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HI MS Helmholtz-Institute Ionics in Energy Storage

meet

Famous quote about safety:
“It will never happen to me”
Captain E.J. Smith (1850 – 1912), Captain of the Titanic

Acknowledgements

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Federal Ministry of Economics and Technology (BMWi)
Federal Ministry for the Environment, Nature Conservation & Nuclear Safety (BMU)
Federal Ministry of Education and Research (BMBF)
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Bundesministerium für Bildung und Forschung

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81. Annual Meeting of DPG and Spring Meeting, Münster, 27 - 31 March 2017

Energy Density, Lifetime and Safety – Not Only an Issue of Lithium Ion Batteries

A. Friesen[#], Falko Schappacher[#] and Martin Winter[#][x]

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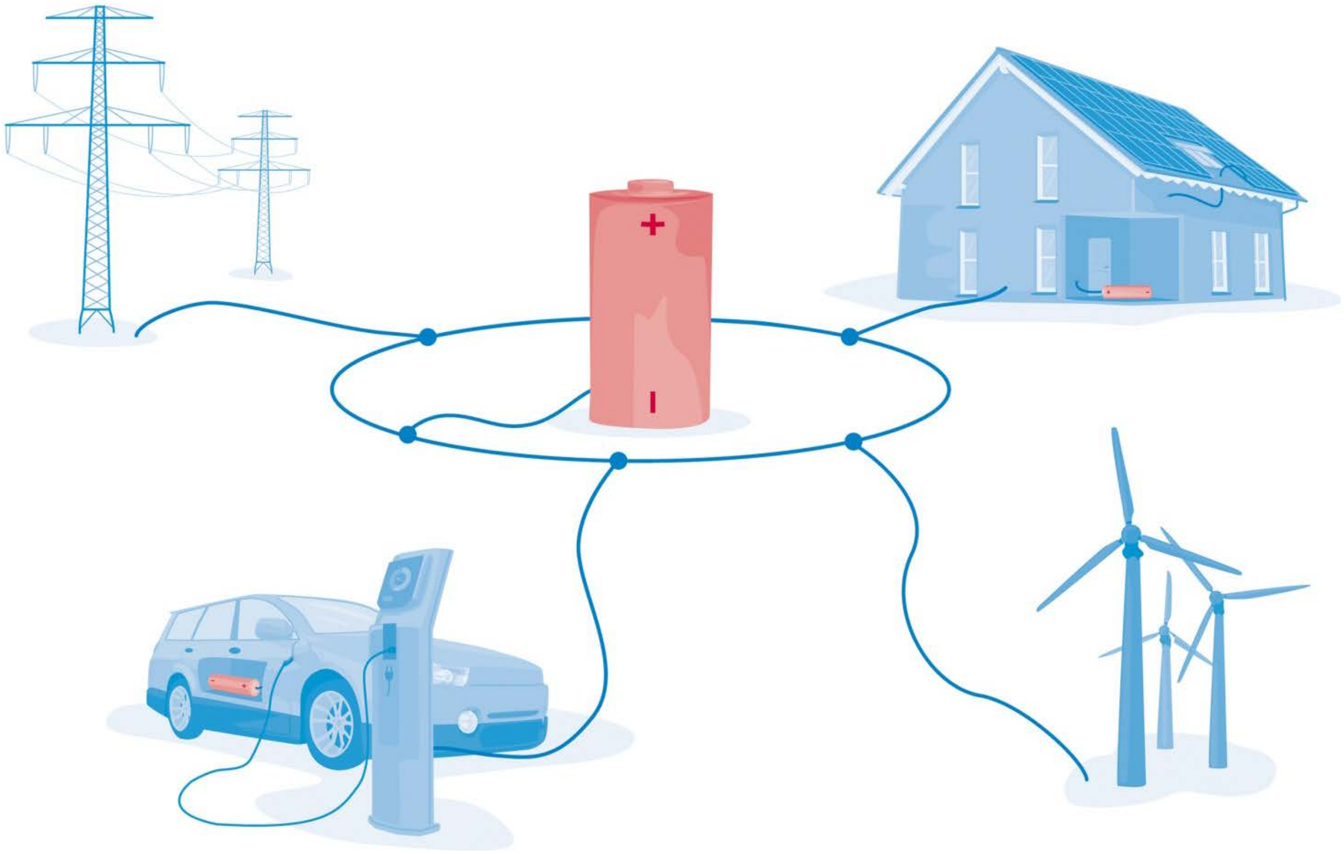
Batteries in the Center of a Sustainable Energy Scenario



The Lithium Ion Advantage: High Energy and/or High Power Densities in Comparison to “Conventional” Energy Storage Systems

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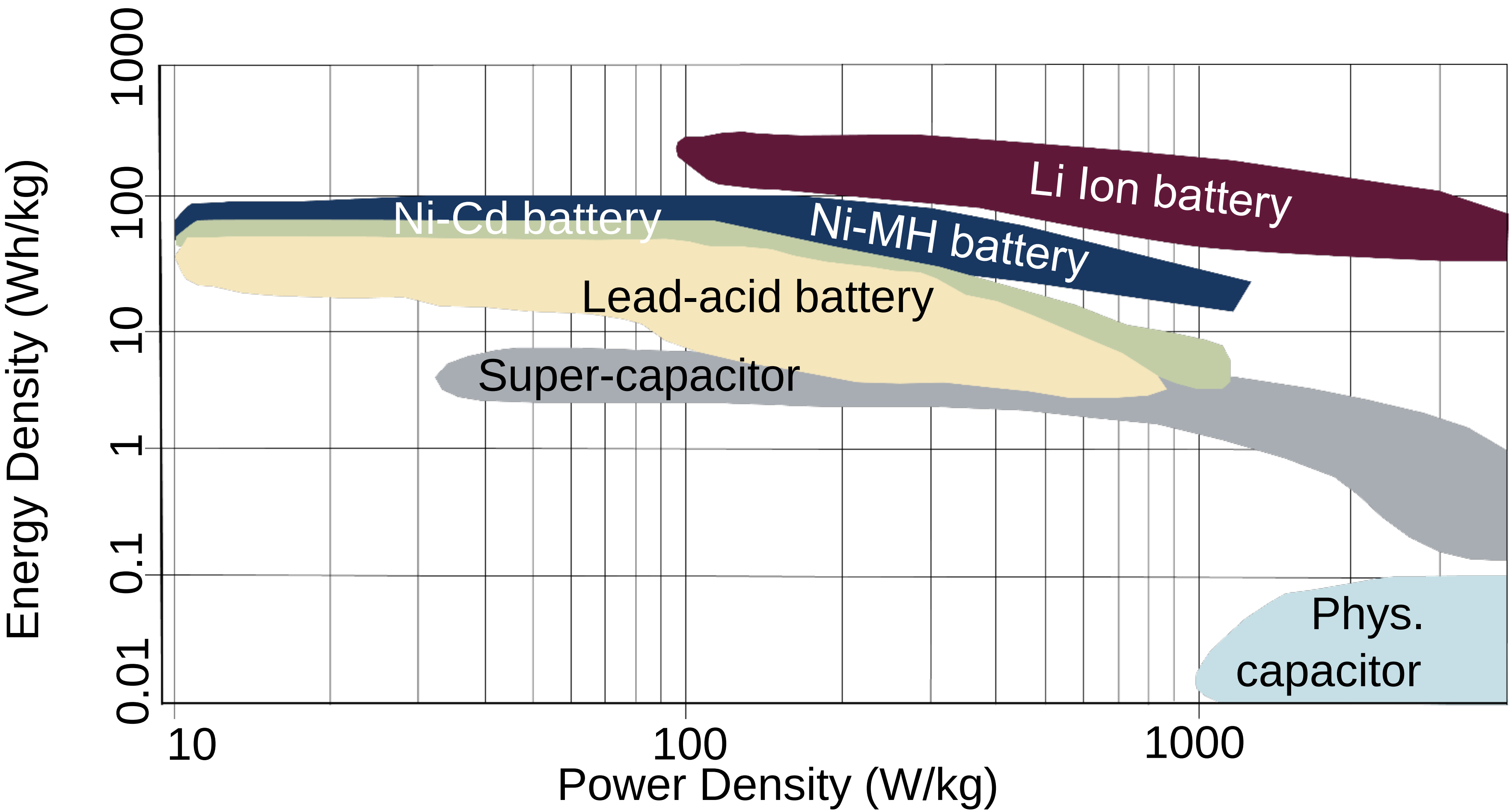

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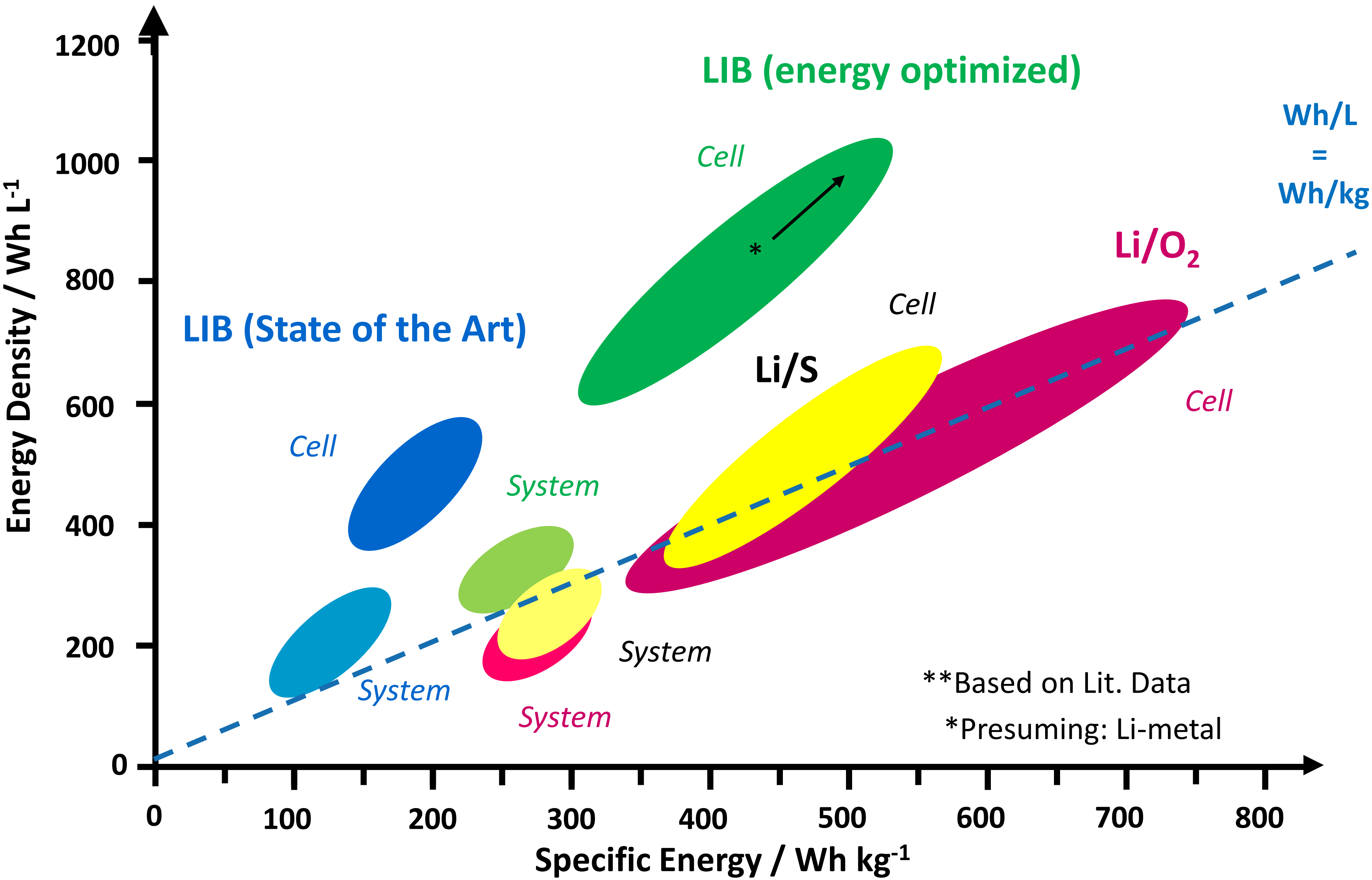
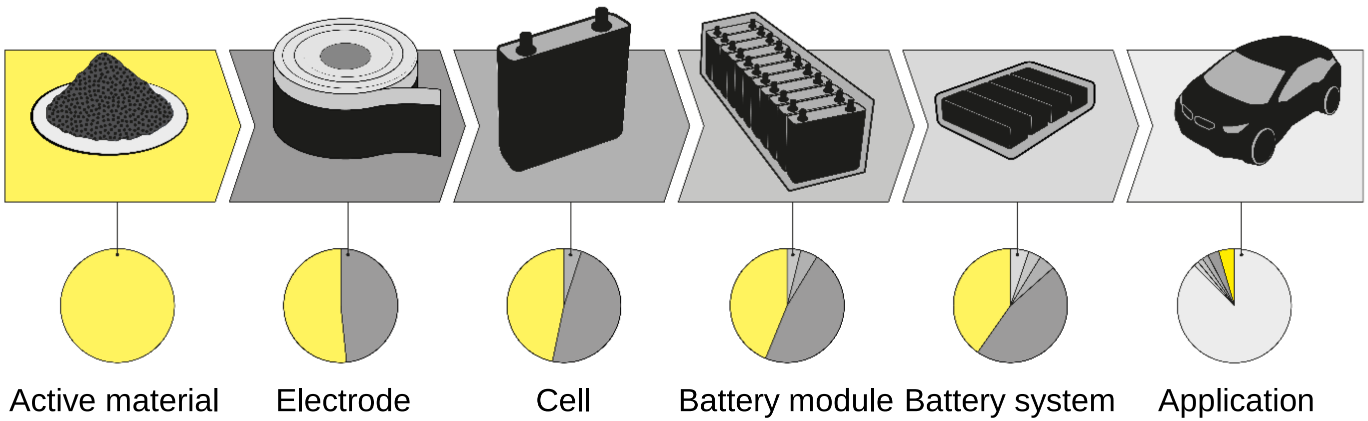
The Lithium Ion Advantage: High Energy Density per Volume in Comparison to Eventual Future Electrochemical Energy Storage Systems**



Active and Inactive Materials: From Material Level to Battery Level



Increasing amount of inactive components → Decreasing energy density

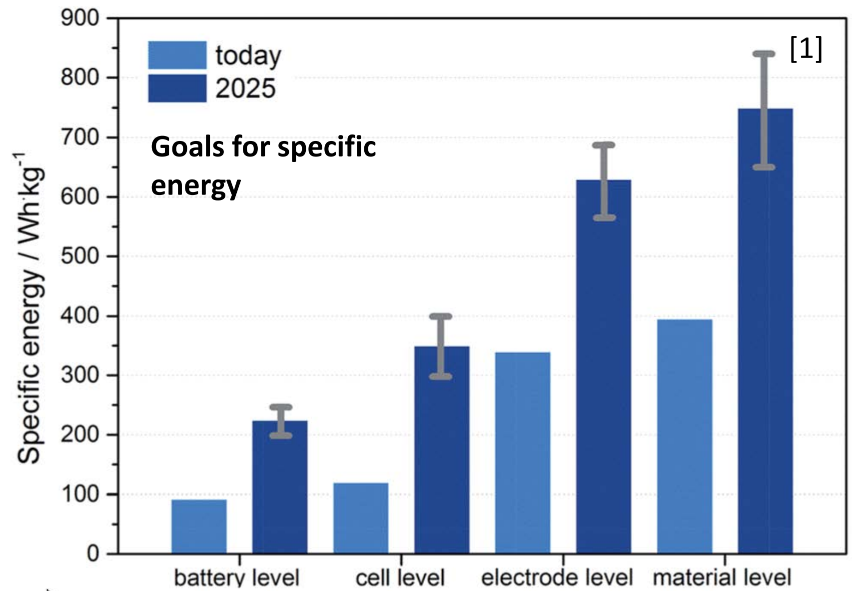
Specific energy/energy density of LIBs:

$$\text{Specific energy}\left[\frac{\text{Wh}}{\text{kg}}\right] = \frac{\text{Capacity (Cell)} * \text{Cell voltage}}{\text{Mass active \& inactive materials}}$$

$$\text{Energy density}\left[\frac{\text{Wh}}{\text{L}}\right] = \frac{\text{Capacity (Cell)} * \text{Cell voltage}}{\text{Volumen active \& inactive materials}}$$

↓

Effect on specific energy/energy density



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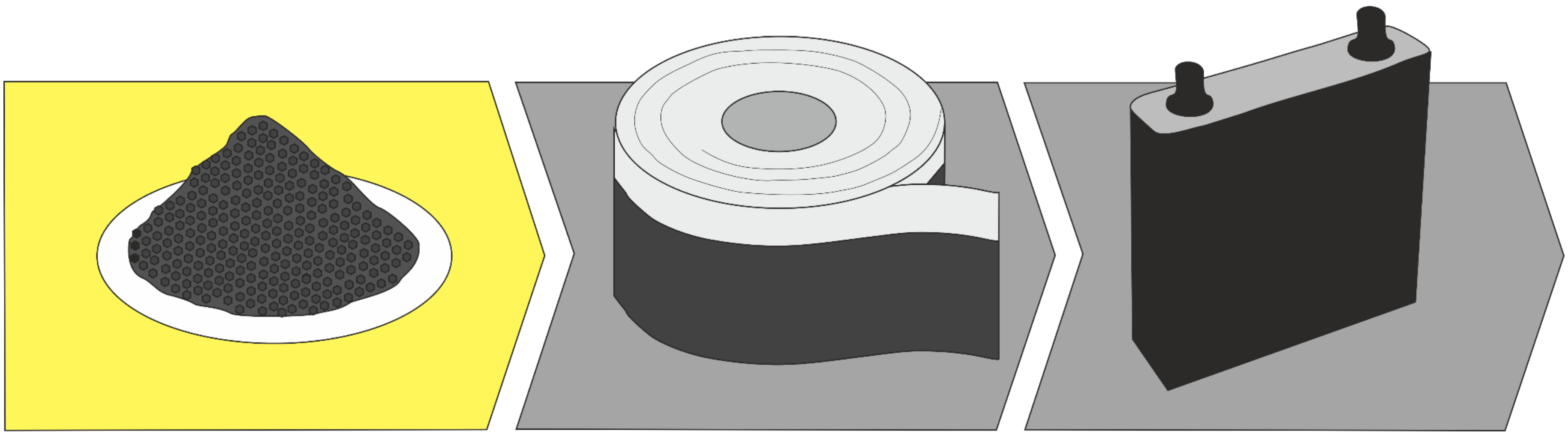
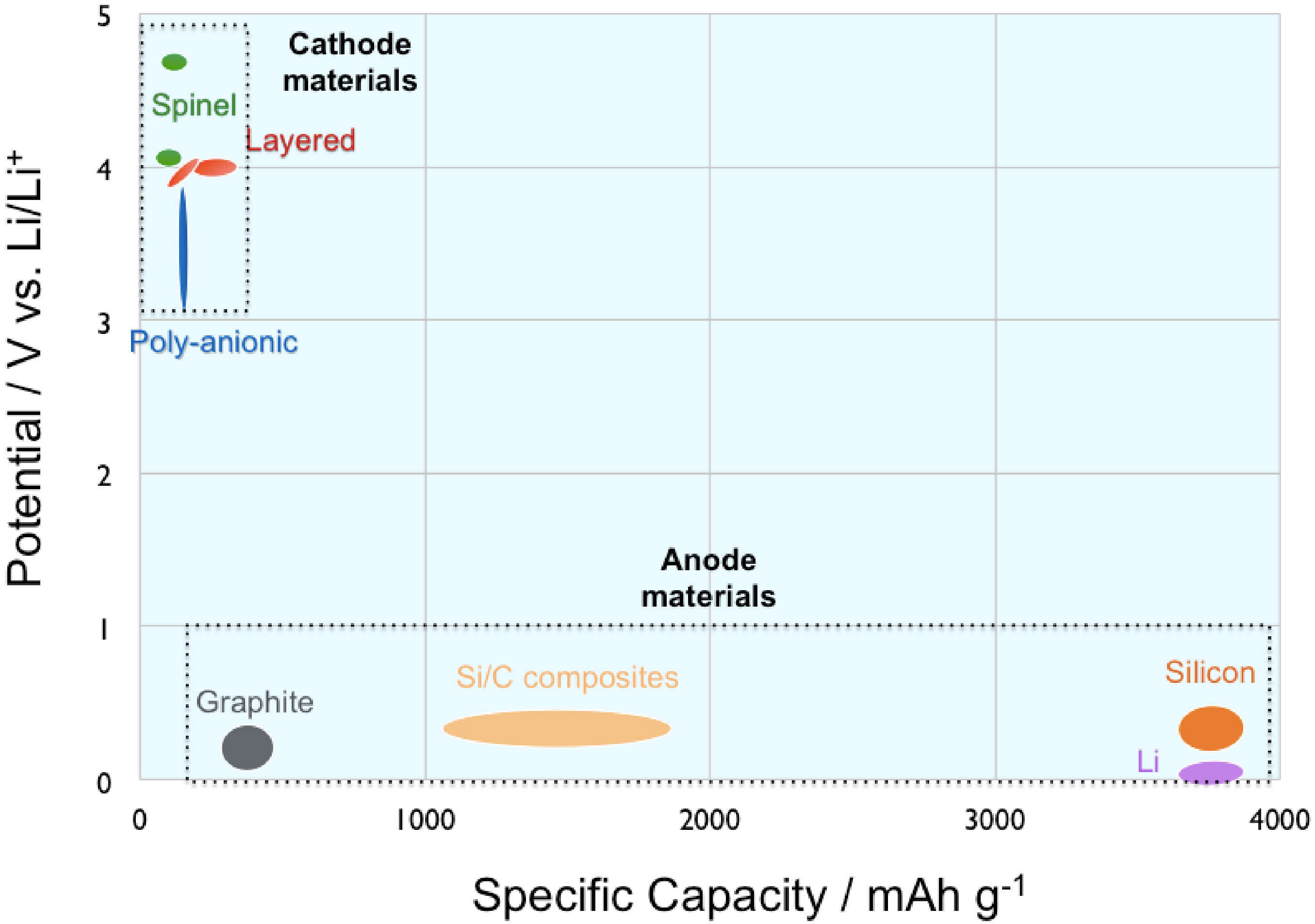
[1] D. Andre, S.-J. Kim, P. Lamp, S.F. Lux, F. Maglia, O. Paschos, B. Stiaszny, Fut J. Mater. Chem. A, 3 (**2015**) 6709-6732.

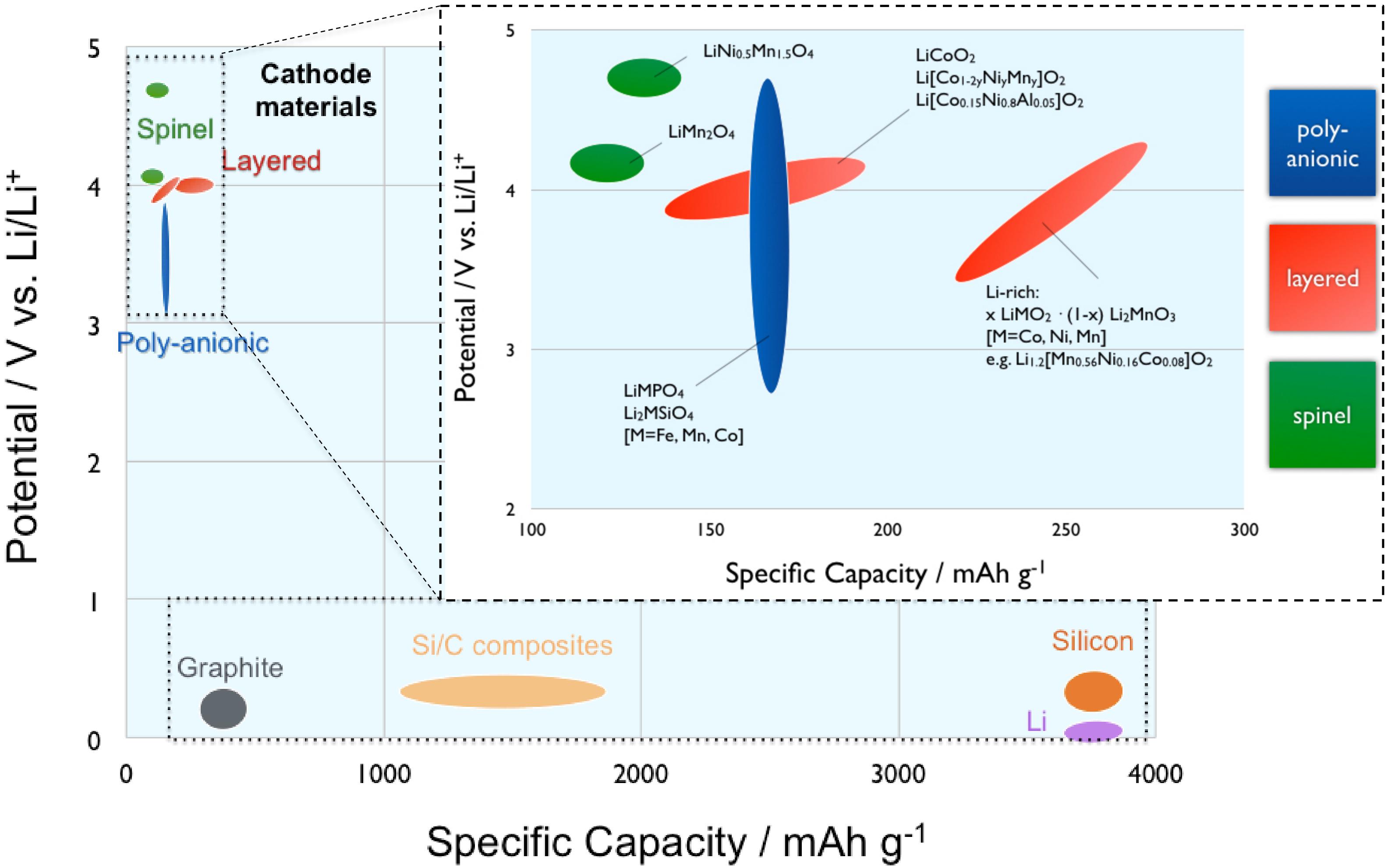
Material



LIB: State of the Art and Near Future



LIB: State of the Art and Near Future



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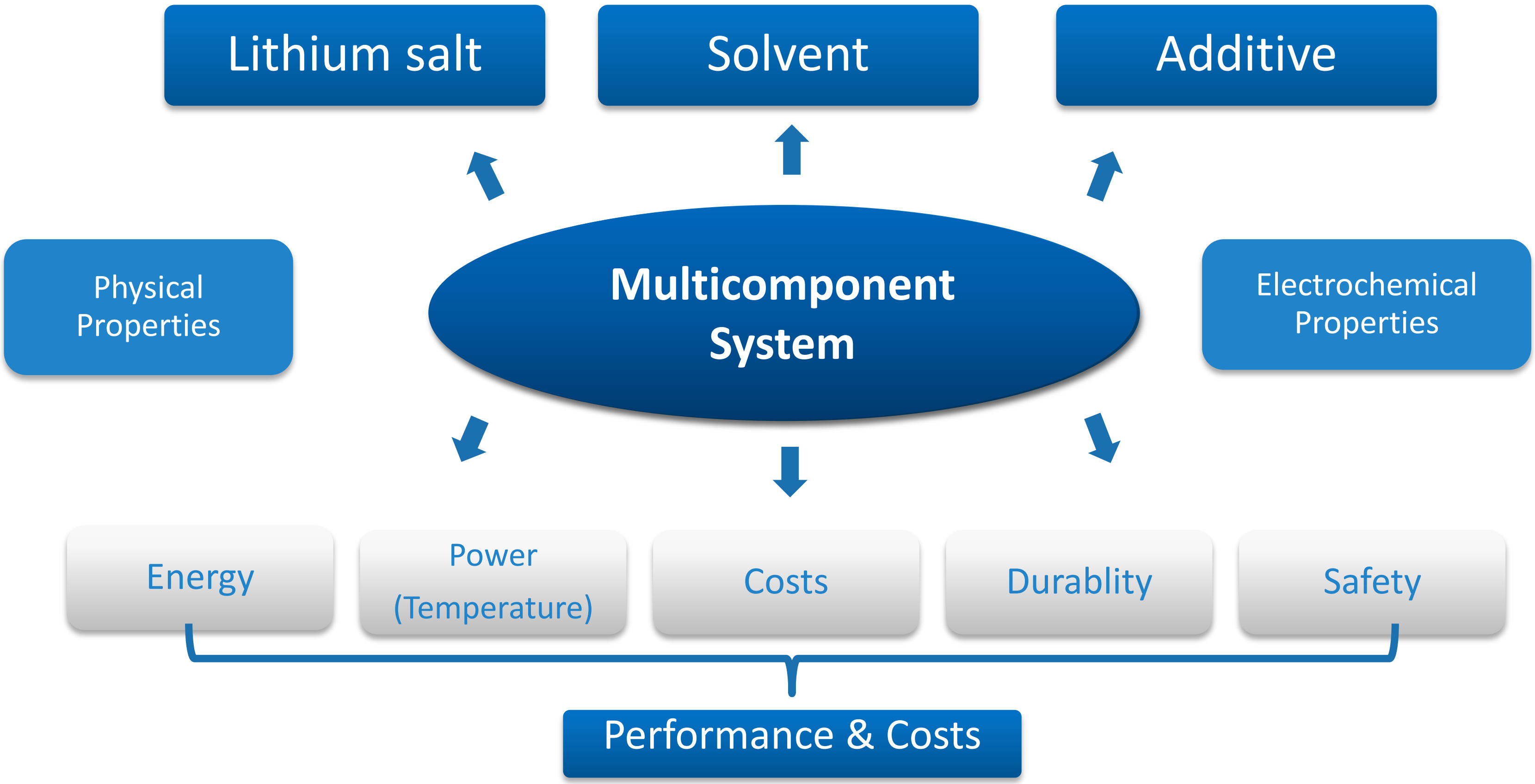
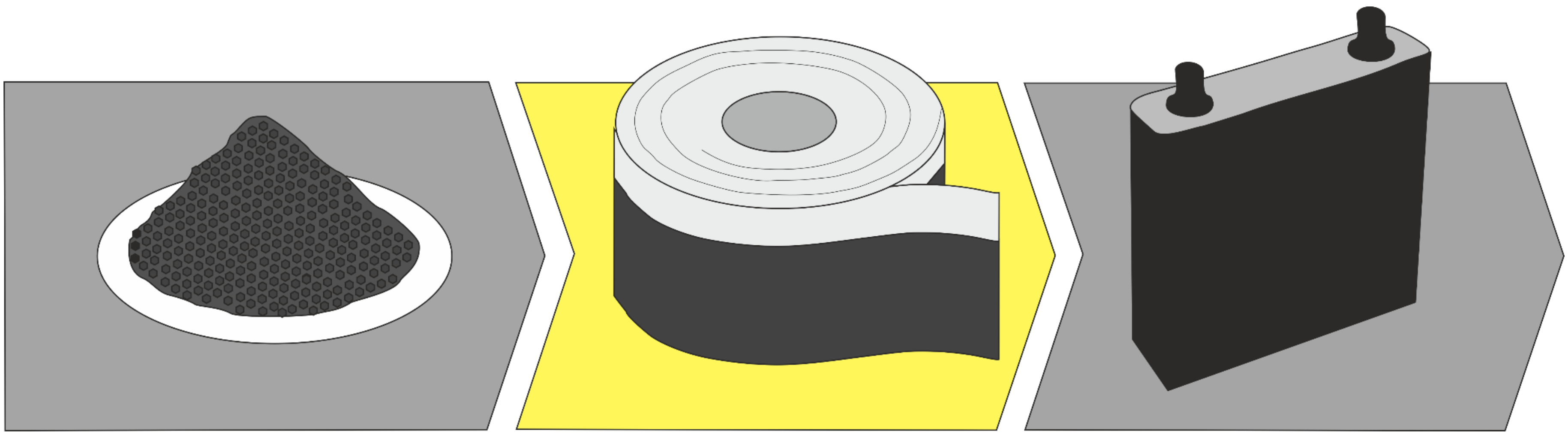
Electrolyte as Key Component of the Battery Cell

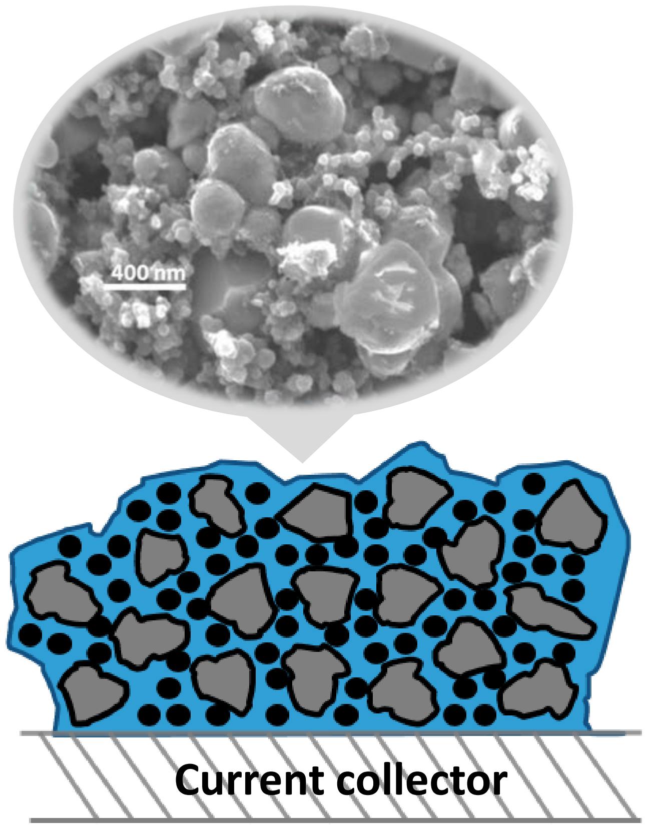


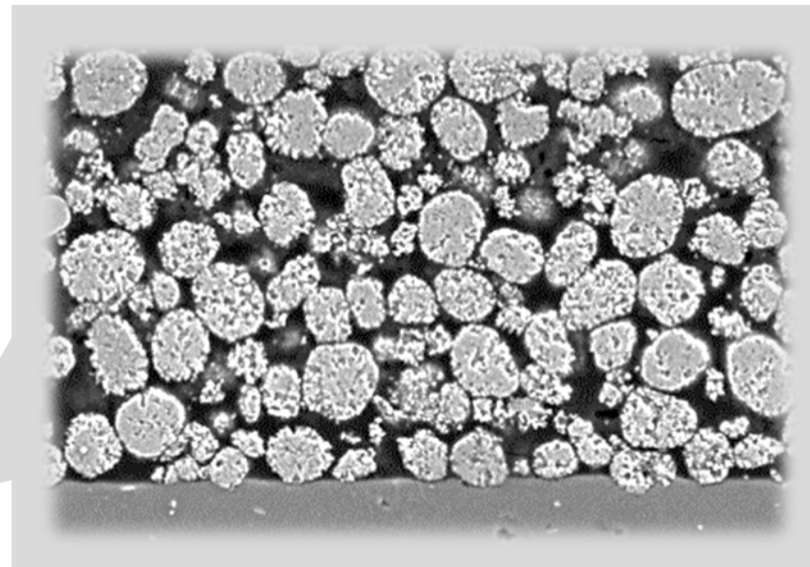
Liquid electrolytes need separator: organic and/or ceramic

Electrode



Powdery Materials→
Composite Electrode Structures





Amount in the composite electrode:

Binder: ~ 1-5 wt.%

Conductive agent: ~ 1-5 wt.%

Active material | **Conductive agent** | **Binder / Porosity / Electrolyte**

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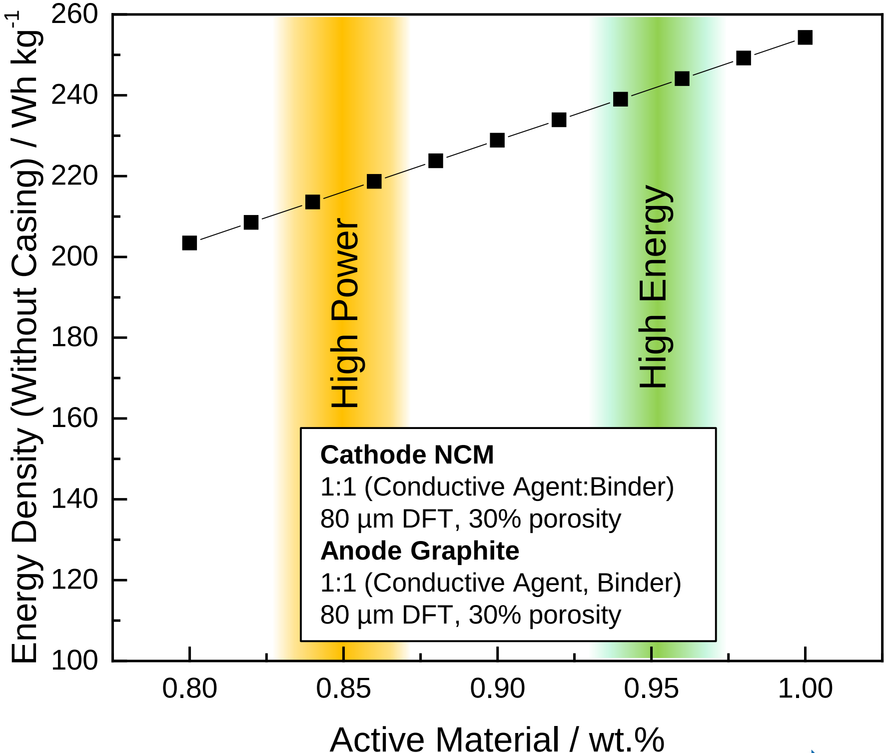
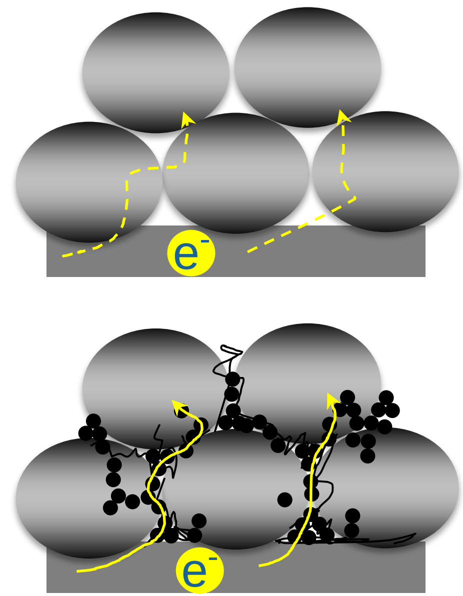
Performance of LIB:
Electrode Level – Active Material



Increasing energy density

Decreasing resistance



High content of active material increases energy density at the expense of power capability

DFT: Dry Film Thickness

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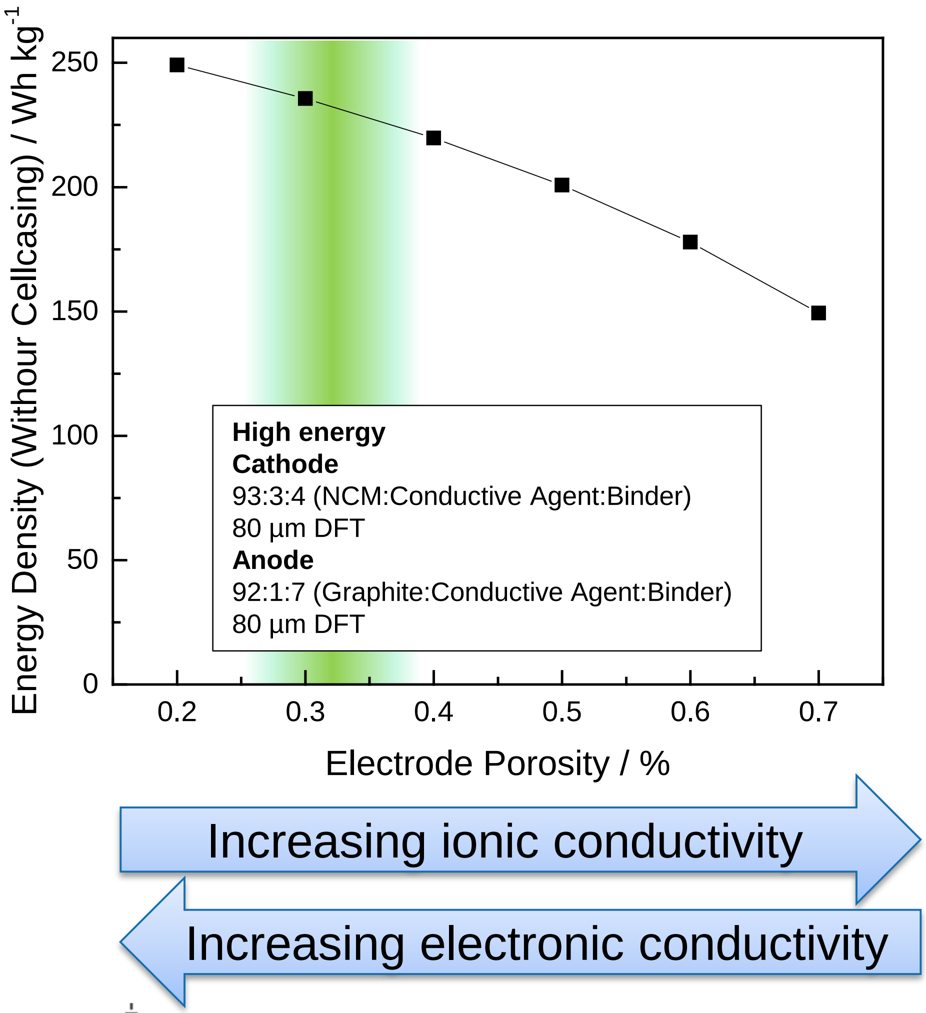
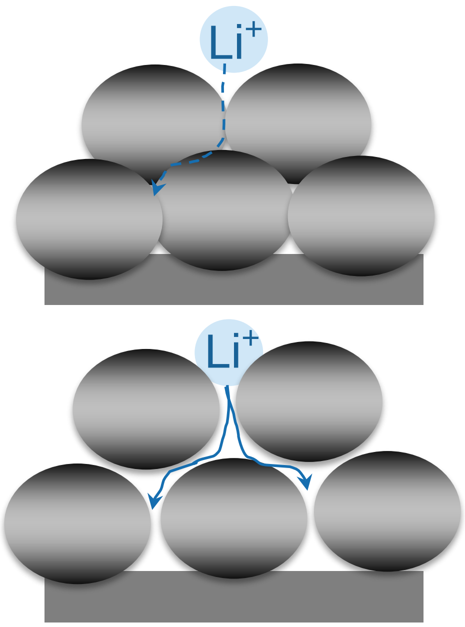
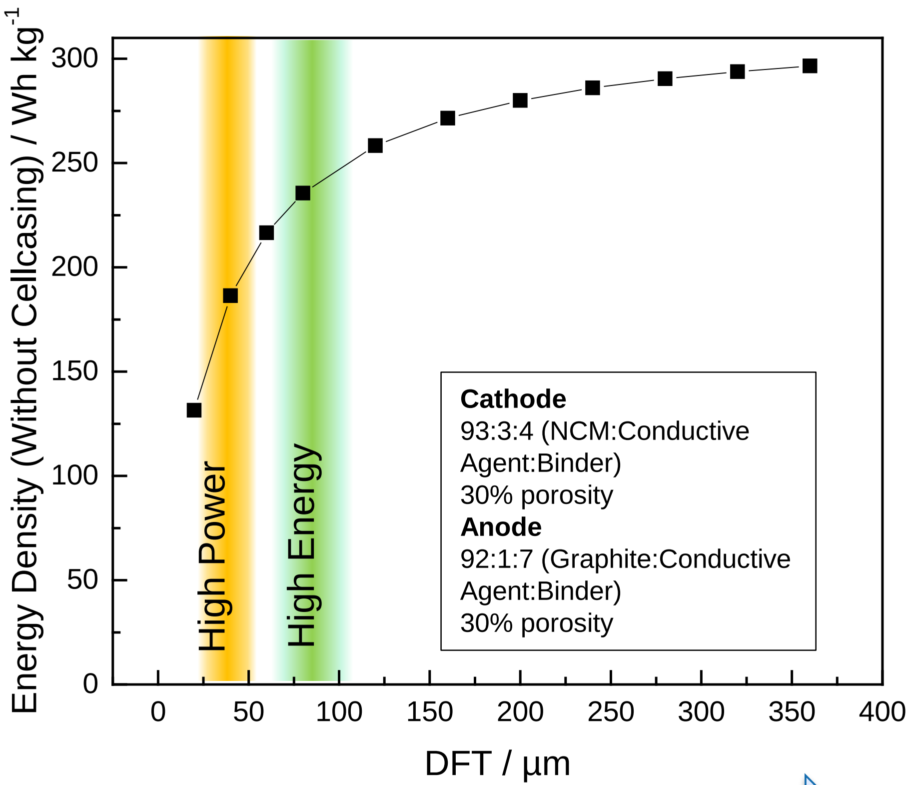
Performance of LIB:
Electrode Level – Electrode Porosity





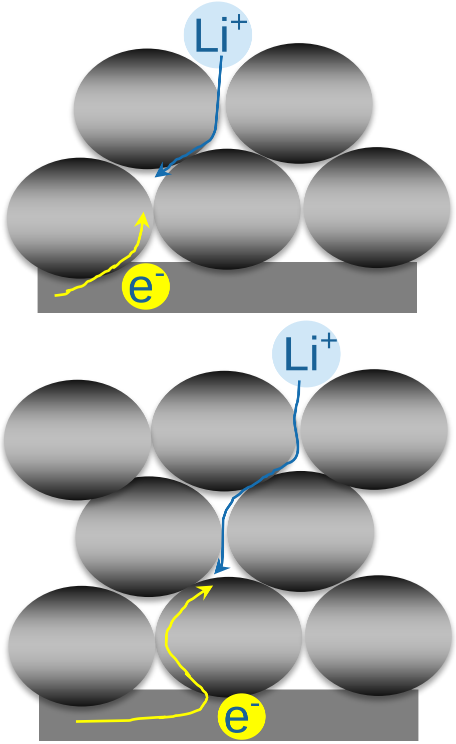
DFT: Dry Film Thickness

Performance of LIB:
Electrode Level – Dry Film Thickness



Increasing Diffusion Distance

Increasing Amount of Inactive Material



Increasing the electrode thickness increases the energy density but enlarges distances for ion and electron transport
→Reduced power capabilities

High potential to increase the energy density

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Performance of LIB: Electrode Level

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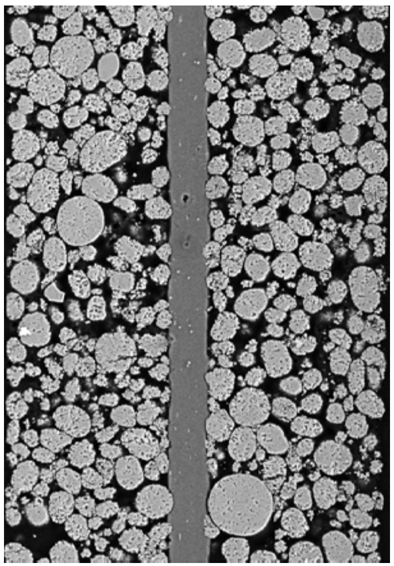
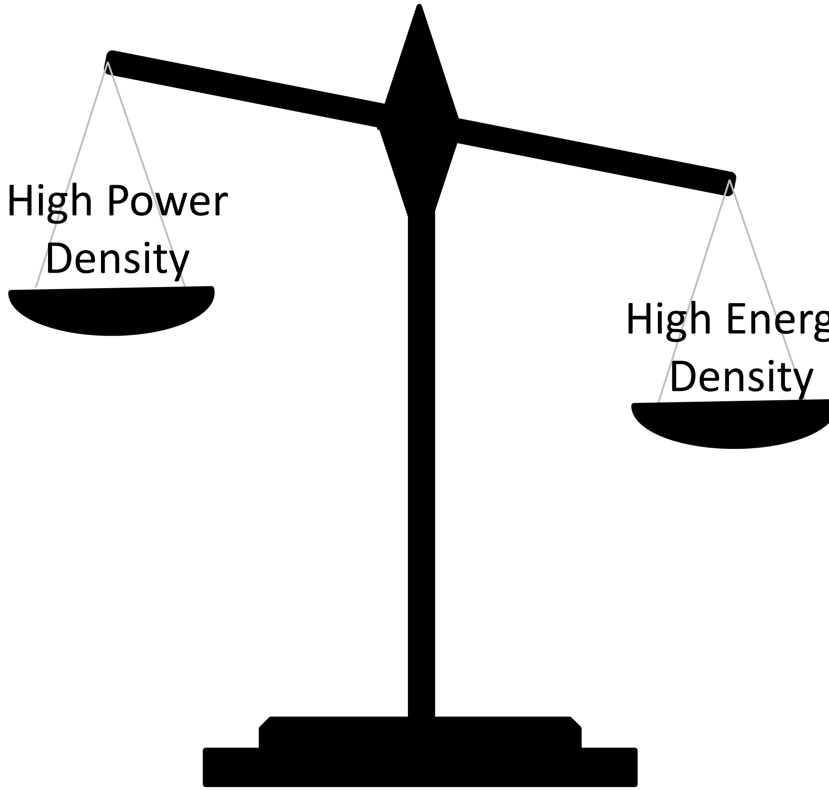
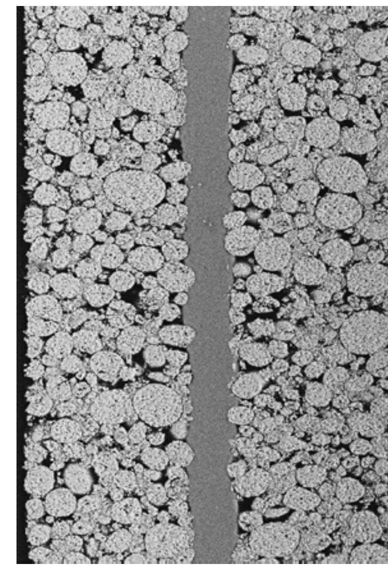
High Power Density Electrode





High Energy Density Electrode



Variation of parameters

- Porosity (Calendering)
- Particle Size (primary and secondary)
- Dry Film Thickness (DFT)
- Current collector thickness
- Tab position
- Tab welding

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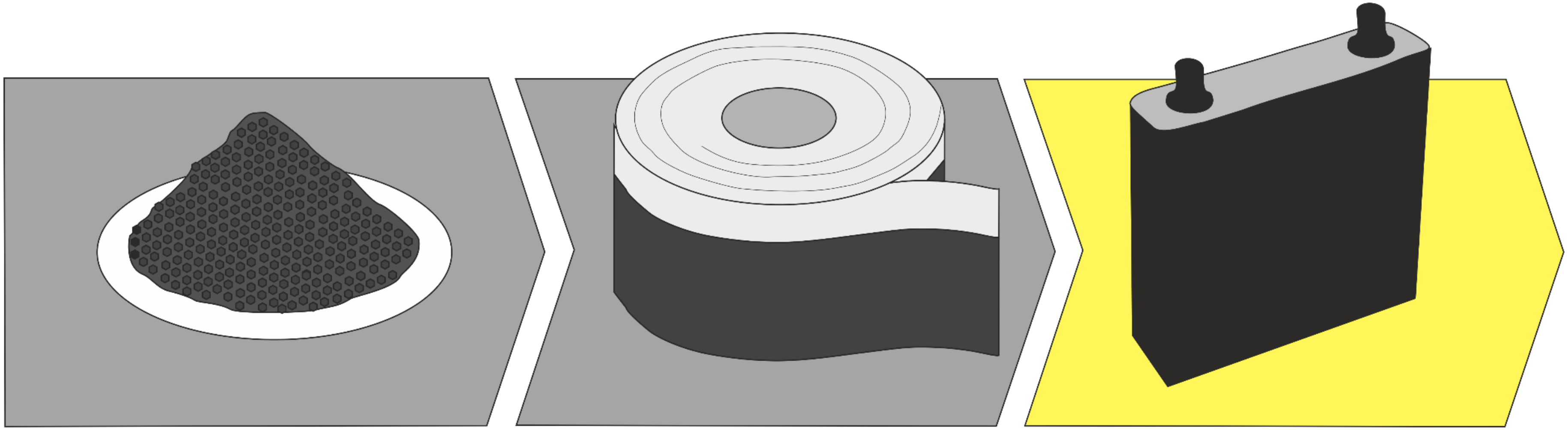
Cell



Comparison of Cell Types: Advantages and Disadvantages

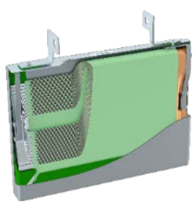
meet

Cylindrical

- High energy density
- Easy and fast manufacturing

- Fast heating

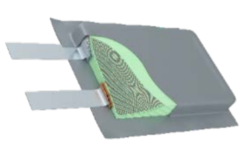
Prismatic



- Heat transfer
- Easy packaging

- Slow and complex manufacturing
- Expensive

Pouch



- Low weight
- Shock- and vibration-tolerant
- Design flexibility

- Mechanical Stability
- External pressure required

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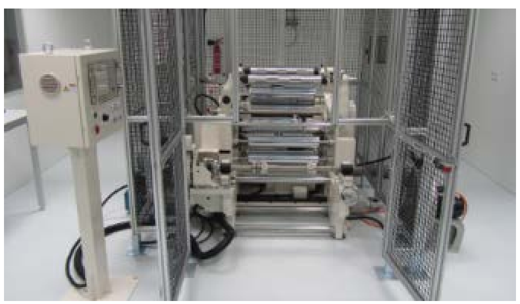
Battery Line in MEET – 5 Ah (Pouch)

Materials

Mixing

Coating and Drying

Calandering

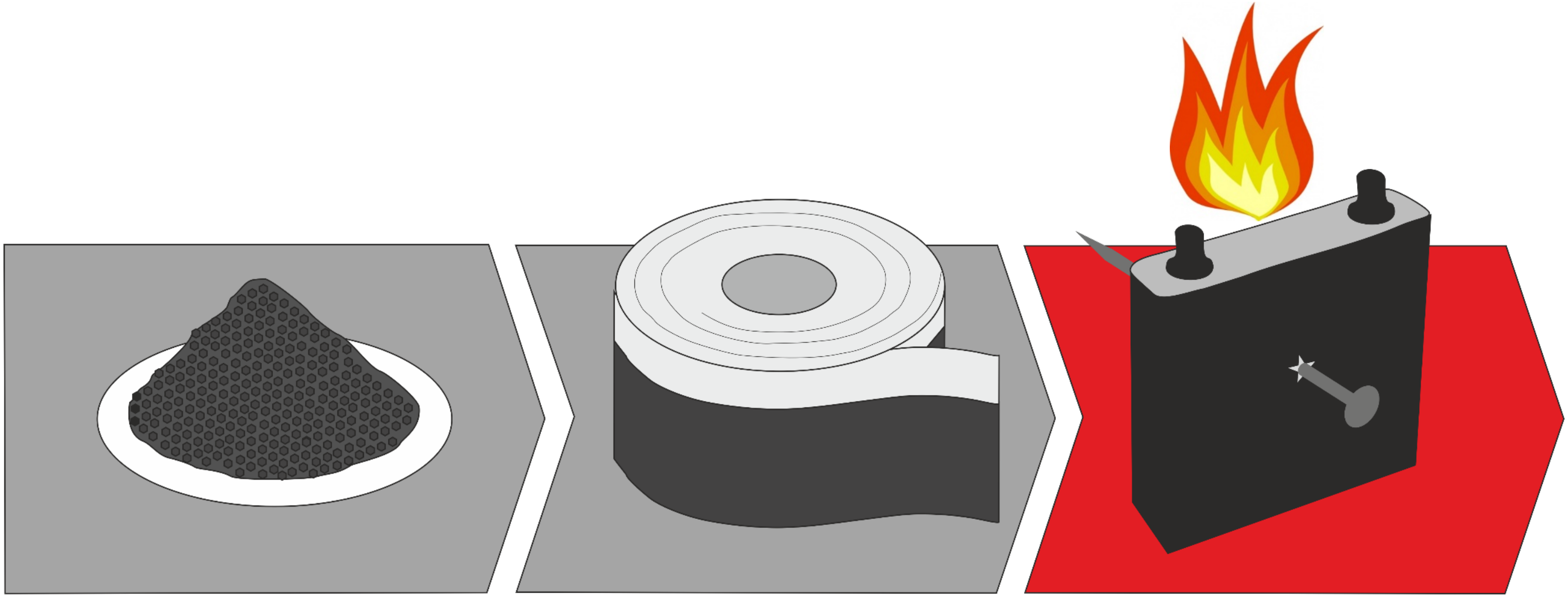


Slitting

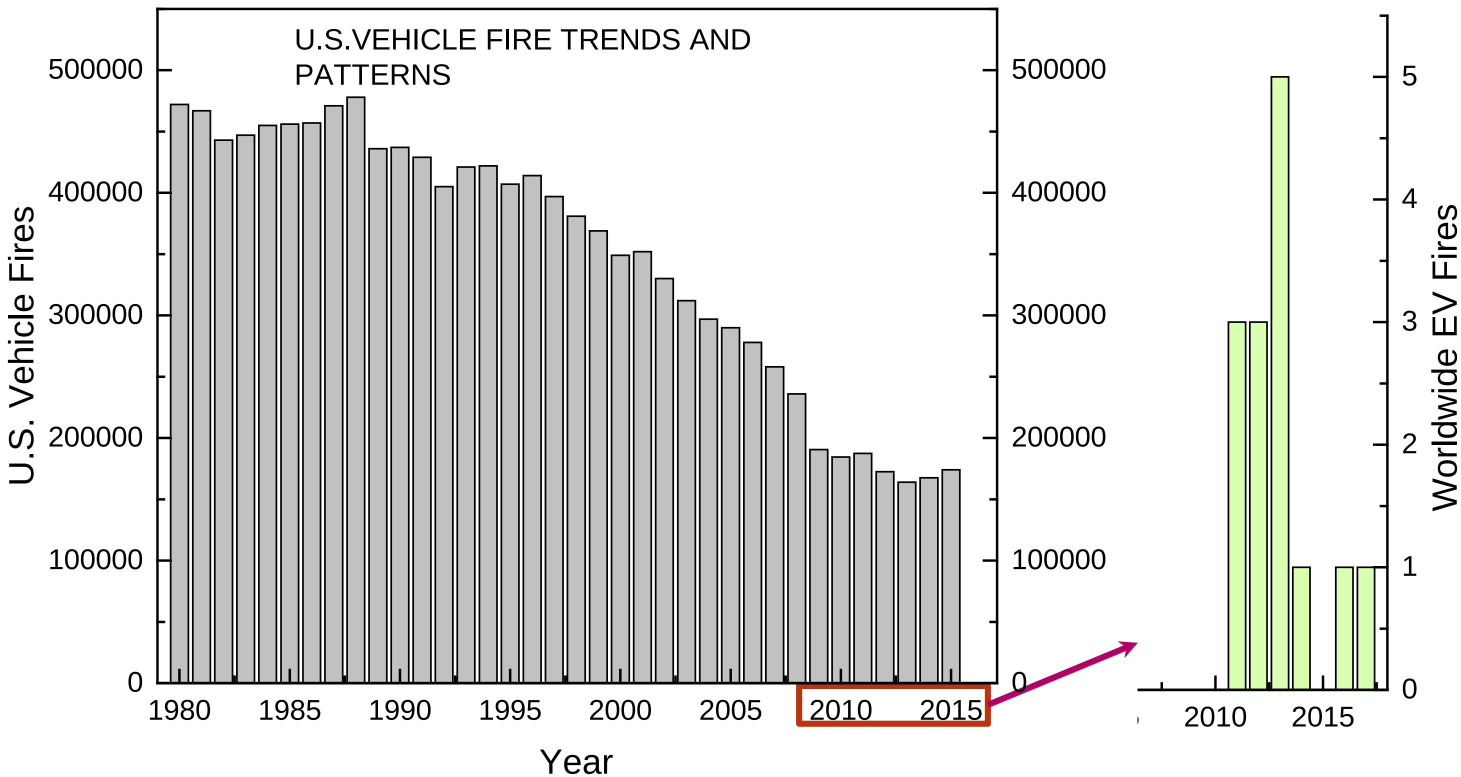
Cell Assembly

Type: 5 Ah

Cell Safety



Fire Incidents with ICE und EV

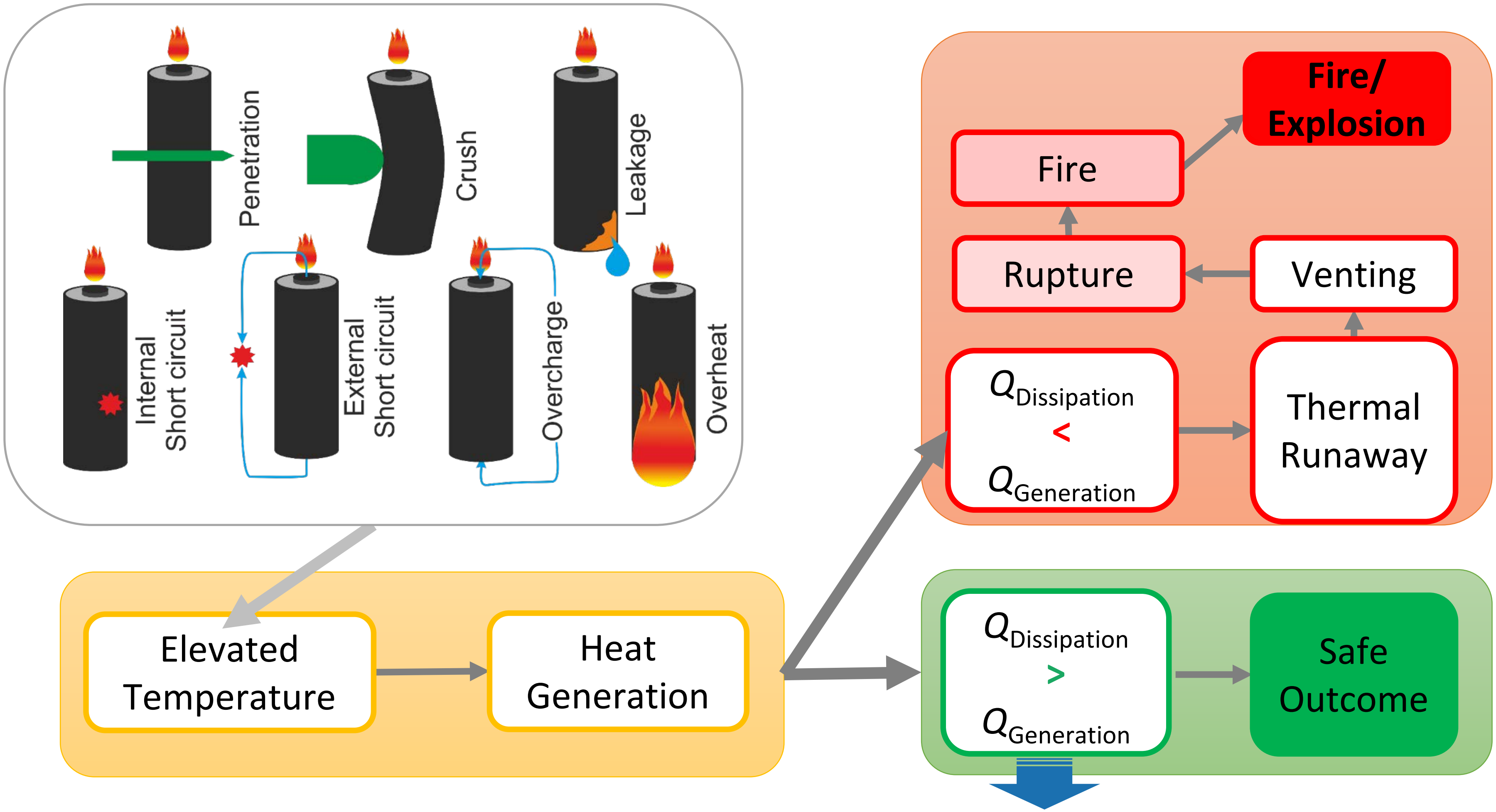


6x Tesla Model S
2x Chevrolet Volt
2x Fisker Karma
1x Zotye
1x BYD e6
2x Mitsubishi

- 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

Abuse Behavior of Lithium Ion Cells

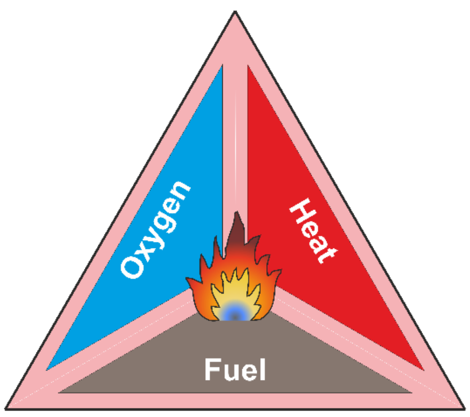


Intelligent design of battery packs
(e.g. heat exchange with active/passive heat sink)

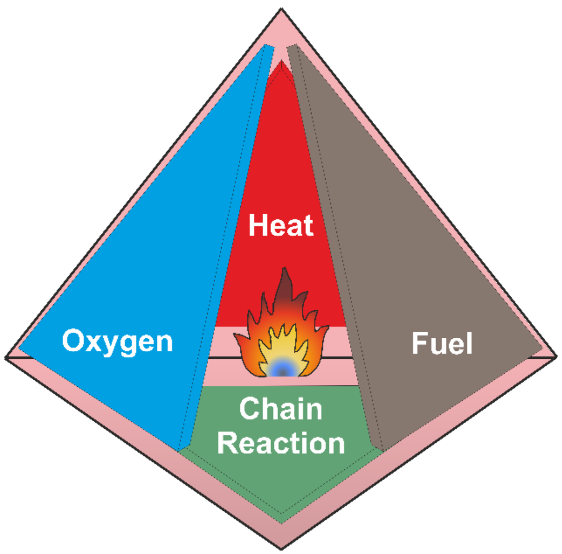
Systematic Approach to Lithium Ion Material Safety

Fire is a by-product of combustion (= process of rapid oxidation of fuel). In order to ignite and burn, a fire requires three **elements**: **Heat**, **Fuel**, and **Oxygen** represented by the **"Fire Triangle"** (cf. *science of fire fighting*). The fire is prevented or extinguished by "removing" any one of them. A fire naturally occurs when the elements are combined in the right proportions (e.g., more heat is needed to ignite some fuels).

Sometimes it is useful to consider a fourth essential element of fire, the sustaining **Chemical Chain Reaction** (⇒ **"Fire Tetrahdron"**)



Fire Triangle



Fire Tetrahedron

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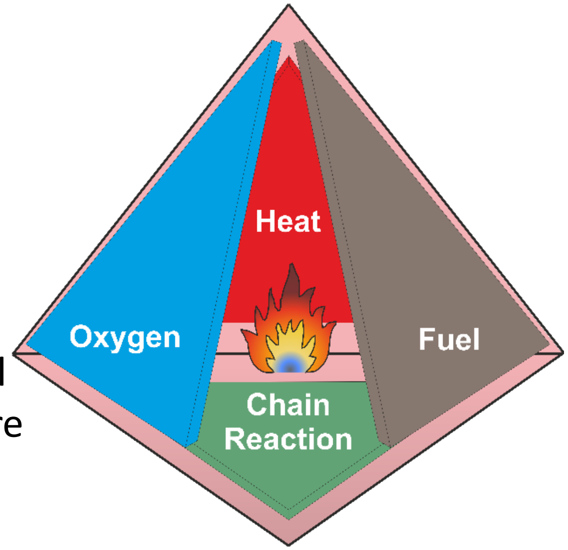
M. Winter, Li-Ion Batteries and Beyond, Industry Report, 2017
http://totalbatteryconsulting.com/industry-reports/Li-Ion-and-beyond-report/overview.html

The Fire Tetrahedron in a Lithium-Ion Cell – Materials View

Heat/Energy Release via

- Anode or cathode decomposition
- Cell short: internal/external

- **Oxygen**
- Release from layered cathodes during overcharge
- Oxygen access to cell after cell rupture/opening via gas pressure build-up or external impact



Fire Tetrahedron

Combustibles

- Li (High surface area)
- Electrolyte solvents (and salts)
- Gases (Hydrogen-rich)

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

The Fire Tetrahedron in a Lithium-Ion Cell – Materials View: Countermeasures

Heat/Energy Release via

- Anode or cathode decomposition
- Cell short: internal external

✓ **Material Stabilization**

✓ **Cooling**

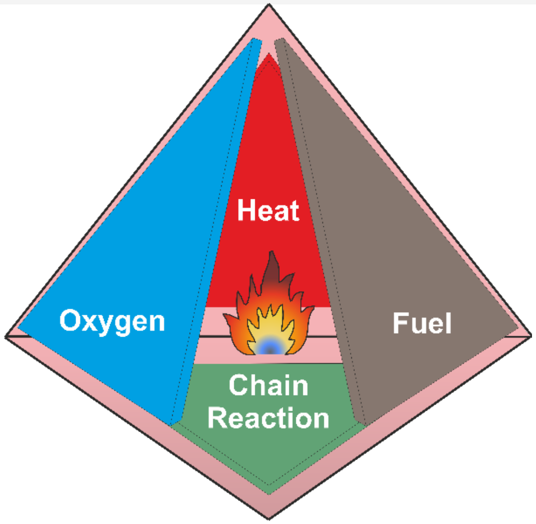
✓ **Rapid Heat Transfer**

Oxygen

- Release from layered cathodes during overcharge
- Oxygen access to cell after cell rupture/opening via gas pressure build-up or external impact

✓ **Stable cathodes, e.g., $LiFePO_4$**

✓ **Suppression of gas pressure, etc.**



Fire Tetrahedron

Combustibles

- Li (Dendrites)
- Electrolyte solvents (and salts)
- Gases (Hydrogen-rich)

✓ **No Li metal**

✓ **Non-flammable electrolytes**

✓ **Gas suppression**

(Radical) **Chain Reaction**

✓ **Radical scavengers**

✓ **Shut-down, etc.**

(additives, separators)

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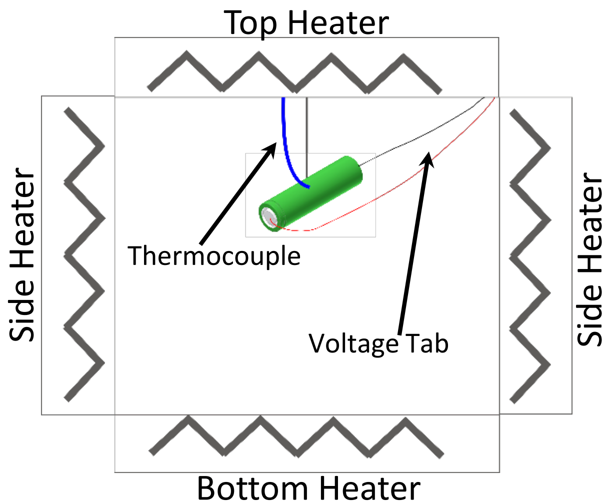
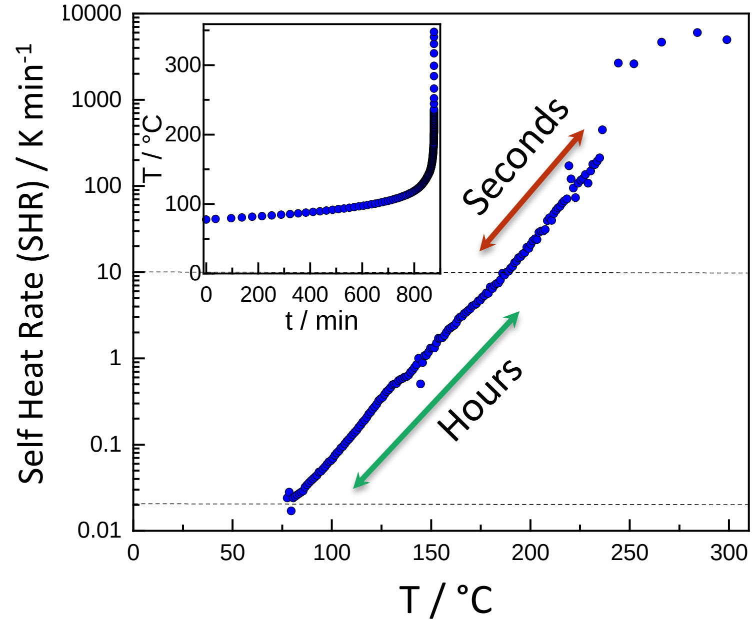
M. Winter, Li-Ion Batteries and Beyond, Industry Report, 2017
http://totalbatteryconsulting.com/industry-reports/Li-Ion-and-beyond-report/overview.html

Accelerating Rate Calorimetry (ARC): Thermal Stability of LIB Cells





- Adiabatic environment
- No heat dissipation into surrounding

Heat Dissipation: $Q_D = 0\,J$

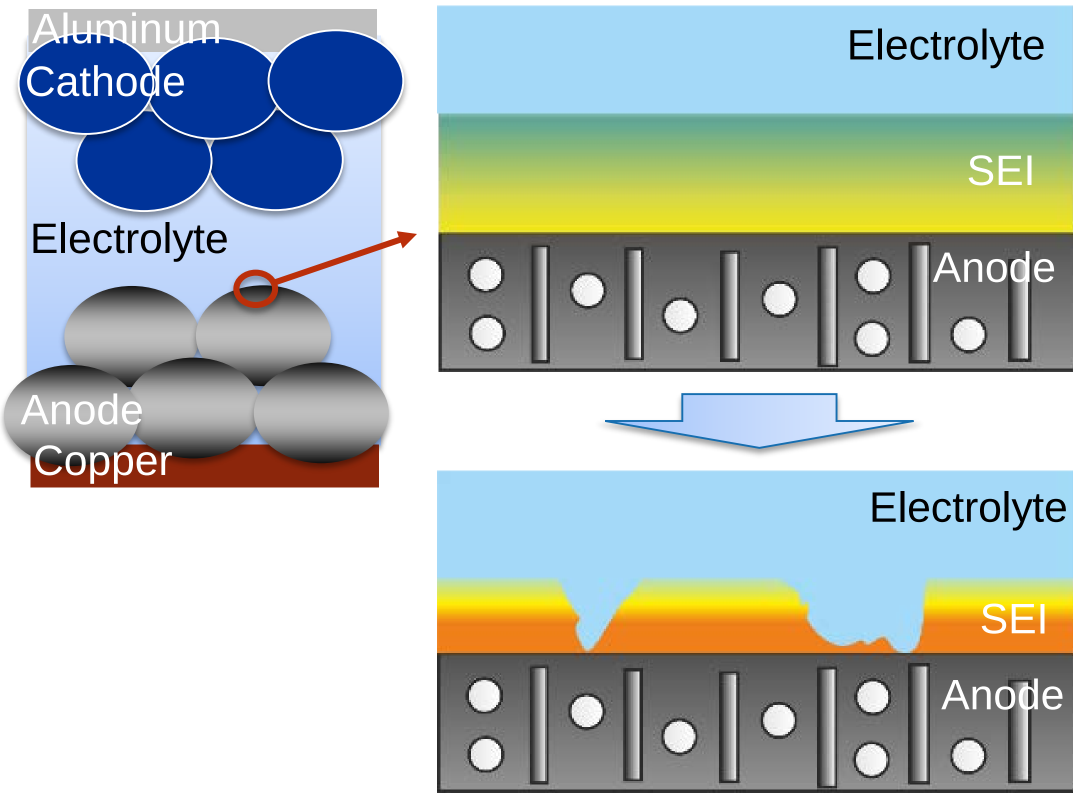
- Measurement of self-sustaining exothermic heat due to decomposition reactions

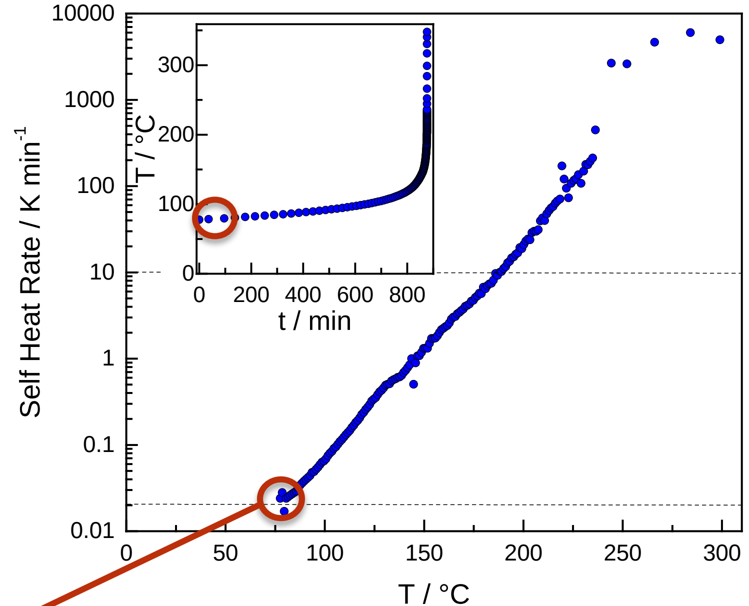
Heat Generation: $Q_G \rightarrow \text{Cell Heating}$

Self-Heat Rate > 10 K min^{-1}: Thermal runaway

👍	High reproducibility
👍	High precision
👎 👍	Thermal runaway
👎	Only thermal abuse

ARC: Thermal Stability of LIB Cells
Processes at Moderate Temperatures

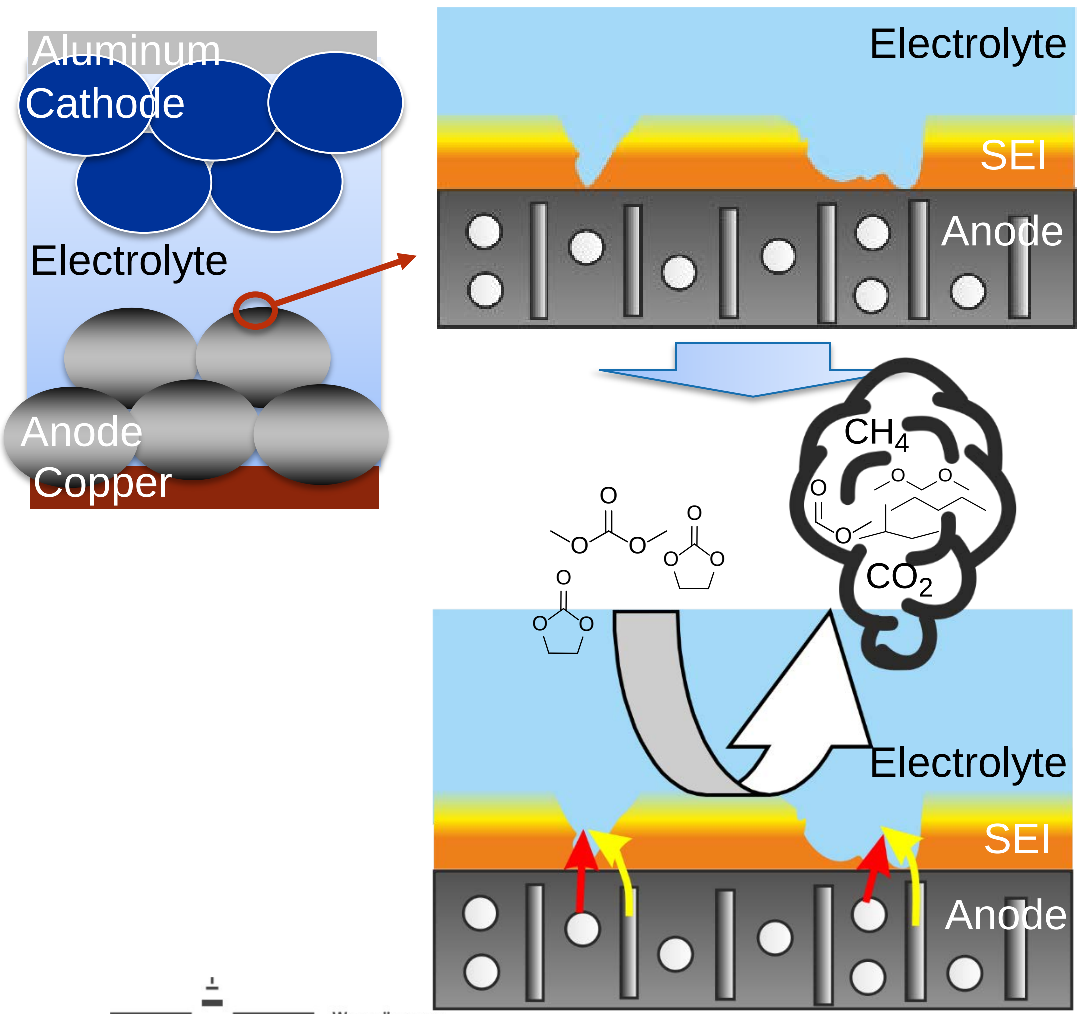


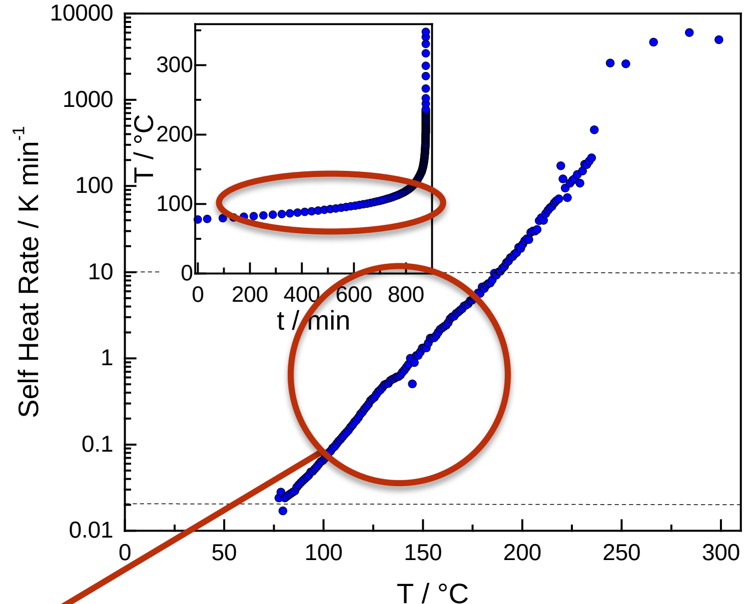


- SEI conversion and decomposition
- Low exothermic heat release

→ At a stage, where it is easy to counteract

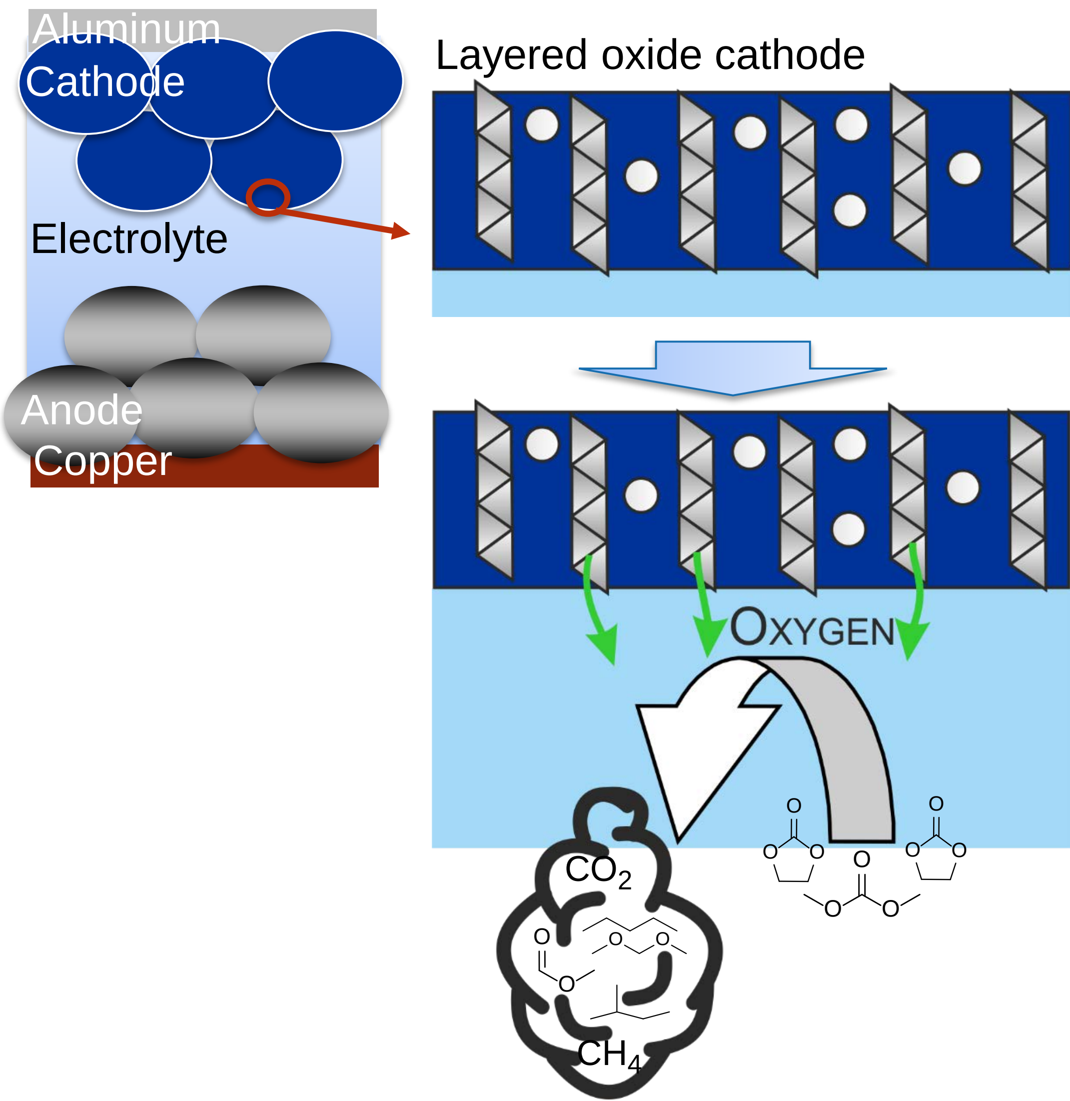
ARC: Thermal Stability of LIB Cells
Processes at Medium Temperatures

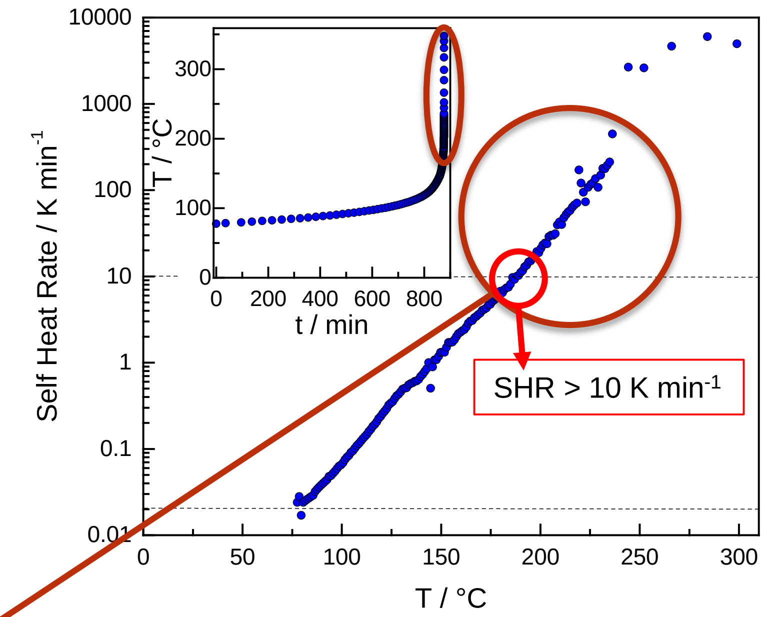




- Li (from anode) reacts with electrolyte
- Temperature dependent reaction rate
- Increased gas evolution
- ➢ Cell venting

ARC: Thermal Stability of LIB Cells
Processes at Elevated Temperatures



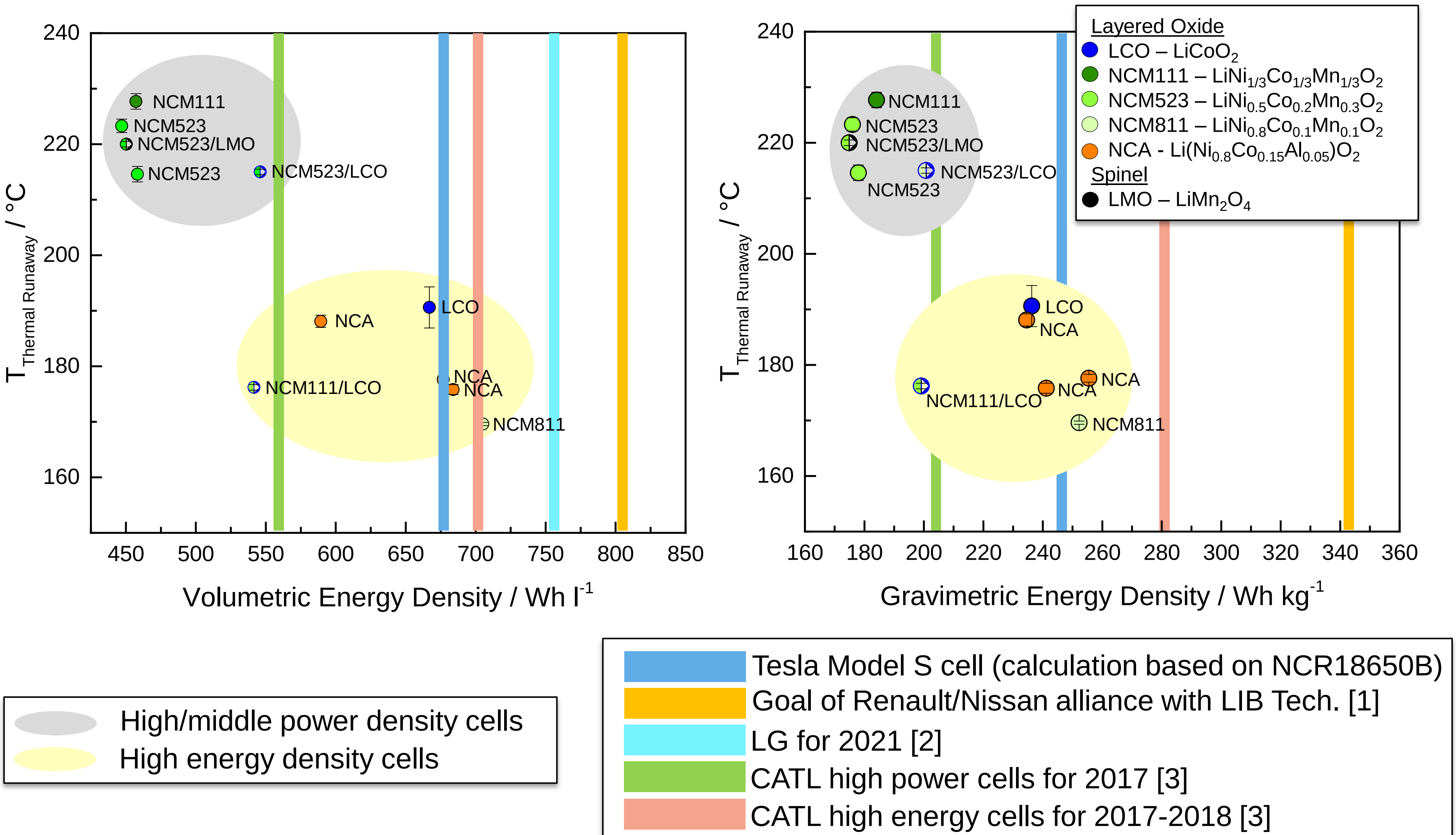


- Cathode decomposition

- O_2 evolution and electrolyte oxidation
- Highly exothermic reaction
- Generation of large amounts of gaseous products

➢ Cell rupture, explosion and fire (worst case)

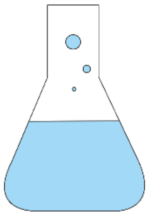
Case Study:
Cell Safety of 18650 Cells



[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

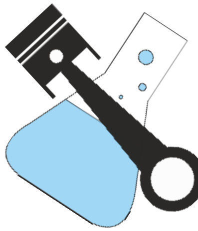
Summary

1. **Material level**
   - Energy density determined by materials
   - Large variety of materials and combinations
   - High research intensity



2. **Electrode level**
   - Power capability determined mostly by the electrode design
   - Power increase at the expense of energy density
   - Many possibilities to increase both power and energy densities

3. **Cell level**
   - Energy density achievable with thermally less stable materials
   - More improvements needed on material and cell level for EV application (both with regard to safety and performance)



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KRAFTWERK Batterie

BATTERIETAG NRW

28. – 30. März 2017 Welcome in Aachen

- Dr. Michael M. Thackeray, Argonne National Laboratory
- Dr. Kai Vuorilehto, EAS Germany GmbH
- Prof. Jeff Dahn, Dalhousie University
- Dr. Ann Laheäär, Skeleton Technologies
- Prof. Jiang Jiuchun, Beijing Jiaotong University
- Prof. Bernd Friedrich, RWTH Aachen University

http://battery-power.eu

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Verhandlungen der Deutschen Physikalischen Gesellschaft e.V.

Früher war alles besser – aber nicht die Batterien

Martin Winter , 30. März 2017

1. Direktor des Helmholtz Institut Münster (HI MS), IEK-12, Forschungszentrum Jülich GmbH, Corrensstraße 46, 48149 Münster, Germany
2. Wissenschaftlicher Direktor des MEET Batterieforschungszentrum, Westfälische Wilhelms-Universität Münster, Corrensstraße 46, 48149 Münster, Germany

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