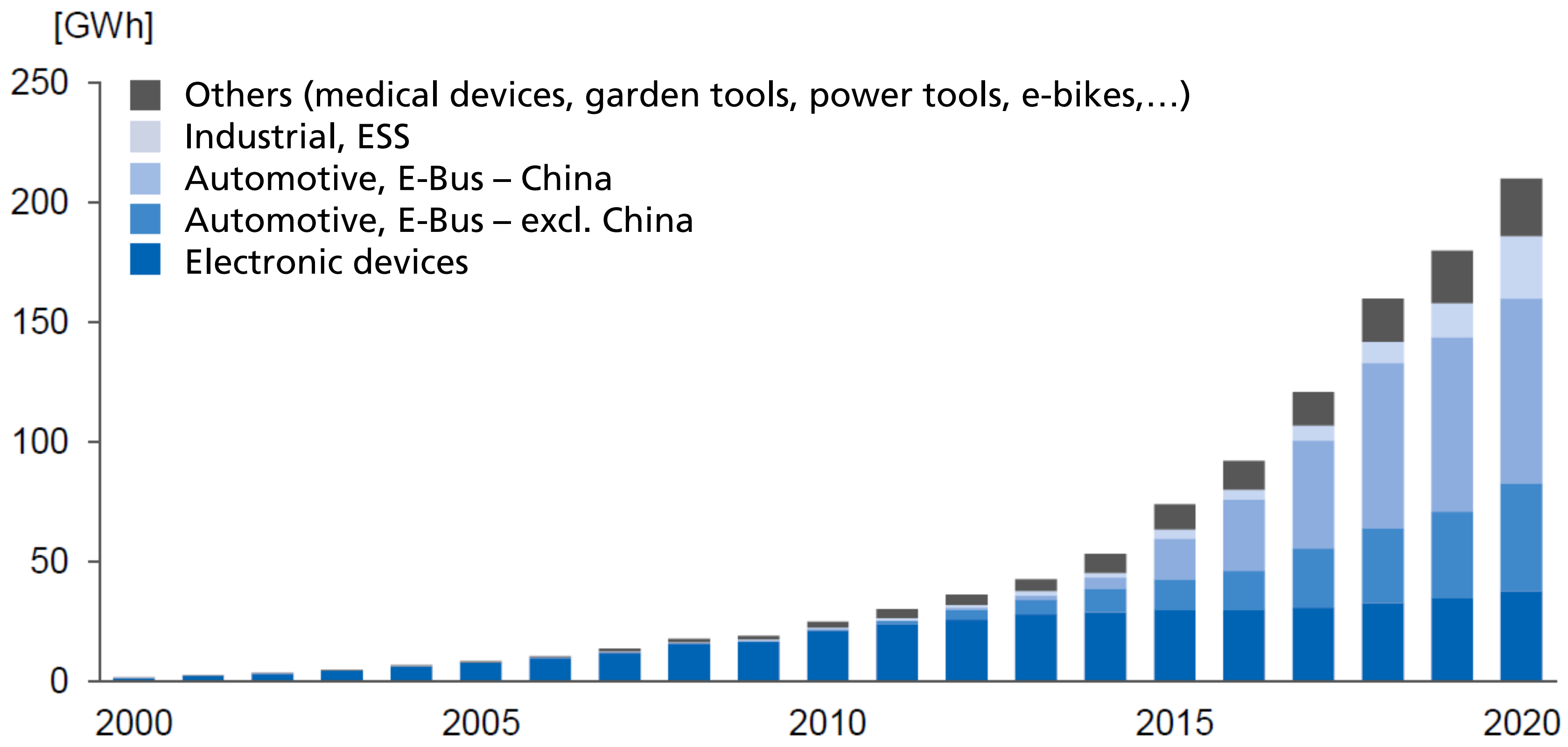
Electromobility – Market developments
Trends in EV battery system sizes

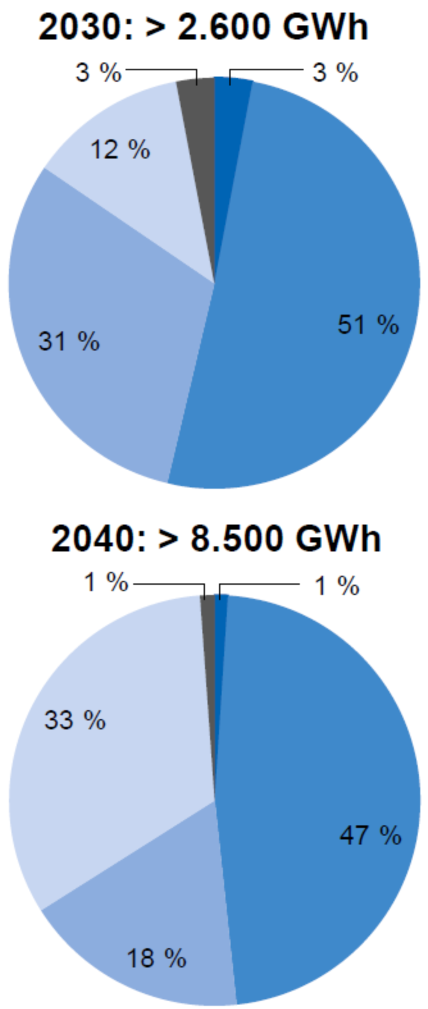


Source: M. Wojtynia: Analysis of future powertrain topologies and evaluation of powertrain setups, 2017.

Battery storage – Market segments and market developments

Lithium-ion batteries





Sources: J. Mählib: Trends im Lithium-Ionen Batteriemarkt, 2020; BloombergNEF, 2020; Roskill, 2020; Avicienne Energy, 2019.

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Battery storage – Cell technologies

Batteries Europe: Strategic Research Agenda – Extract: Lithium batteries

- Lithium-ion "evolution"
- Solid state "revolution"

→ Lithium dominates the current decade

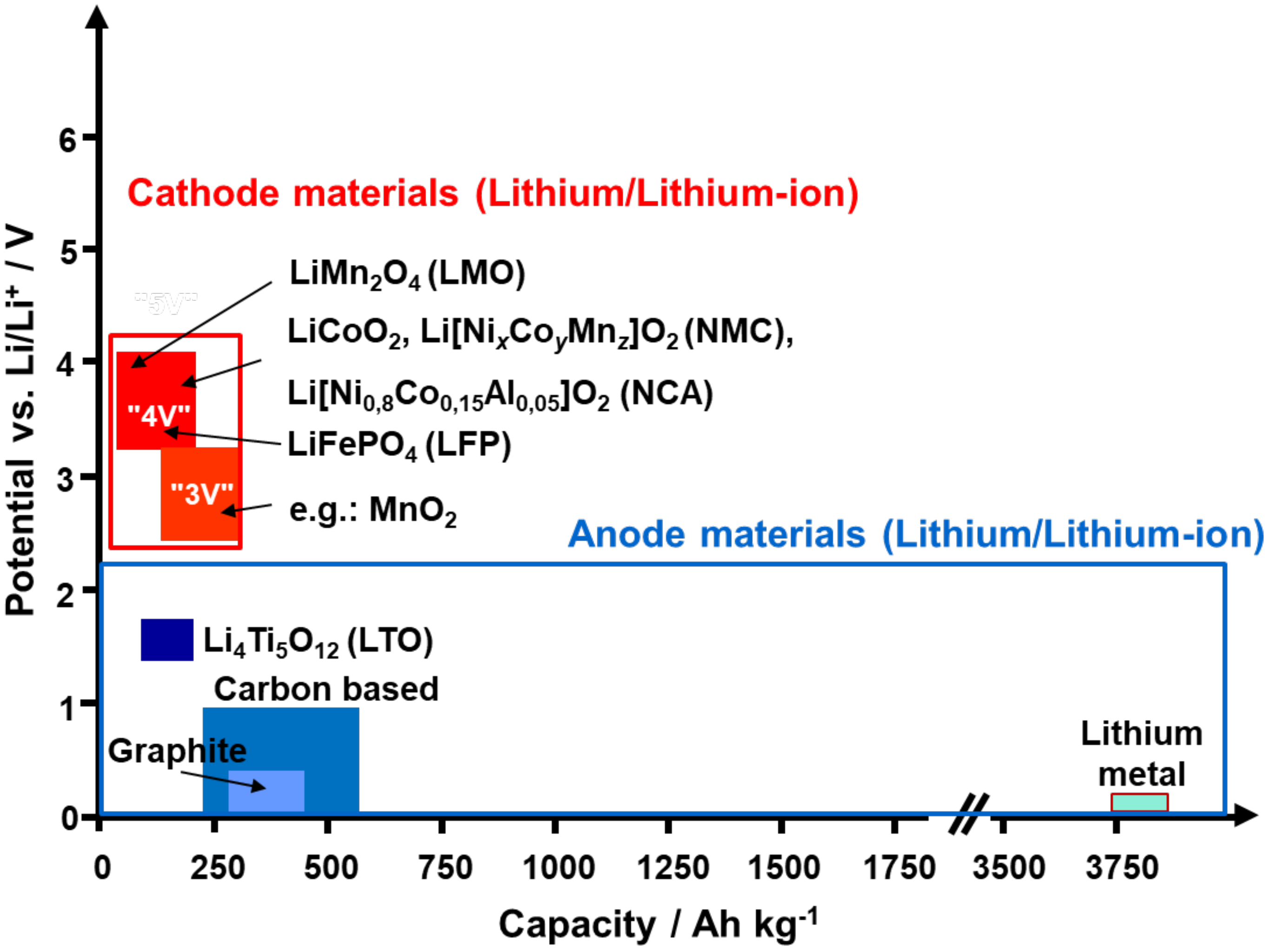
→ Technology targets are mainly driven by the transport sector !

Battery Generation	Electrodes active materials	Cell Chemistry / Type	Forecast market deployment
Gen 1	• Cathode: LFP, NCA • Anode: 100% carbon	Li-ion Cell	current
Gen 2a	• Cathode: NMC111 • Anode: 100% carbon	Li-ion Cell	current
Gen 2b	• Cathode: NMC523 to NMC 622 • Anode: 100% carbon	Li-ion Cell	current
Gen 3a	• Cathode: NMC622 to NMC 811 • Anode: carbon (graphite) + silicon content (5-10%)	Optimised Li-ion	2020
Gen 3b	• Cathode: HE-NMC, HVS (high-voltage spinel) • Anode: silicon/carbon	Optimised Li-ion	2025
Gen 4a	• Cathode NMC • Anode Si/C • Solid electrolyte	Solid state Li-ion	2025
Gen 4b	• Cathode NMC • Anode: lithium metal • Solid electrolyte	Solid state Li metal	>2025
Gen 4c	• Cathode: HE-NMC, HVS (high-voltage spinel) • Anode: lithium metal • Solid electrolyte	Advanced solid state	2030
Gen 5	• Li|O_2 – lithium air / metal air • Conversion materials (primarily Li|S) • new ion-based systems (Na, Mg or Al)	New cell gen: metal-air/ conversion chemistries / new ion-based insertion chemistries	>2030

Source: E. Sheridan: Batteries Europe, European Technology and Innovation Platform – Overview of Strategic Research Agenda, Batteries Europe Webinar, 28th of October 2020.

Battery storage – Cell technologies: Lithium

The “evolution” of the battery capacity



Source: FVEE, 2016.

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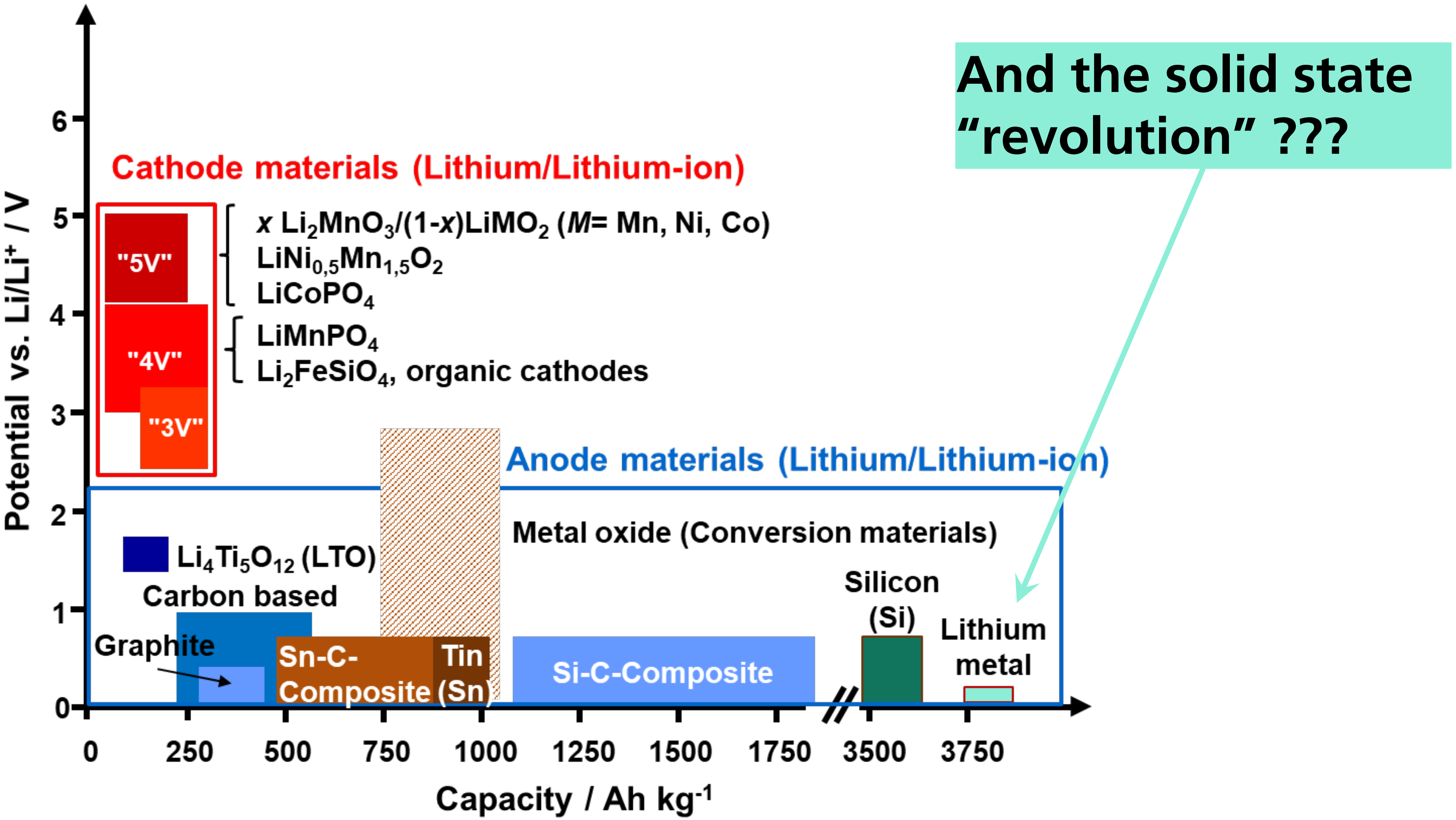
Battery storage – Cell technologies: Lithium
The “evolution” of the battery capacity



Source: FVEE, 2016.

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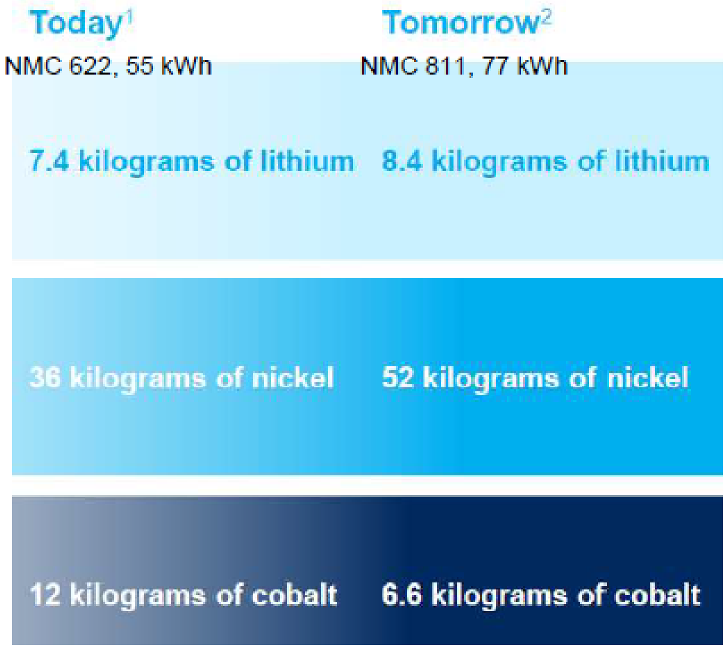
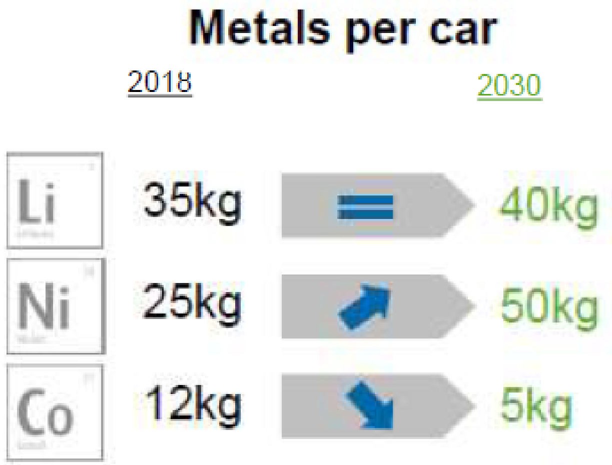
Battery storage – Cell technologies: Lithium
Trends of cathode materials – Example NMC

Battery metals content per car: For NMC:811, 50-52 kg Ni, 8-40 kg Li, 5-6.6 kg Co. For today: 25-36 kg Ni, 7.4-35 kg Li, 12 kg Co. Change: +70% Ni, +14% Li, -52% Co.



McKenzie, AABC Strasbourg, 1/19



Umicore, AABC Strasbourg, 1/19

Source: T. Johnson: Review of Battery Electric Vehicles, International Battery Seminar, Fort Lauderdale, 2019.

Battery storage – Cell technologies: Lithium

Trends of anode materials – Example “silicon-rich”

amprius

2007 Si nano anode invention in Cui group
2008 April, Amprius founded by Cui
2009 Feb, Series A $5M
2011 Mar, Series B $25M
2013 Dec, Series C $30M
2014 Wuxi City Joint Venture, Series D $40M, production
2016 More than a few million batteries sold in market

Amprius Product Line:
Line 1: 750Wh/L, 290Wh/kg
Line 2 : 900-1300Wh/L, 400-435Wh/kg

Airbus Zephyr S:
25 day continuous flight time, 70,000 feet.
with Amprius Si nanowire battery:
435 Wh/kg, 1200Wh/L.

Source: Yi Cui, Stanford University, International Battery Seminar, Fort Lauderdale, 2019.

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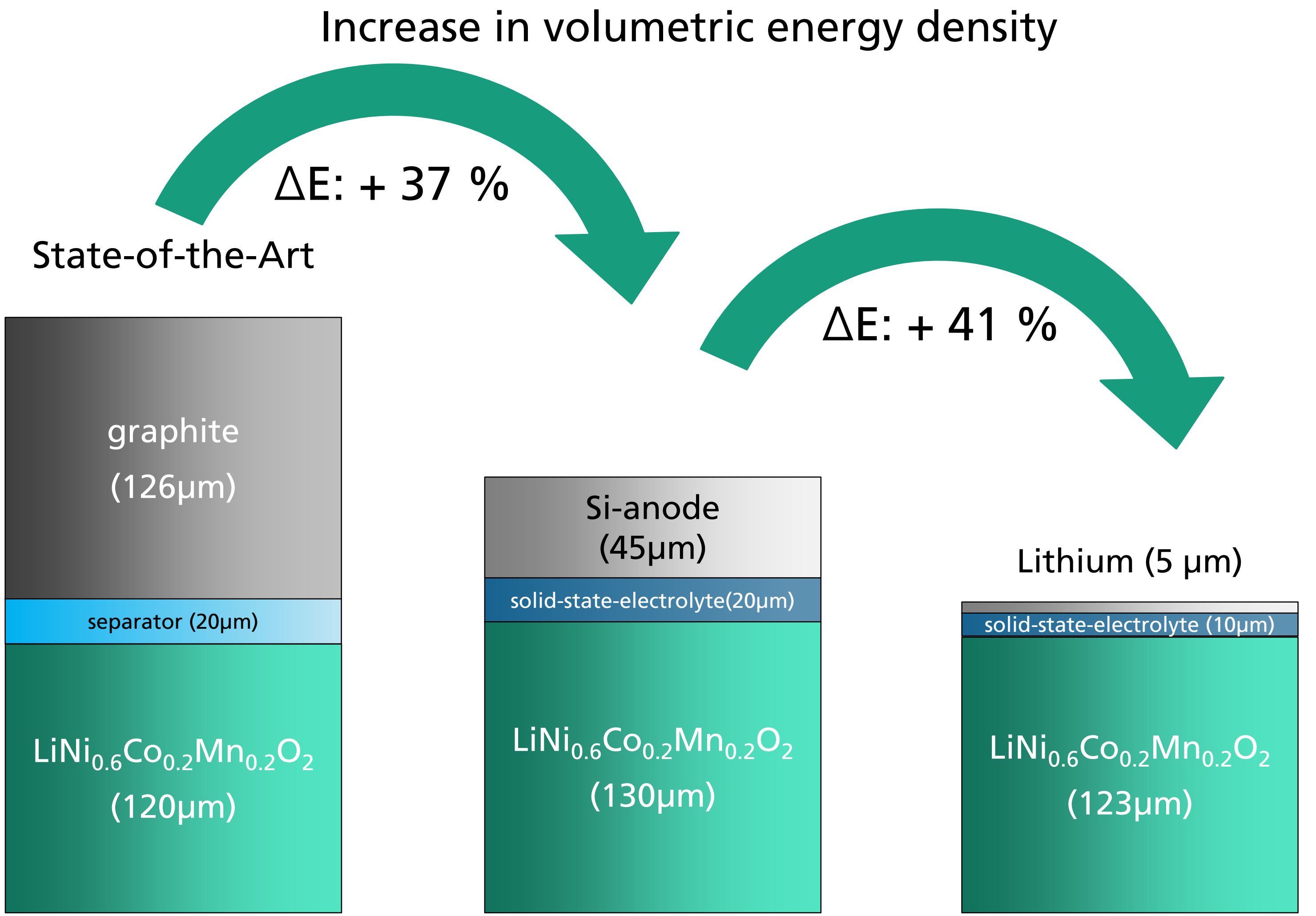
Battery storage – Cell technologies: Lithium
Towards the solid state "revolution"

Printed all solid state batteries with silicon anodes

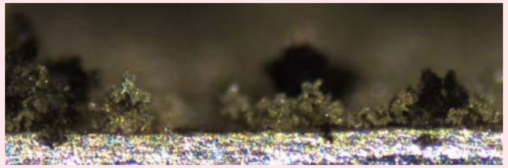
- Silicon anodes as intermediate technology in between graphite and lithium metal
- Approaches to solve specific problems of silicon (high volume change) are being investigated



Battery storage – Cell technologies: Lithium

Towards the solid state “revolution” – Solid ion conductors

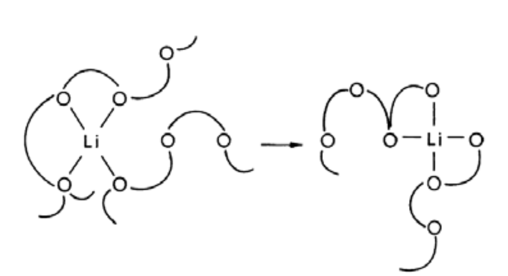
Liquid electrolyte



- State of the art
- High ionic conductivity (10^{-2}S/cm)
- Can tolerate volume changes
- Penetrates pores, good wetting
- Limited thermal stability
- Flammable
- Lithium metal anode:
  → Formation of dendrites
- Graphite anode – SEI formation:
  → Time consuming process in production
- Bipolar stacking difficult

http://ns.umich.edu/new/multimedia/videos/24295-a-window-into-battery-life-for-next-gen-lithium-cells

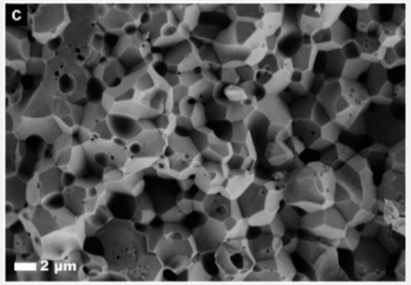
Polymer



- Most famous example: Polyethylene oxide
- Li^+ transport by movement of polymer chains
- Polymer chains become immobile below glass temperature
- Then: low conductivity
- Typically heating needed (e.g. 80°C)
- Good processability
- Limited suppression of lithium dendrites
- Up to 10^{-3} S/cm (polymer (60°C) or gel type (RT))

doi:10.1016/j.eurpolymj.2005.09.017

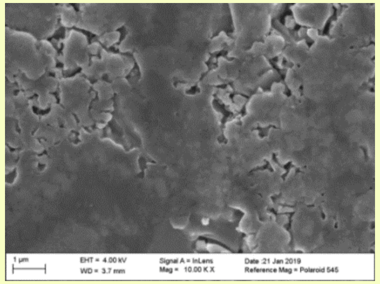
Oxide ceramics



- Up to 10^{-3} S/cm
- Critical: grain boundaries
- High process temperatures above 500°C needed
- Good electrochemical stability
- High mechanical strength

Al doped LLZO (garnet), Li 6.25 Al 0.25 La 3 Zr 2 O 12, sintered at 1070°C for 10h, doi: 10.1002/aenm.201600736

Sulfides



- Up to 10^{-2} S/cm
- Good processability due to high ductility
- Low grain boundary resistances even for processes with low temperature
- Printing possible
- Limited electrochemical stability
- Sensitive to moisture

Li_6PS_5Cl powder after pressing at 100°C for 45min

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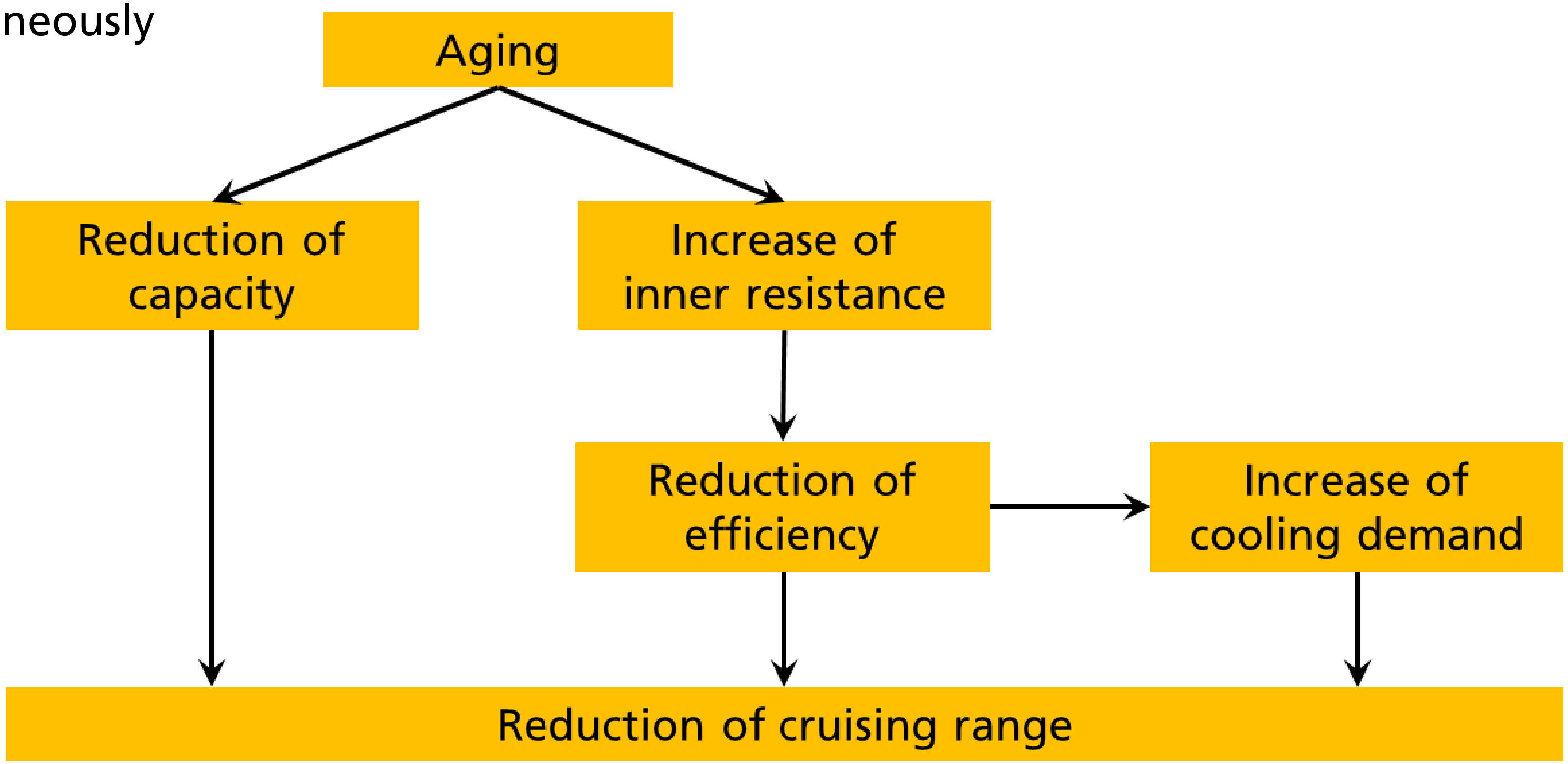
Battery life cycle
Influence of cell aging

Aged cells in battery electric vehicles
→ Several effects result in reduction of cruising range simultaneously



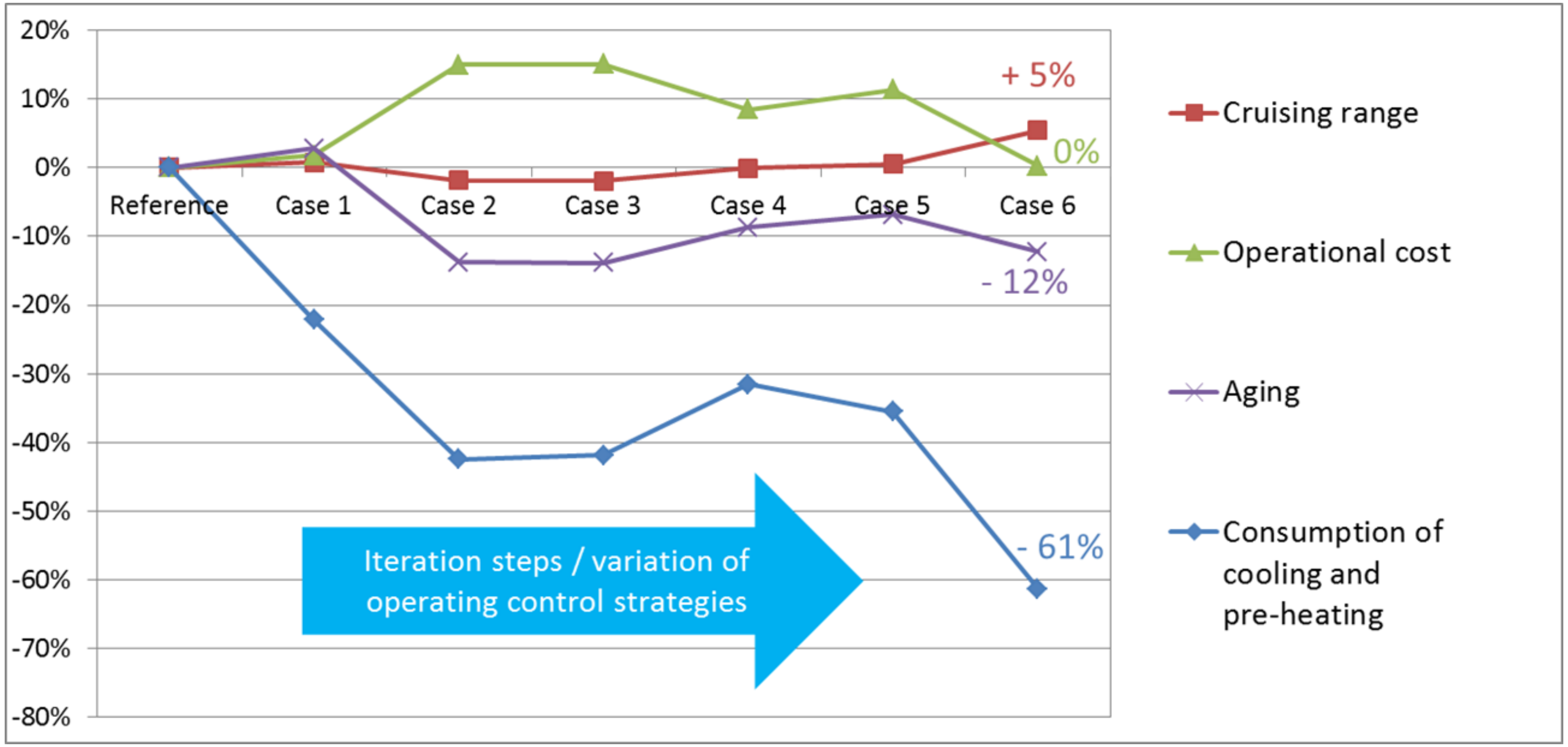
Battery life cycle

Prolonging useful life time via optimized control strategies in 1st life

Optimized thermal management for EV batteries

→ Decelerating aging mechanisms

→ Increasing cruising range



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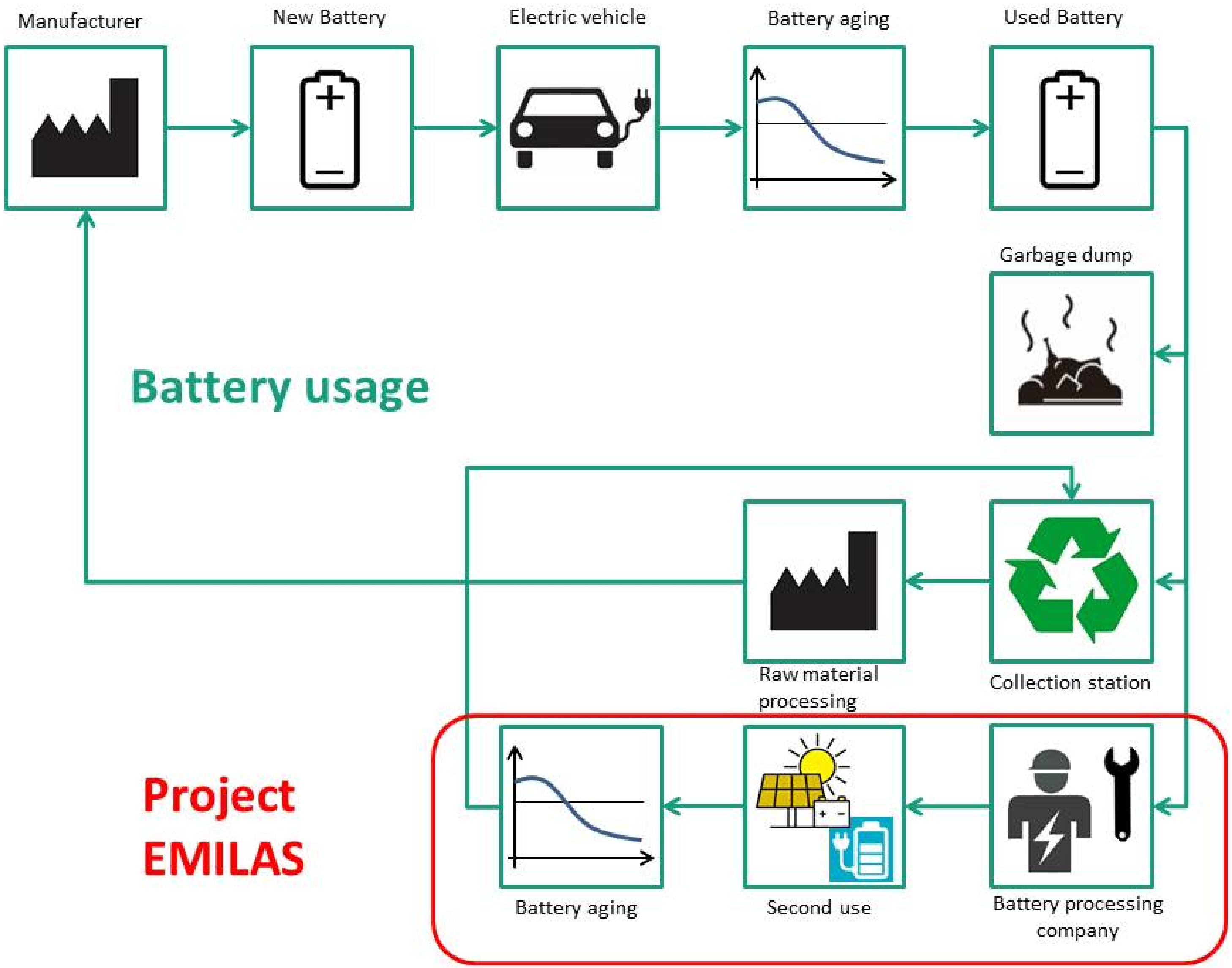
Battery life cycle
Prolonging useful life time via 2nd life applications

Project EMILAS:

- Electromobility in apartment buildings via smart charging stations with 2nd life battery storage
- Funded by the German Federal Ministry for Economic Affairs and Energy



Battery life cycle
Prolonging useful life time via 2nd life applications

Objectives of project EMILAS

- Use of 2nd life EV batteries as stationary buffer storage for building integrated charging stations
- Enabling of EV fast charging (!)
- Integration of 2nd life battery storage into building energy management system
- Coupling with building integrated PV: Increased self-sufficiency via buffer storage
- Integration of a local car sharing fleet with "bidirectional" EVs ("vehicle to building")
- Innovative business models

Funded by the German Federal Ministry for Economic Affairs and Energy

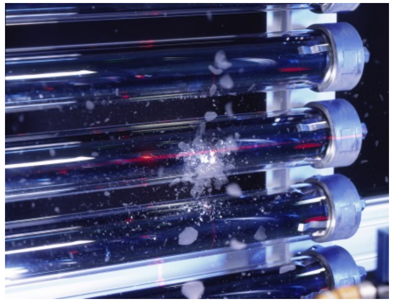
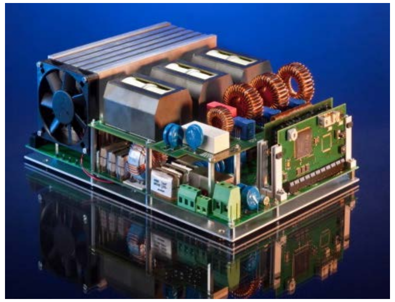
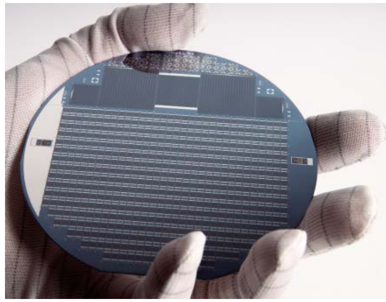
emilas VDE RENEWABLES dexer BECK AUTOMATION DSG ENERGIEKONZEPTE Fraunhofer ISE

Conclusions

- Electromobility towards mass markets
  - Accelerated development of advanced battery cell technologies
    - → Increasing energy densities for higher cruising ranges
    - → Reducing cost
    - → Increasing safety
  - Current decade will be dominated by lithium
    - → Lithium-ion evolution
    - → Solid state "revolution" (?)
- "CO2 backpack" of battery cell production has to be addressed
  - Prolonging useful life time via optimized control strategies in 1st life
  - Prolonging useful life time of EV batteries via 2nd life applications
- Charging at home has to be enabled also in apartment buildings
  - Use of decentralized (renewable) power generation capacities
  - Stationary buffer storage enables flexible charging of EVs

Thanks for your attention !!!

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