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HI MS HELMHOLTZ-INSTITUTE IONICS IN ENERGY STORAGE

meet

10th International AVL Exhaust Gas and Particulate Emissions Forum
Ludwigsburg, Germany, February, 20 – 21, 2018

Opportunities and Challenges for Electrochemical Energy Storage

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Acknowledgements

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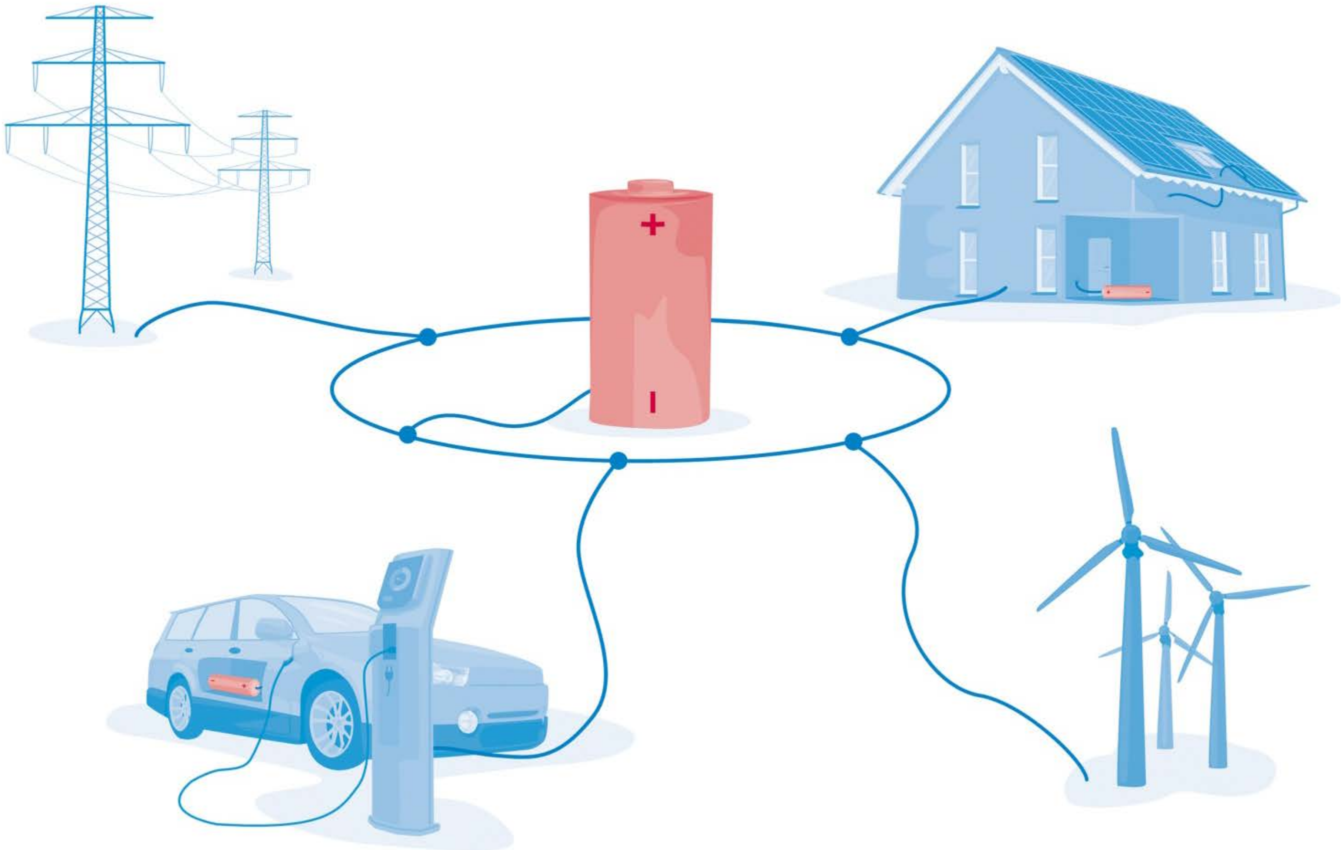
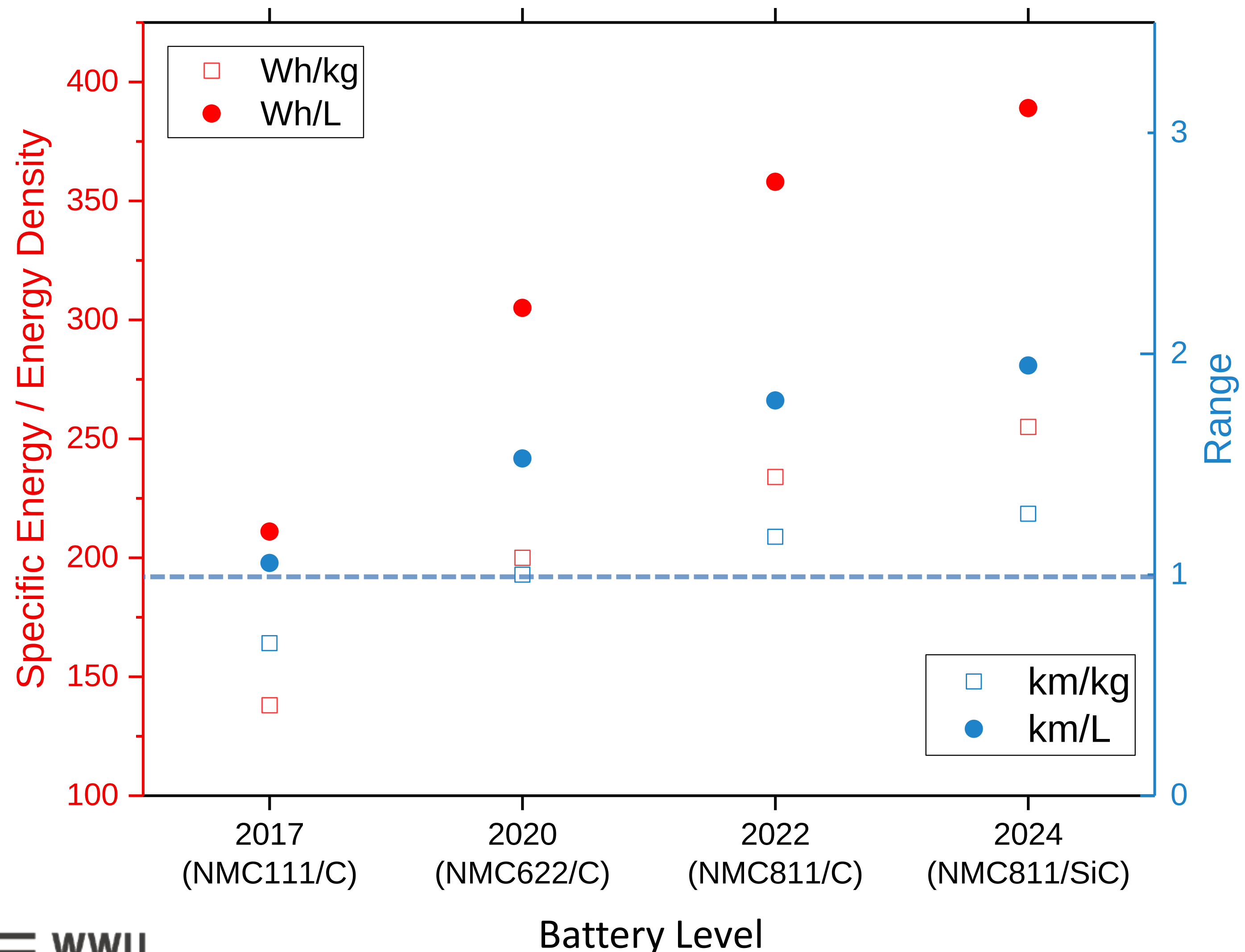
None of us is as smart as all of us

The Battery in the Center of the Future Energy Scenario



Normalized Driving Distances of Lithium Ion Battery Chemistries (Battery Level)



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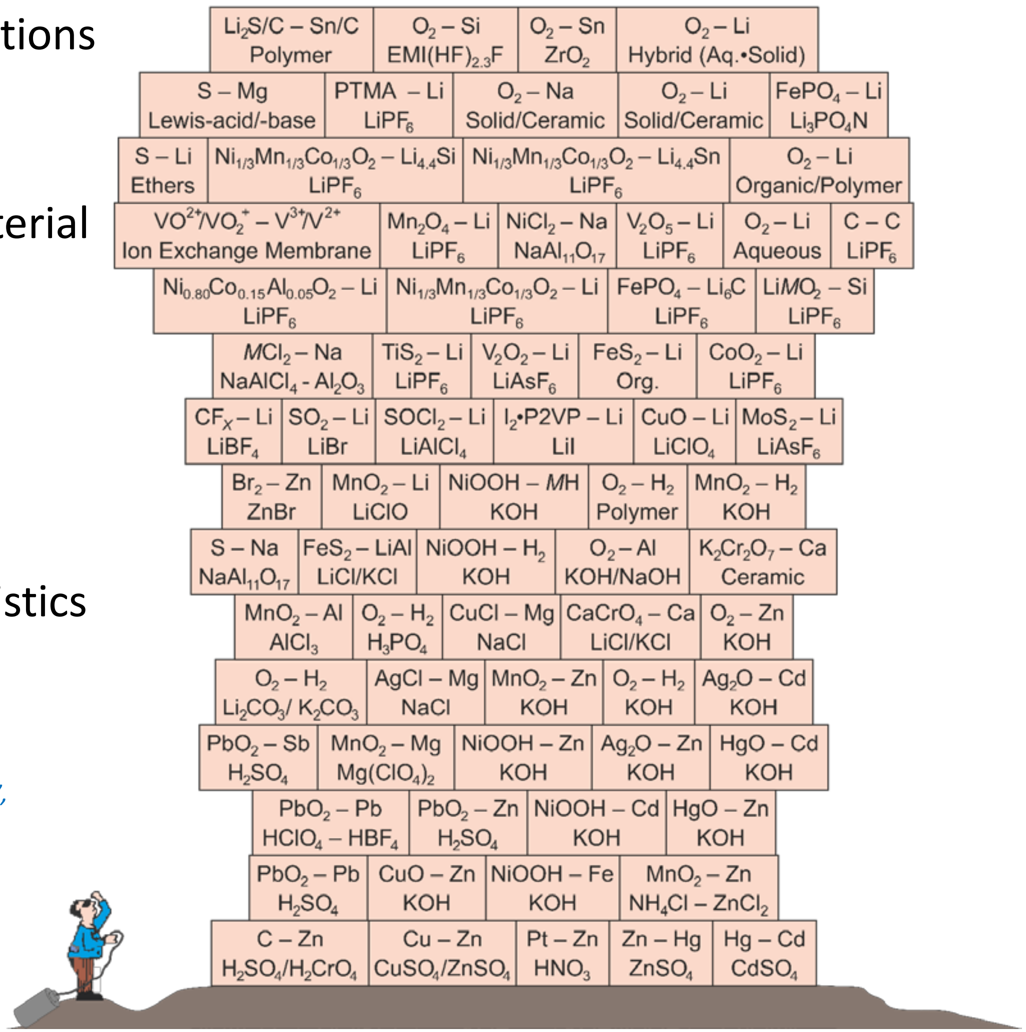
Numerous Material Combinations Possible

- Several hundred thousand combinations of electrode materials have been investigated
- Less than 50 of these electrode material combinations have been commercialized
- By variation of the electrolyte, even more cell chemistries are possible
- Different cell chemistries
  → different performance characteristics
  → different applications

The 'Tower of Babylon' of Cell Chemistries



M. Winter, "Li-Ion Batteries and Beyond", Industry Report 2017, http://totalbatteryconsulting.com/industry-reports/Li-Ion-and-beyond-report/

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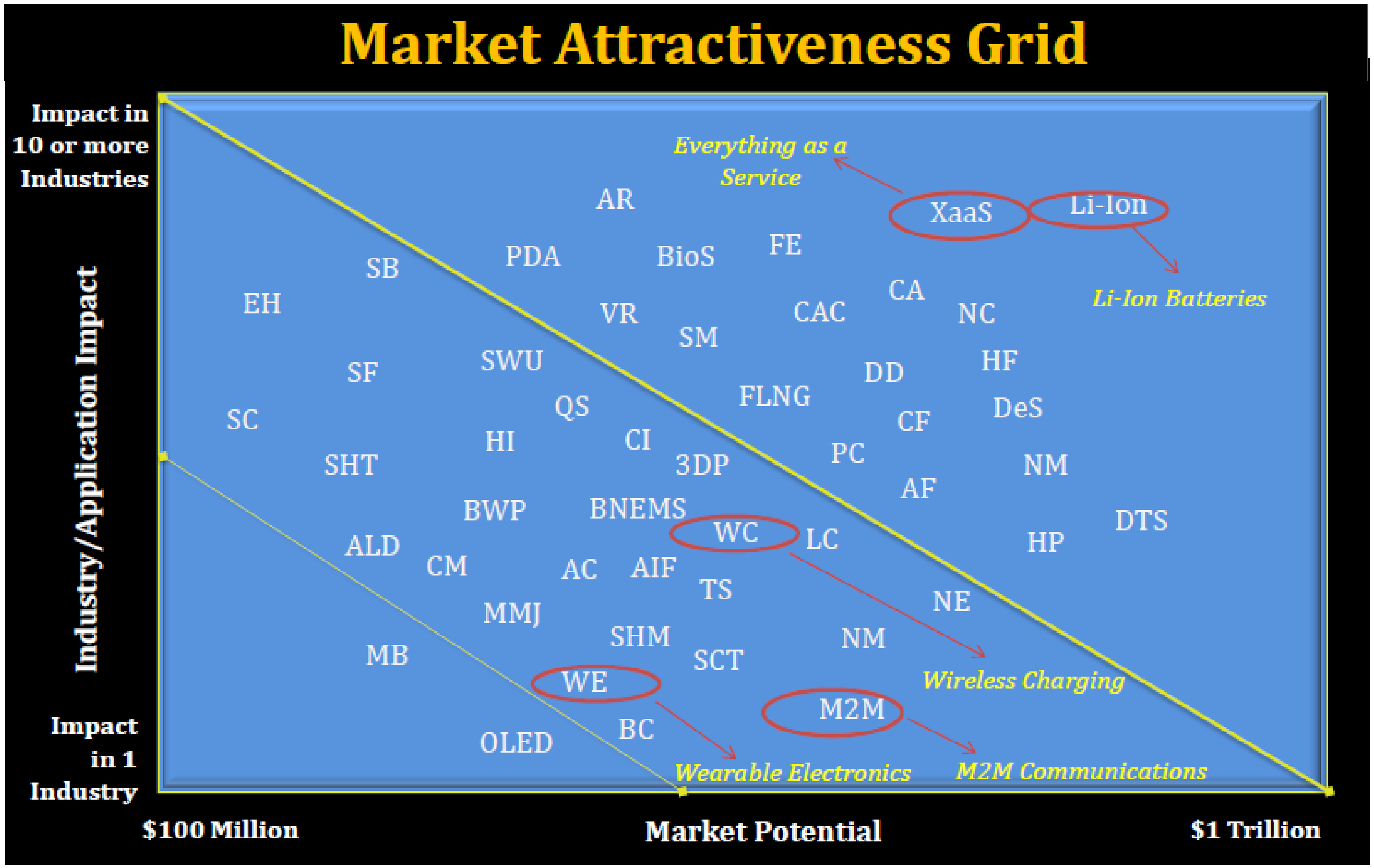
Among the 50 Most Disruptive Technologies Li-Ion Technology is Predicted to Have Highest Market Volume and Impact



Source: Frost and Sullivan, 2014, 'Fast-Forward to 2020: New Trends Transforming the World as We Know It'

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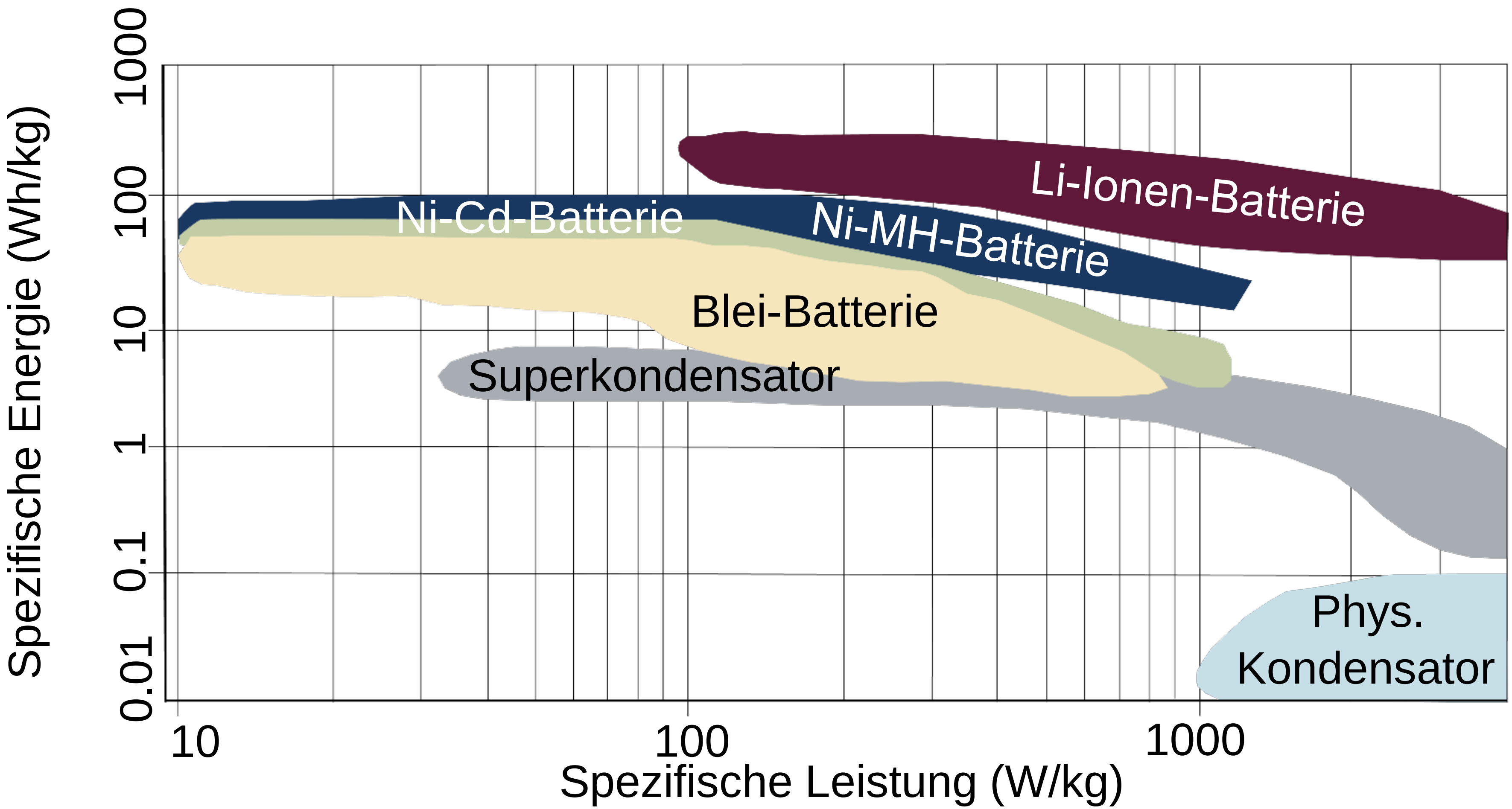
The Lithium-Ion Advantage Compared to Conventional Batteries: High Energy and High Power are Possible



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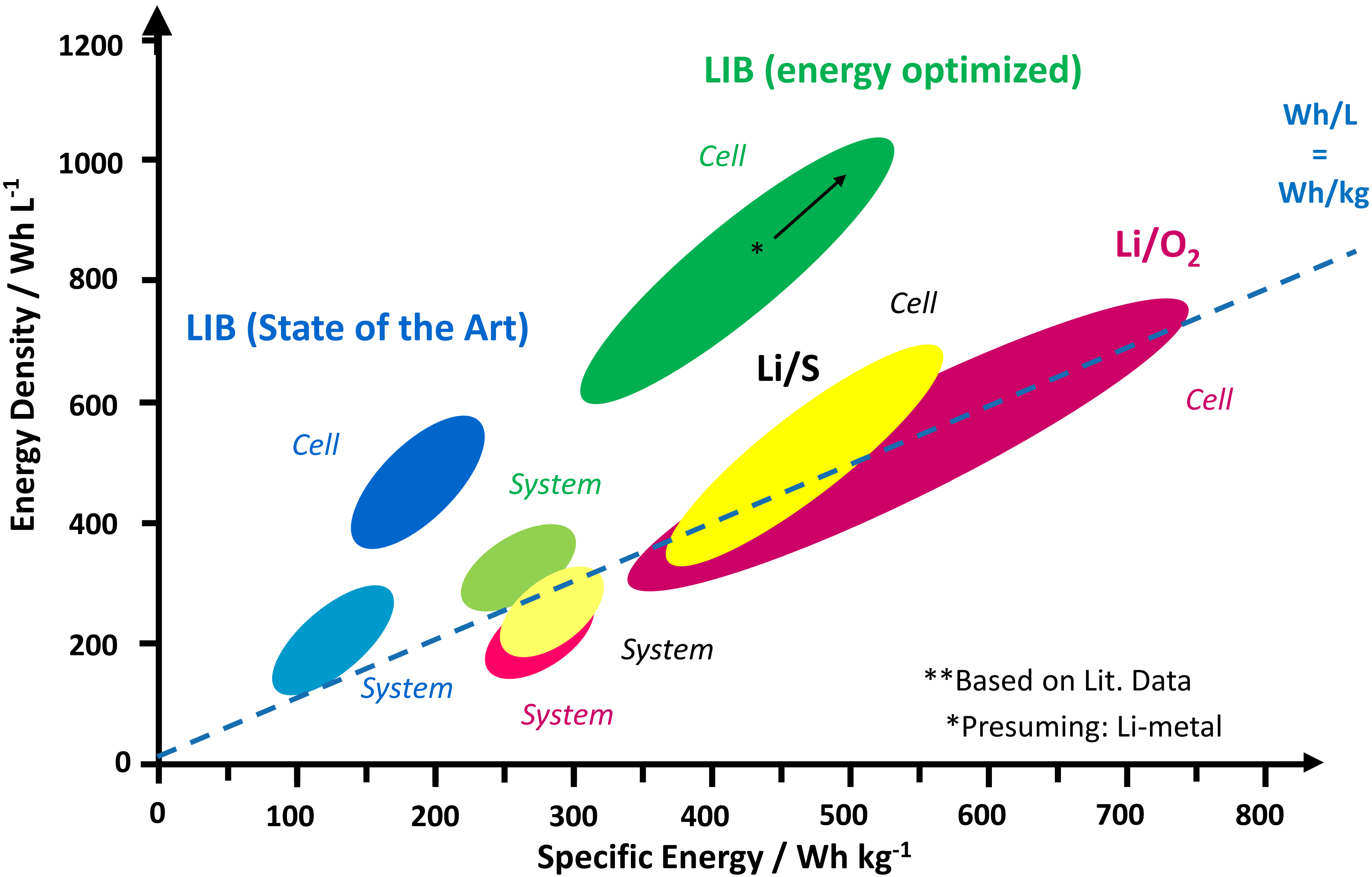
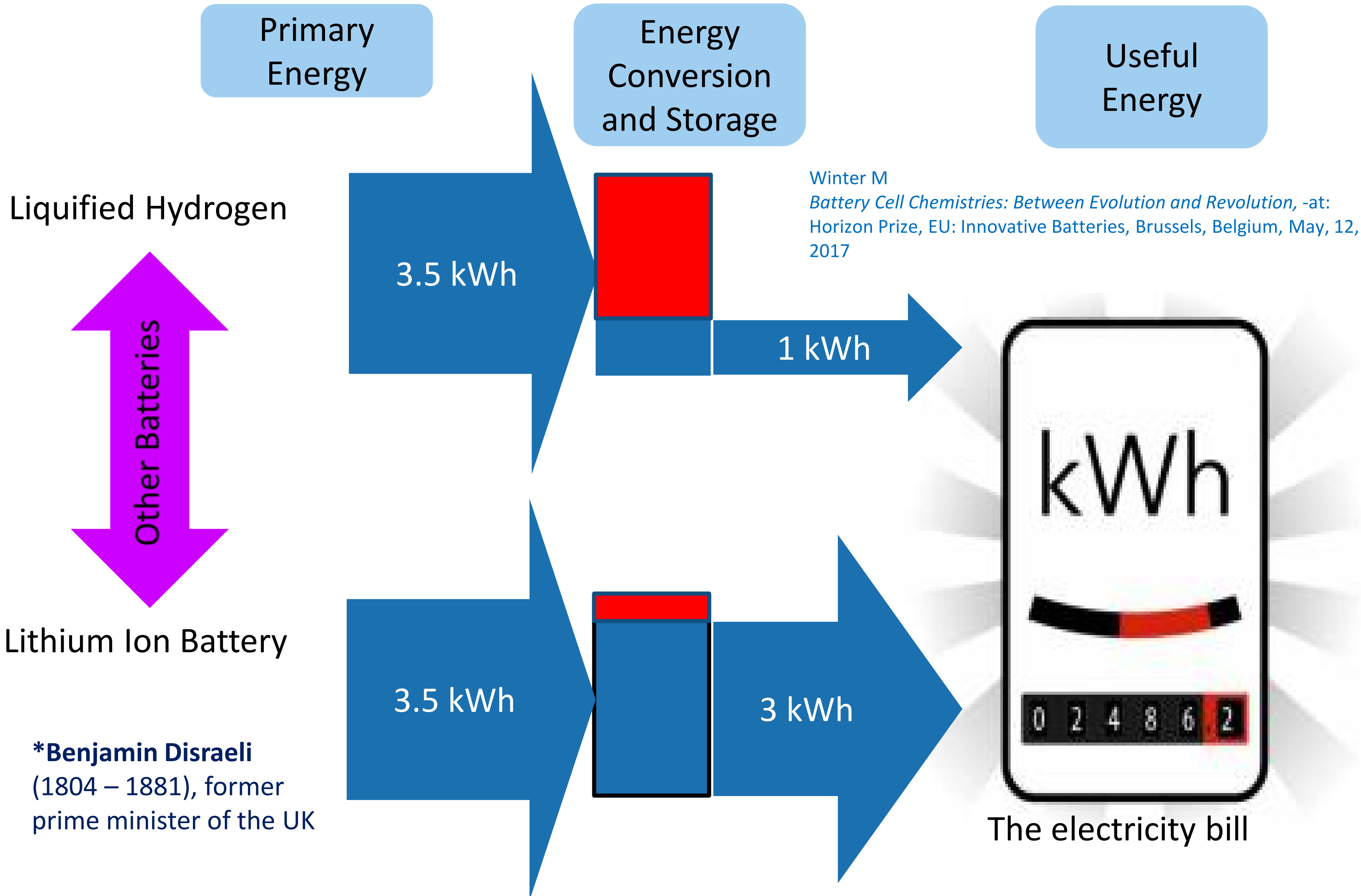
The Lithium Ion Advantage: High Energy Density per Volume in Comparison to Eventual Future Electrochemical Energy Storage Systems**



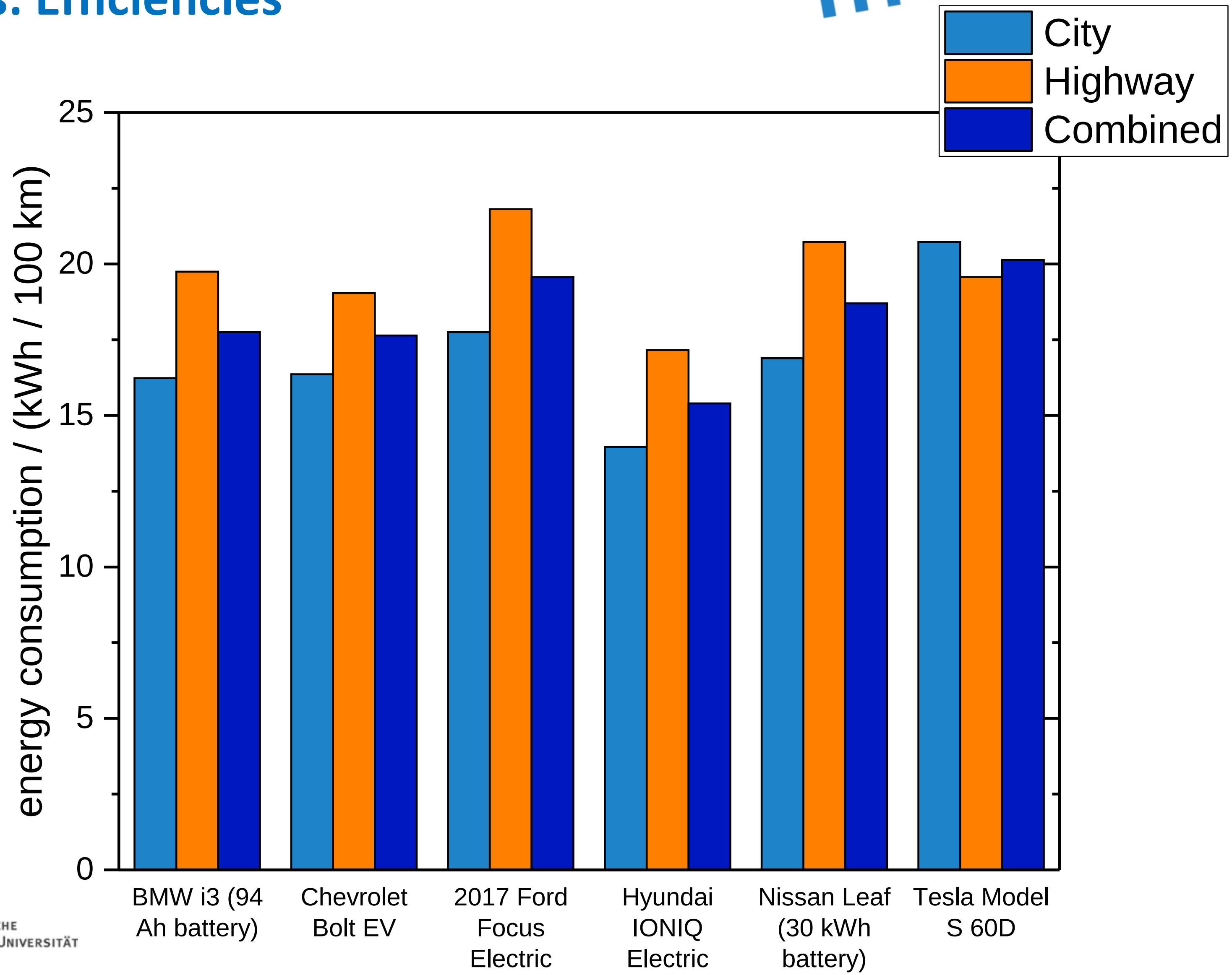
*“There can be economy only, where there is efficiency.”**



Winter M
Battery Cell Chemistries: Between Evolution and Revolution, -at: Horizon Prize, EU: Innovative Batteries, Brussels, Belgium, May, 12, 2017

***Benjamin Disraeli**
(1804 – 1881), former prime minister of the UK

Electric Cars: Efficiencies



http://pushevs.com/2016/11/23/electric-cars-range-efficiency-comparison/

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Can One type of Battery Fulfil All Requirements? “Die eierlegende Wollmilchsau“ ?

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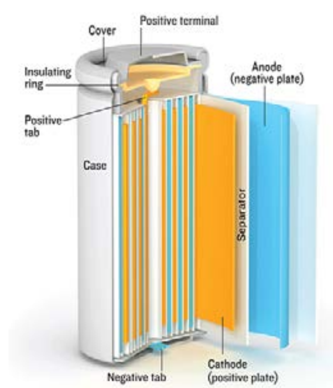
The Lithium-Ion Battery

External Appearance

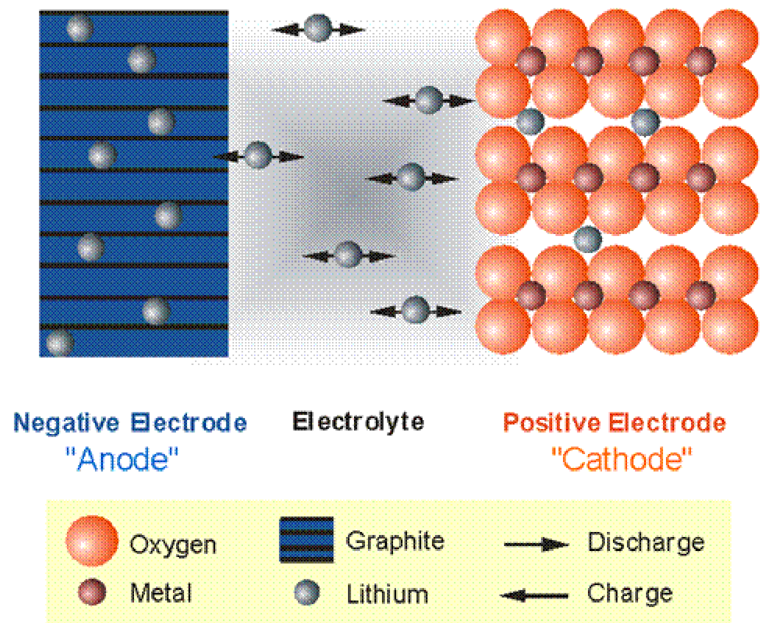
Chemistry & Physics
Materials Science
Electrochemistry
Thin-Film-Technology
Nano-Technology



Internal Design

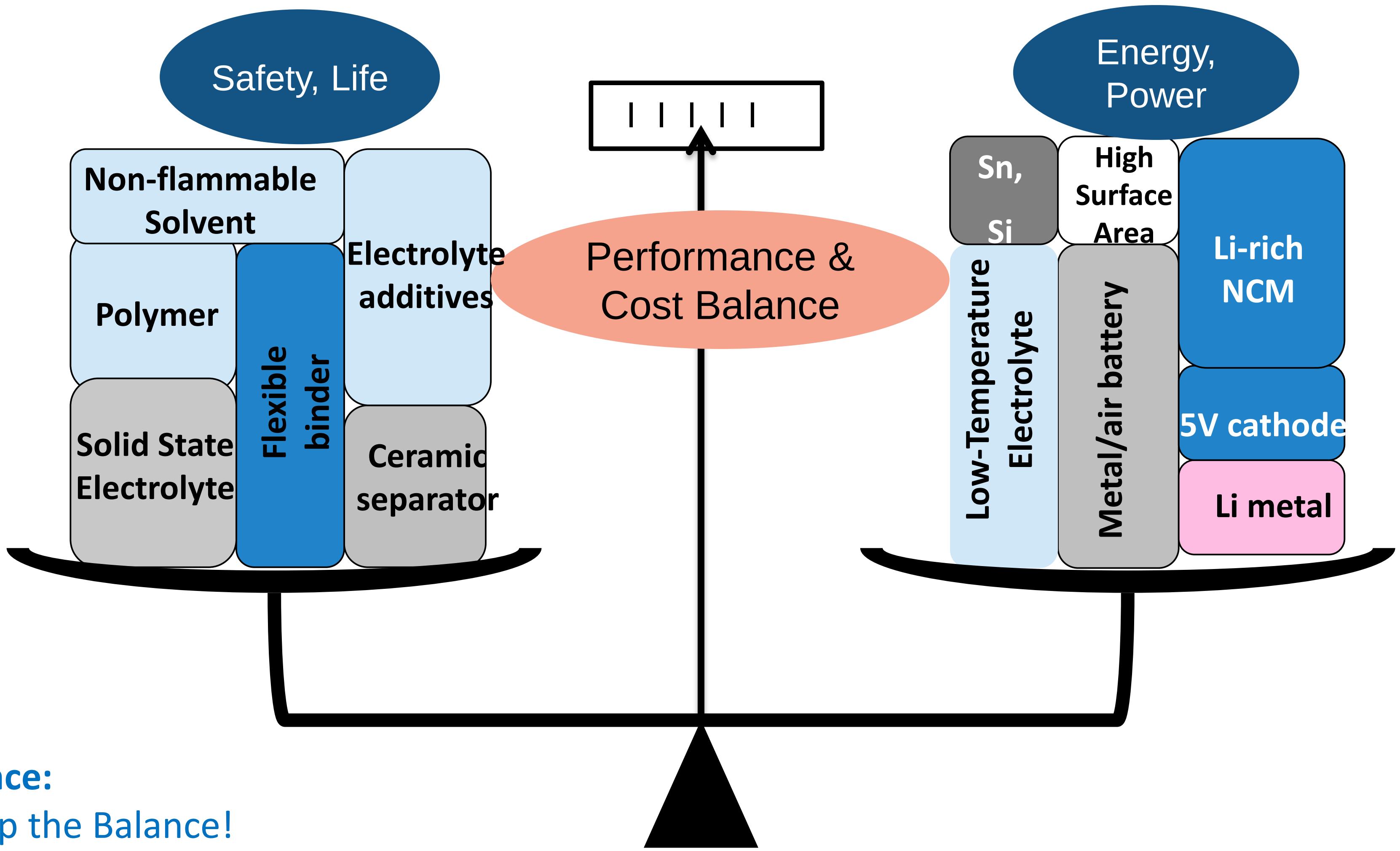
Internal Chemistry

$$Li_xC_n \underset{C}{\overset{D}{\rightleftarrows}} C_n + xLi^+ + xe^- \qquad Li_{1-x}MO_2 + xe^- + xLi^+ \underset{C}{\overset{D}{\rightleftarrows}} LiMO_2$$



Huge variety of materials
⇒ Evolutionary technology progress by "Drop-in-Approach"
⇒ "Roadmap → generations"

No Independent Optimization of Parameters

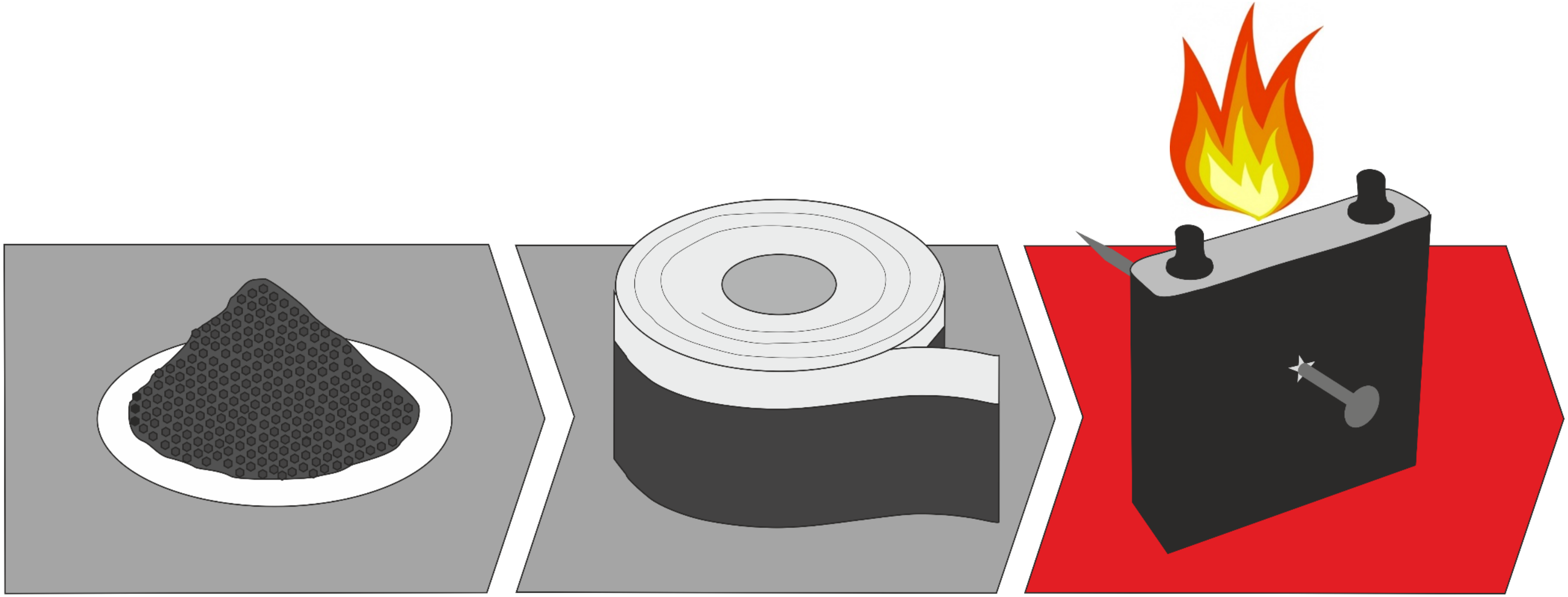


Hence:

Keep the Balance!

Follow a System Approach!

Cell Safety



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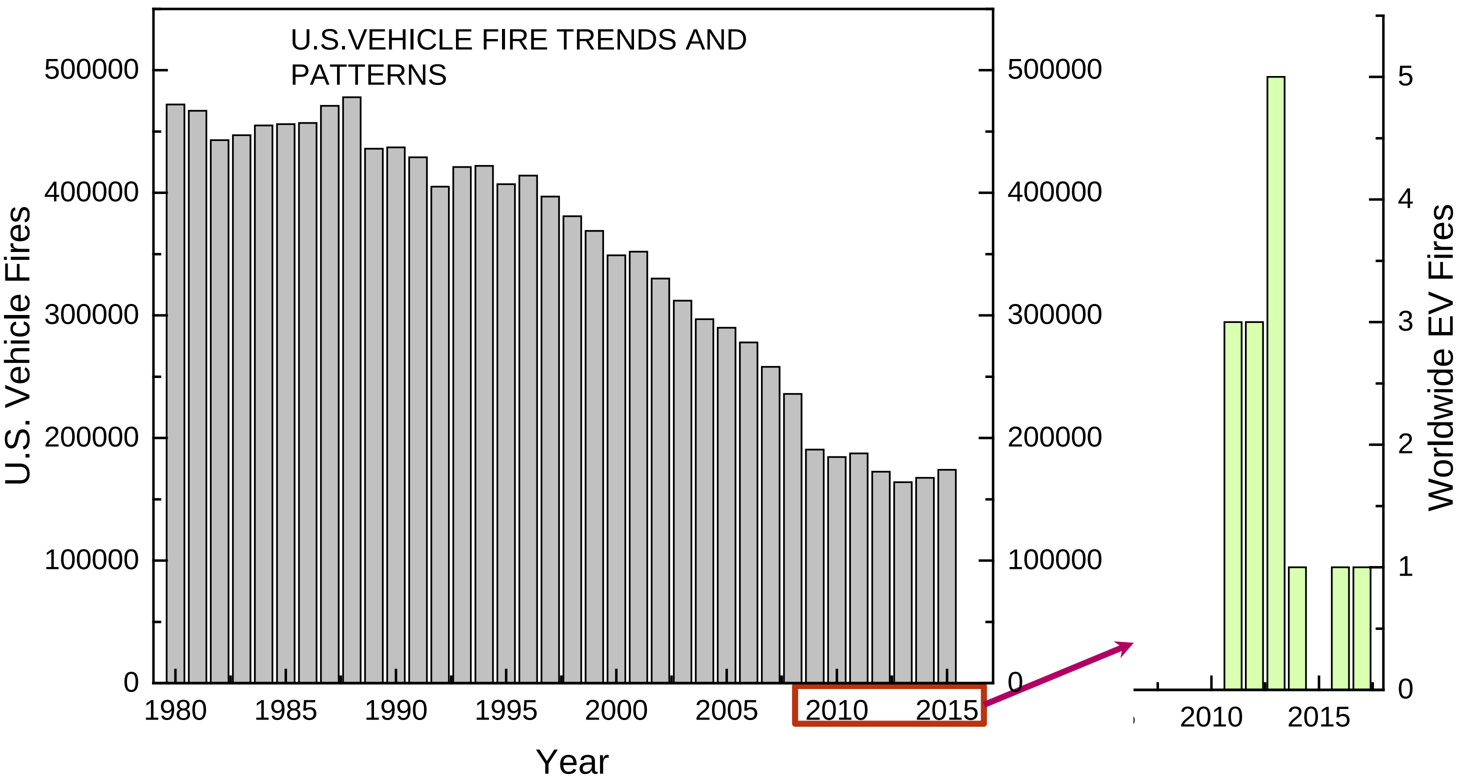
Fire Incidents with ICE und EV: Too Early to Make a Conclusion



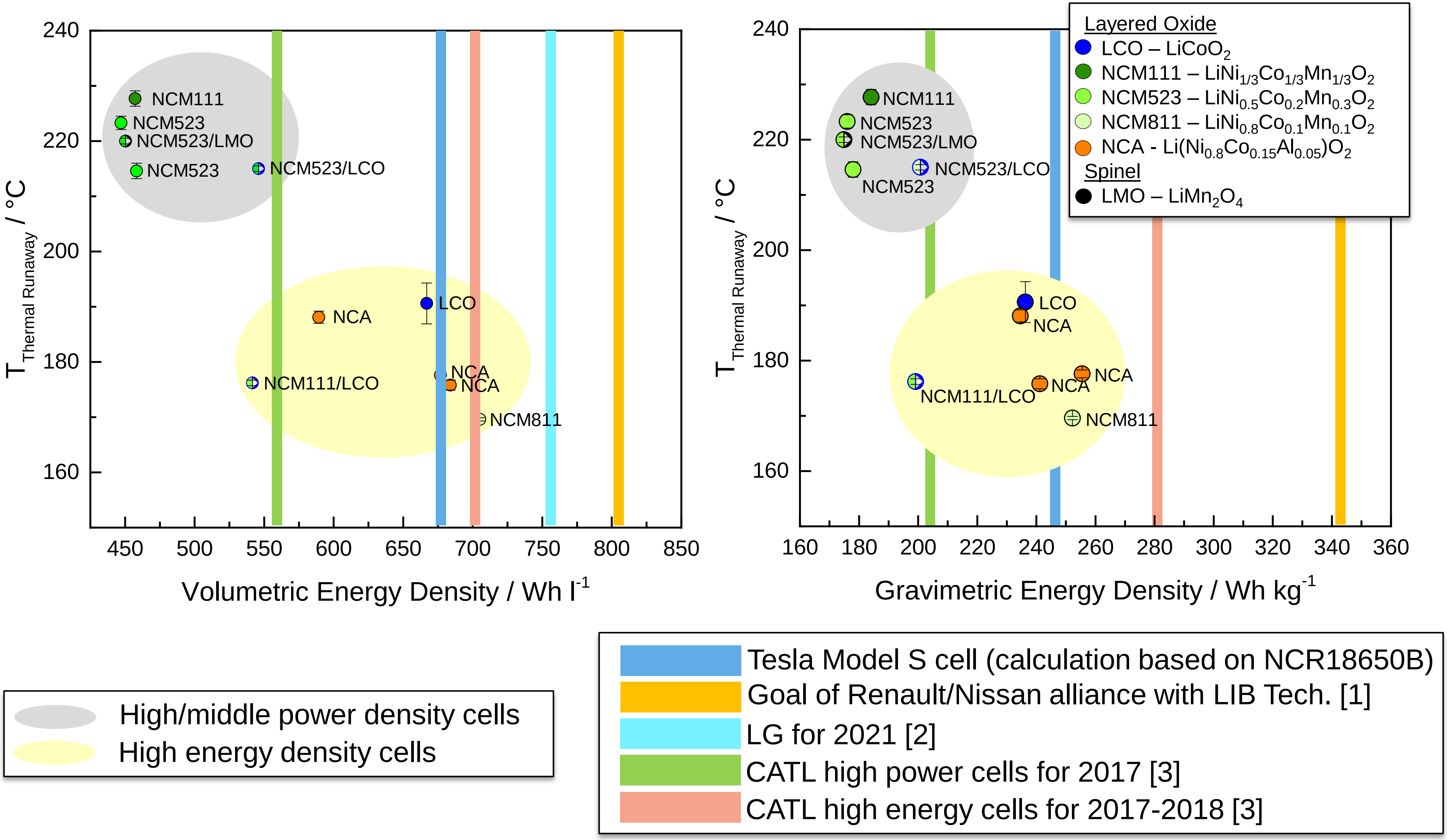
6x Tesla Model S
2x Chevrolet Volt
2x Fisker Karma
1x Zotye
1x BYD e6
2x Mitsubishi

- 90 vehicle fires per billion miles of ICE (only US data)
- 12 Total Fire Incidents with EV (Worldwide)
- 6 Tesla fires (total) and 3 billion miles driven

  → 2 Tesla fires per billion miles

http://insideevs.com/number-of-fire-related-deaths-per-year-caused-by-evs/

Cell Safety of 18650 Cells (ARC-HWS Tests)



[1] ZOE Battery Durability, Field Experience and Future Vision, AABC 2017, Mainz, Germany, [2] Advances in High-Energy Density Lithium-ion Polymer Battery for EV, AABC 2016, Mainz, Germany [3] Advanced xEV Battery Development at CATL, AABC 2017, Mainz, Germany

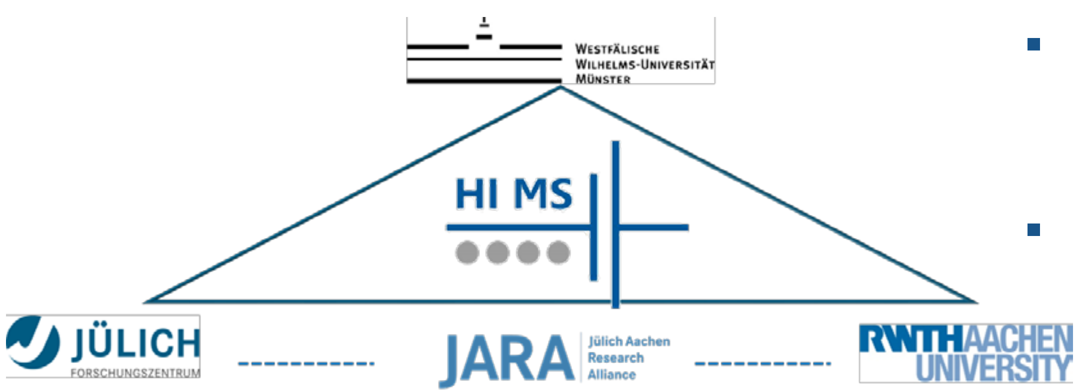
Helmholtz Institute Münster (HI MS): Better Electrolytes Will Enable Better Batteries

The electrolyte as “lifeblood“ of the battery cell

Example: Liquid electrolyte lithium battery

- Electrolyte is a system component in the center of the cell
- Electrolytes are decisive for lifetime, power and safety of the battery
- Electrolytes have a direct and indirect influence on the costs of batteries

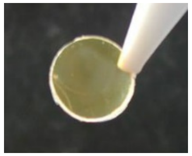
HI MS – Pool Competencies → Synergy



- >25 years of Battery Experience
- Long lasting tradition of co-operation between the 3 partners, also beyond electrolyte research
- Large infrastructure at all 3 sites

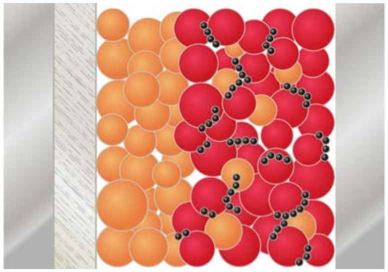
Why Solid Electrolytes (SE)?

- **Safety**
  - Non-flammability of ceramic compounds (!) and polymers (?)
  - Free of liquid → No leakage
  - High temperature stability



- **Energy Density (Wh/L) and Specific Energy (Wh/kg) *Via* New Materials**
  - In particular with materials that show incompatibility with liquid electrolytes
- **Power**
  - Fast charging ability, also at low temperatures
  - Room temperature single ion conductor; t_{Li+}~1
- **Cell and Battery System Design**
  - Bipolar-design of battery
  - Less system components, as the SE stability is not sensitive to temperature

Why Solid Electrolytes (SE) Not in Rechargeable Batteries Right, So Far?



➢ Chemical and Electrochemical Reactivity

- ➢ Reactivity with air and moisture
- ➢ Reactivity at interfaces

➢ Cell and Electrode Design

- ➢ Mutual integration of electrode and SE
- ➢ Fixation of interfaces between electrode and SE
- ➢ Minimization of SE thickness and amount

➢ Manufacturing of All-Solid-State-Batteries (ASSB)

- ➢ Homogeneous particle distribution
- ➢ Fixation of interfaces through high-temperature treatment and external pressure
- ➢ High speed manufacturing (Roll-to-Roll R2R)?

➢ Experience with ASSB Cell Performance

- ➢ There is no benchmark system

Liquid vs. Solid Electrolyte (SE): LIB with Graphite / NMC Electrodes

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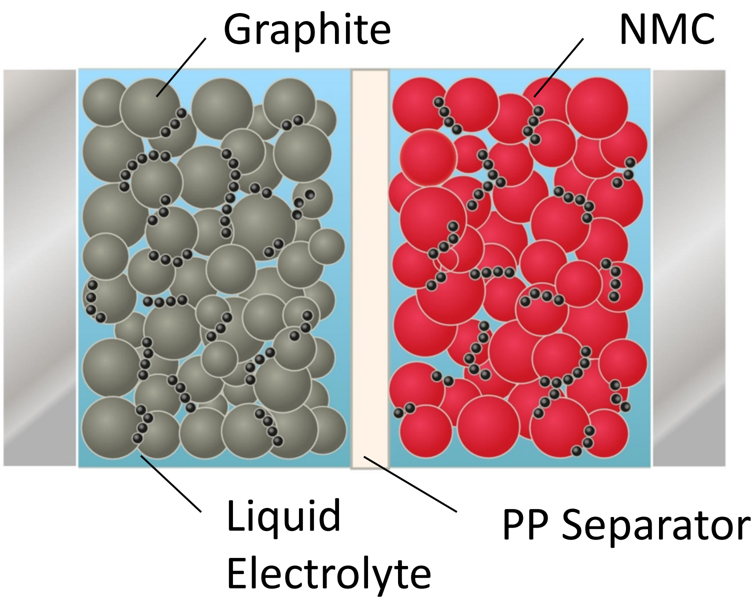

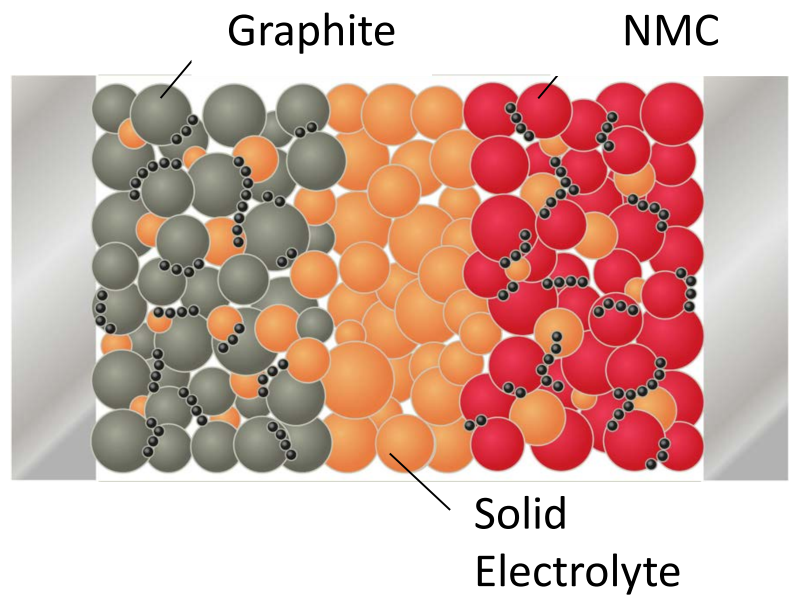

- Specific Energy ~**295 Wh/kg**
  - with d_{NMC}=100µm; d_C=120µm; d_{PP}=20µm
  - 30% electrode porosity

- Specific Energy ~**278 Wh/kg**
  - with d_{NMC}=100µm; d_C=120µm; d_{LPS}=20µm
  - 30 vol-% SE-content

-10% in Specific Energy

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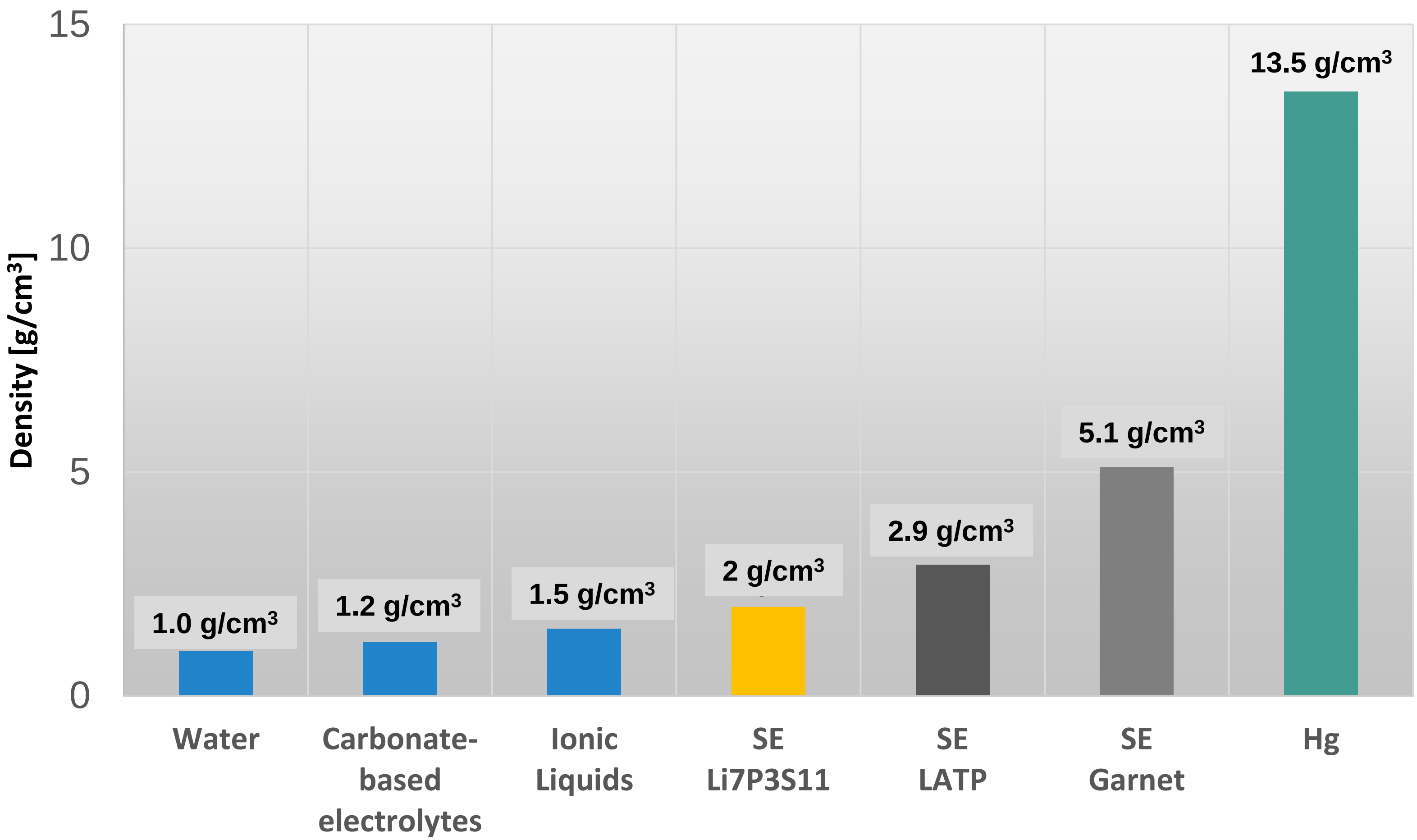
Comparison of Densities



SE: Solid Electrolyte
LATP: $Li_{1.5}Al_{0.5}Ti_{1.5}(PO_4)_3$
Granat: $Li_7La_3Zr_2O_{12}$

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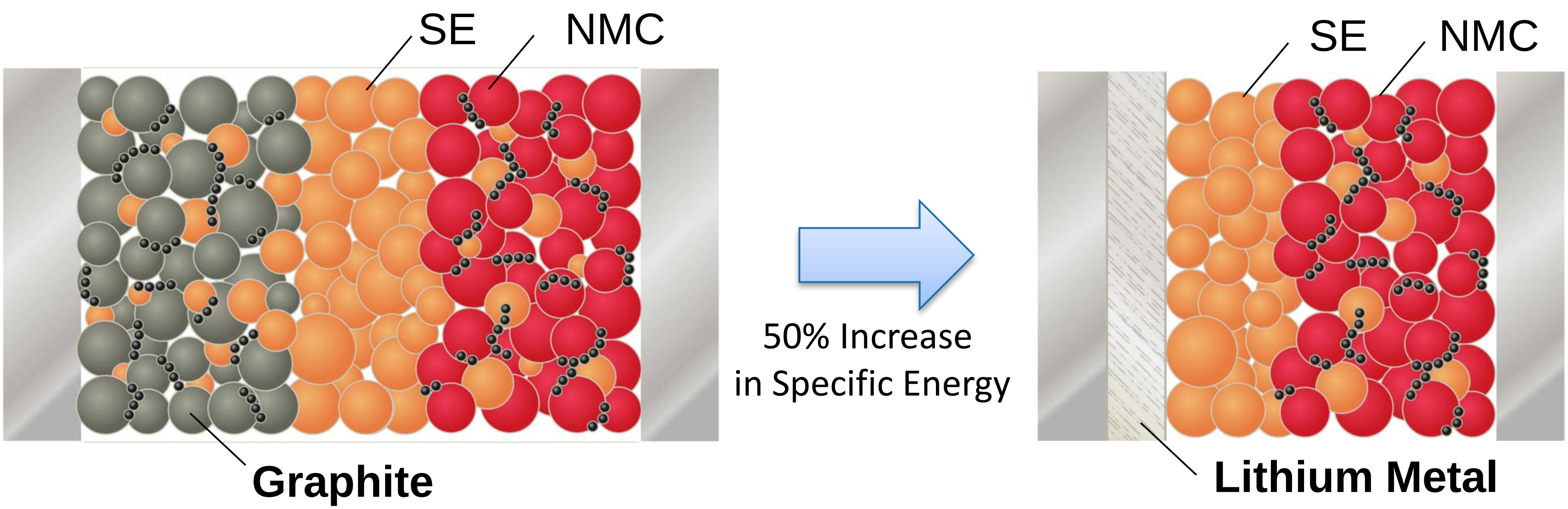
Solid Electrolytes:
From Graphite to Lithium Metal Anodes



- Specific Energy ~**278 Wh/kg**
  - with d_{NMC}=100µm; d_C=120µm; d_{LPS}=20µm
  - 30% SE content

- Specific Energy ~**426 Wh/kg**
  - with d_{NMC}=100µm; d_{Li}=30µm; d_{LPS}=20µm
  - 30% SE content

Impact on Energy Density (Wh/L)
can be expected, too!

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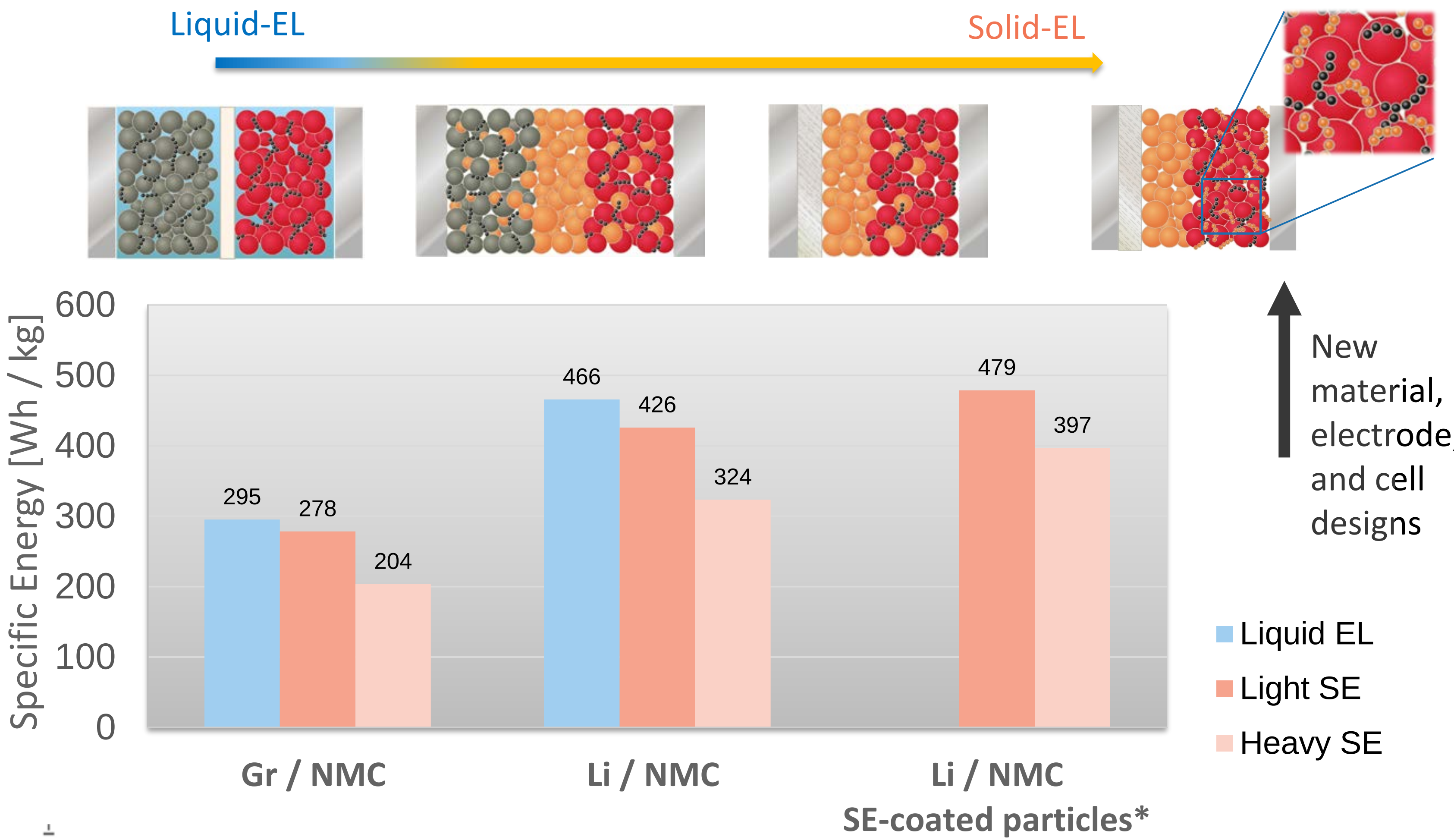
From Liquid to Solid Electrolytes: Possible Development



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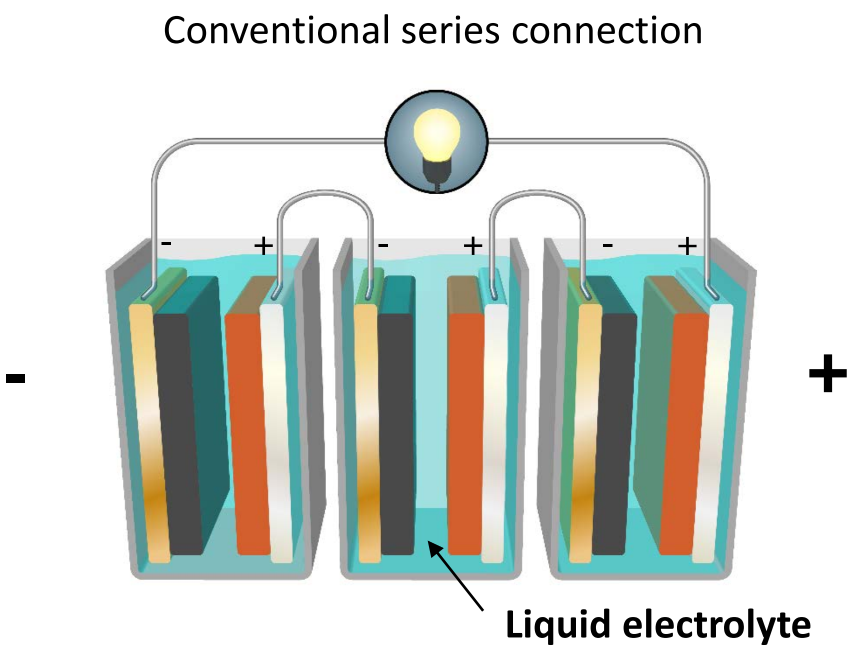
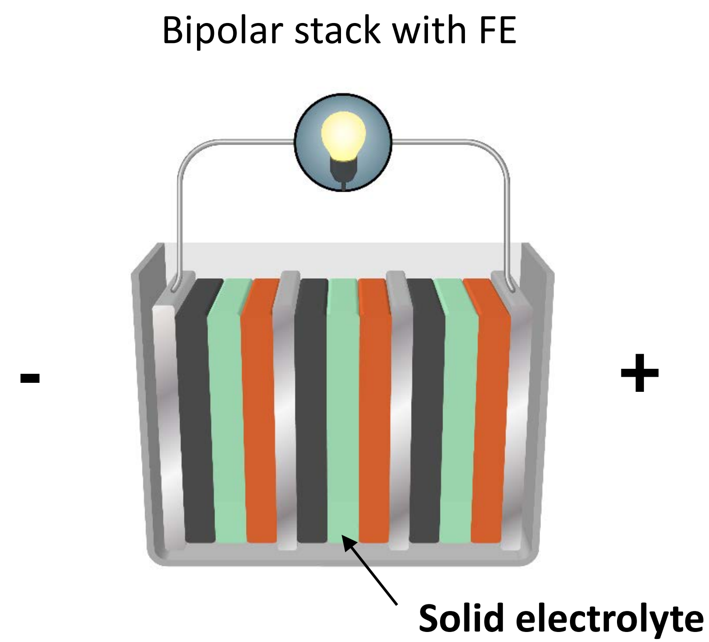
with d_{NMC}=100 µm; d_{Sep}=20 µm; 30% porosity or SE-content
*assumption: FE-content in cathode 15 vol.%

Battery System Design:
Conventional vs. Bipolar Architecture





- SE-based LIB- and Li-metal cells with identical cell volume and design have lower specific energies (Wh/kg) than cells based on liquid electrolyte
- An SE enabling Rechargeable Li metal will lead to high specific energy
- A gain in specific energy of LIB-ASSBs might be possible on system level

Solid Electrolyte (SE) is of Interest but SE is a Component, <u>Not</u> a Cell Chemistry

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- Recent enhancements in SE Li conductivity at room temperature have stimulated a renewed interest in their use for Li-based batteries
- Less interest in using SE in lithium ion batteries
  - While safety could improve, cell cost and weight will rise and manufacturability and cycle life are challenging
- SE can be an enabler for Li-metal-based cells (and other new cell chemistries?)
- Stability, conductivity, manufacturability, and cost are all still TBD and challenging
- Reliable SE source has to be established
- Sulfide-based SE show lower density than oxide-based SE
  → better specific energy, but handling is an issue


aabc Conference Calendar
8th INTERNATIONAL
aabc europe advanced automotive battery conference
29 January - 1 February 2018 • Mainz, Germany
AdvancedAutoBat.com/Europe
18th INTERNATIONAL
aabc advanced automotive battery conference
June 4 - 7, 2018 • San Diego, CA
AdvancedAutoBat.com/US
2nd INTERNATIONAL
aabc ASIA advanced automotive battery conference
October 16 - 18 2018 • Osaka, Japan
AdvancedAutoBat.com/Asia
9th INTERNATIONAL
aabc europe advanced automotive battery conference
28 - 31 January 2019 • Strasbourg, France
AdvancedAutoBat.com/Europe

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Battery Conference in Münster

- Dr. Ulrich Ehmes, TerraE Holding GmbH
- Mark Lu, ITRI
- Dr. Christophe Pillot, Avicenne
- Dr. Venkat Srinivasan, Argonne National Lab
- Dr. Andreas Wendt, BMW Group
- Prof. Stanley Whittingham, Binghamton Univ.

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