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Overview on current status of lithium-Ion batteries

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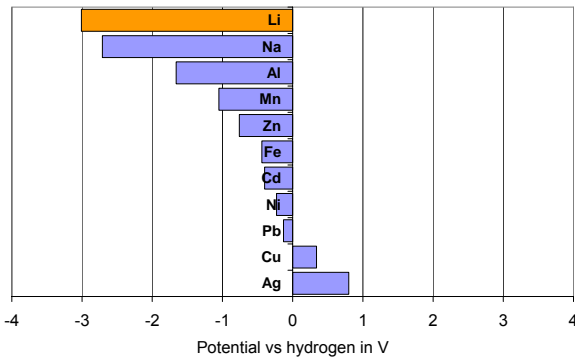
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Overview

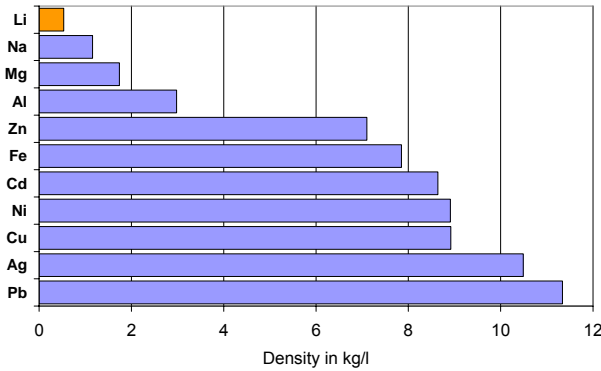
- Why is Lithium an interesting material for batteries?
- Principle of Li-Ion batteries
- Possible Material combinations
- Today's driving forces for Li-Battery development
- State of the art technologies
- Chances and risks of using large lithium batteries for stationary applications
- R&D required
- Lifetime, costs and economical aspects



Why Lithium?



Lithium is the material with the most negative voltage → **high cell voltage**



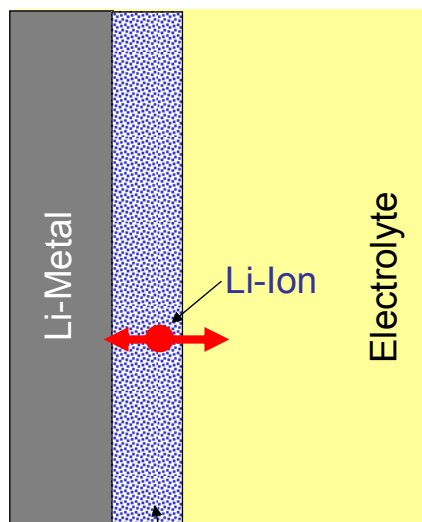
Lithium is the metal with the lowest density. → **high specific Energy**

Why Lithium?

Lithium is able to form a protection layer that allows the transport of Li-Ions

→ **Layer does not block current flow**

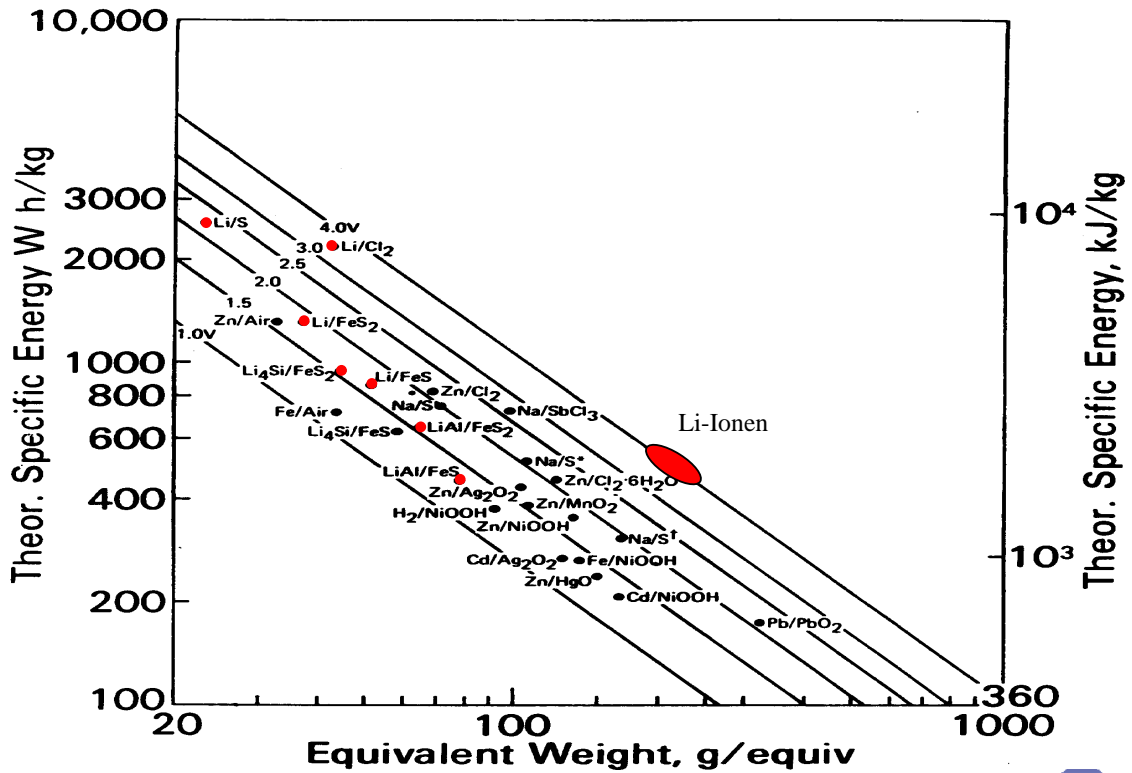
→ **Layer protects electrode**
→ **good lifetime is possible**



Lithium can be used for Batteries with **high cell voltage** and **high specific energy**

Protection Layer protects Lithium for further dissolution
(Solid electrolyte interface / SEI)

Possible Lithium Systems

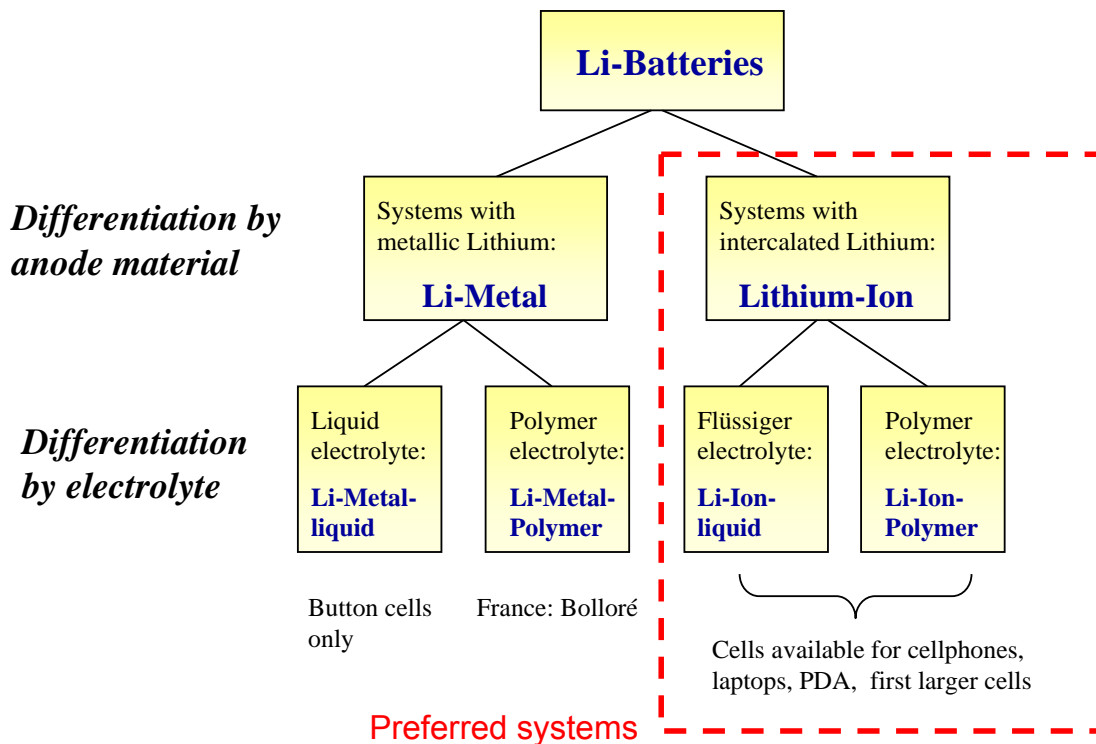


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*E. J. Cairns, in "Lithium Battery Technology", ed. by H. V. Venkatesetty, John Wiley & Sons (1984) 179



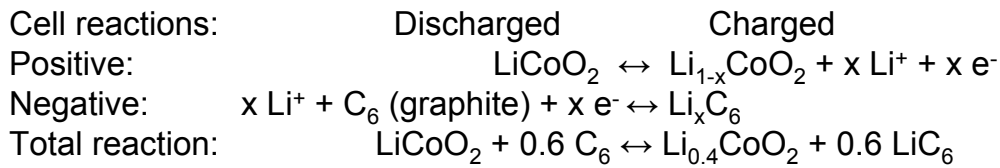
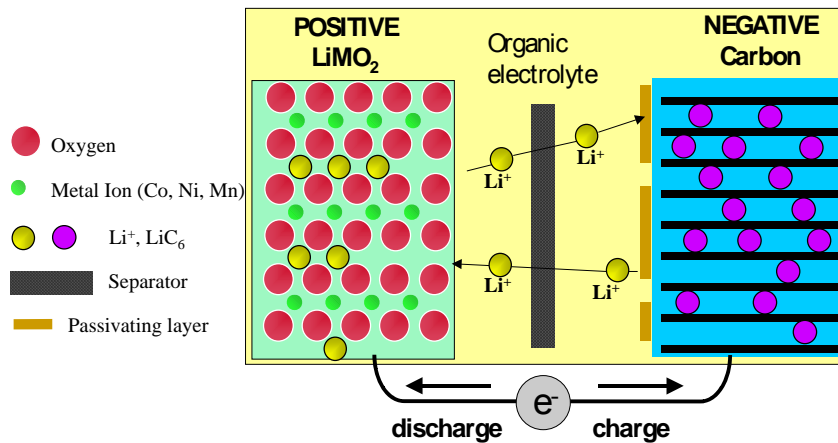
Types of Lithium Batteries



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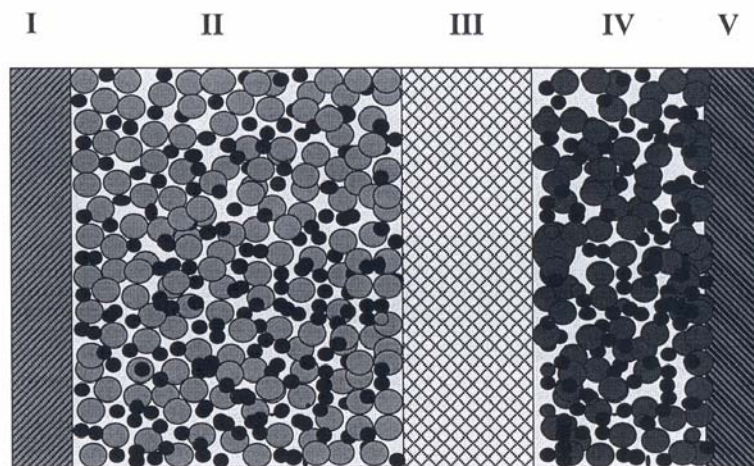


The Lithium-Ion System



No Li metal in the cell. The electrolyte does not participate in the cell reaction. It constitutes only a vehicle for Li-Ion transfer. No excess of electrolyte is therefore required.

Cell design of Li-Batteries



- I: Al-Collector (18-25 μm)
- II: Positive Electrode (40-200 μm)
- III: Separator (16 - 35 μm)
- IV: Negative Electrode (30-150 μm)
- V: Cu-Collector (12-20 μm)

Thin electrodes are necessary!

Source: LTC-GAIA

Cell design of Li-Batteries

Cylindrical cell



Coffee bag cells

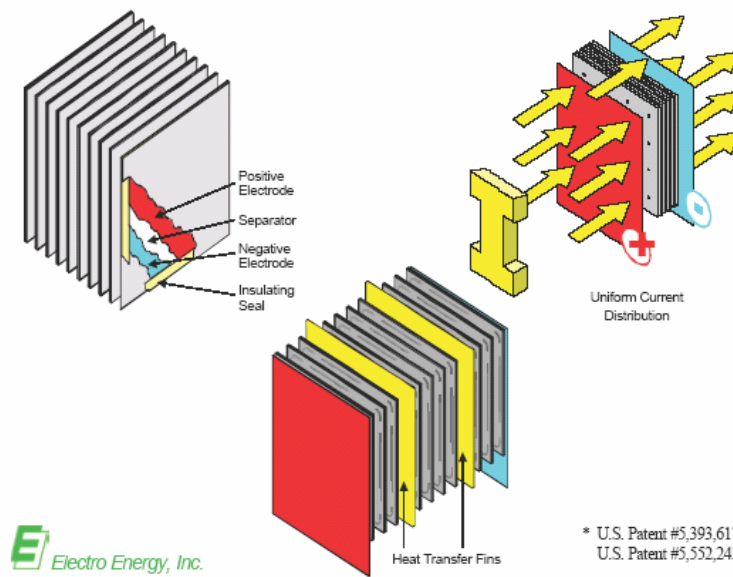


Prismatic cells



Cell design of Li-Batteries

Electro Energy Inc. received 1.5 Mio US \$ for developing of a bipolar Li-Battery



Quelle: <http://www.greencarcongress.com/>, 10. Nov 2005



Battery System for Plug-In Hybrid

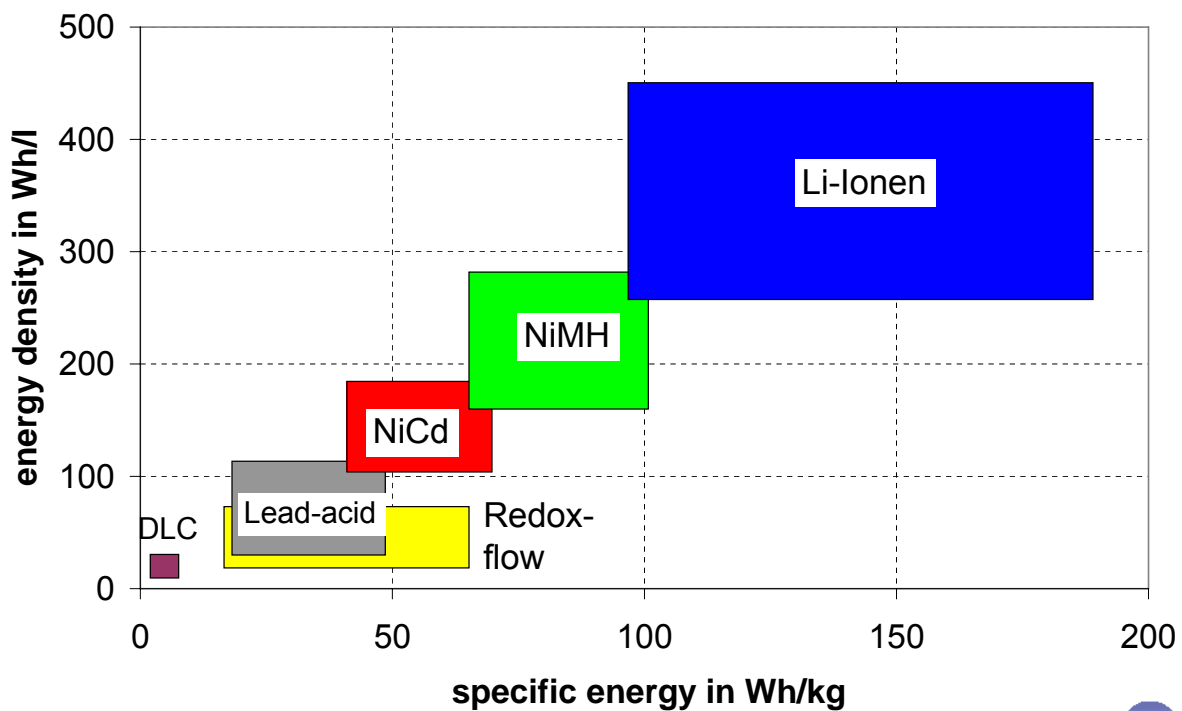


Li-Ion Battery
63 cells (LiFePO_4)
200V / 35Ah (7 kWh)

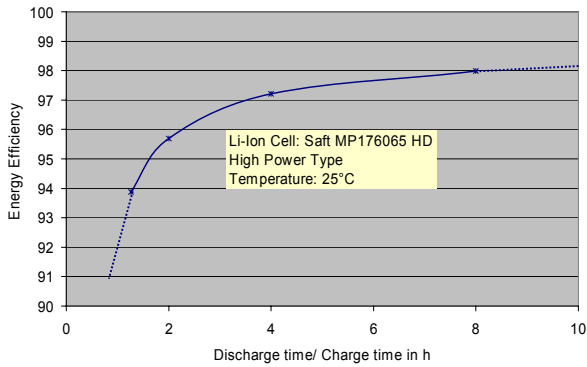
Battery-management with single cell voltage monitoring and charge-equalizing is required.

Source: GAIA

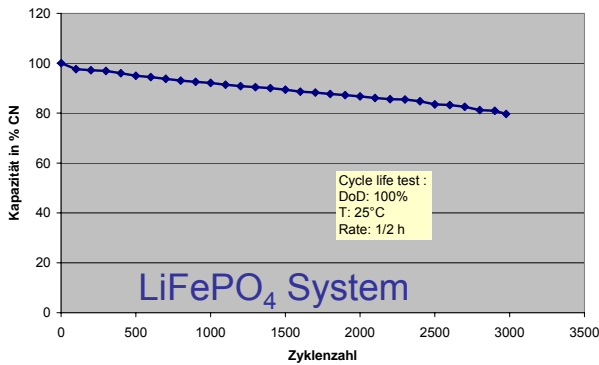
High Energy Storage



Good Performance Achieved



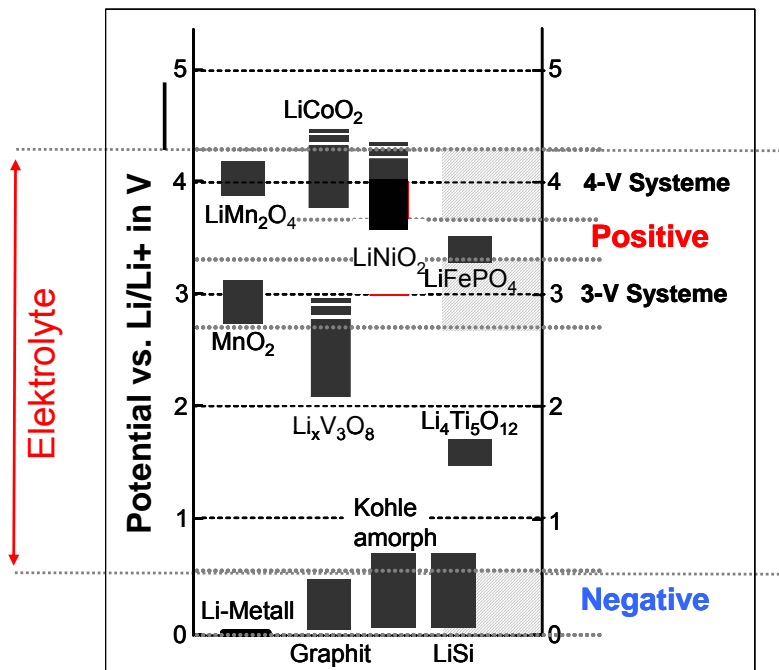
Lithium Batteries show an **excellent energy efficiency**.
 > 95% (2 h Rate)
 > 98% (10 h Rate)



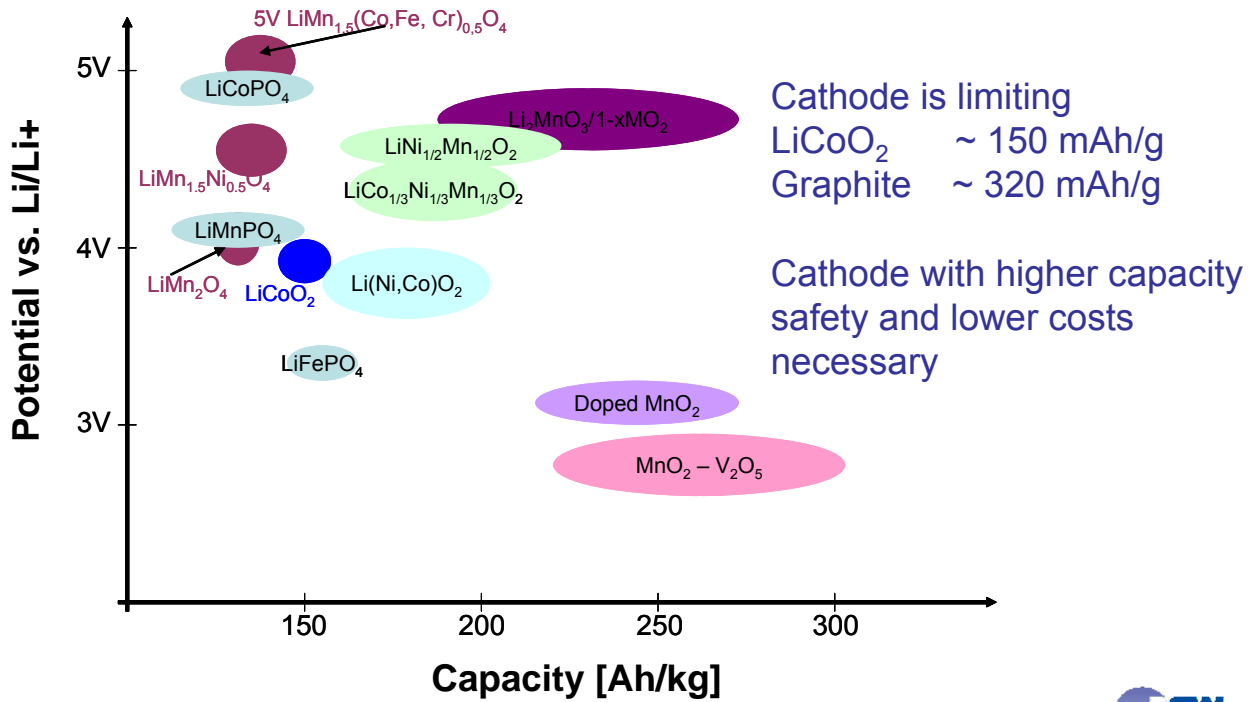
Lithium Batteries show a **long cycle life**.
 3000 cycles today



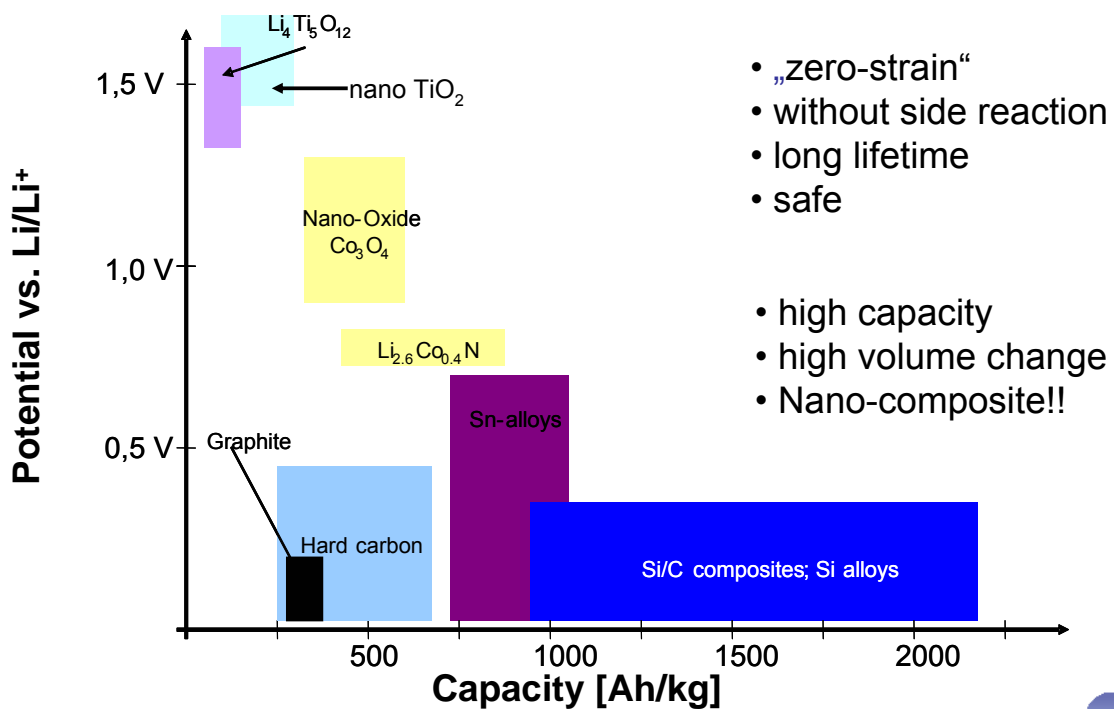
Materials for Lithium-Ion-Batteries



New Cathode Materials



New Anode Materials



Today's Driving Forces in Li-Battery development

Mobile electronics (cellular phone, Laptop etc.) // < 100Wh

very high specific energy,
low cost,
2-3 years/200 cycles lifetime

Hybrid Electric Vehicle (HEV) // 1 kWh

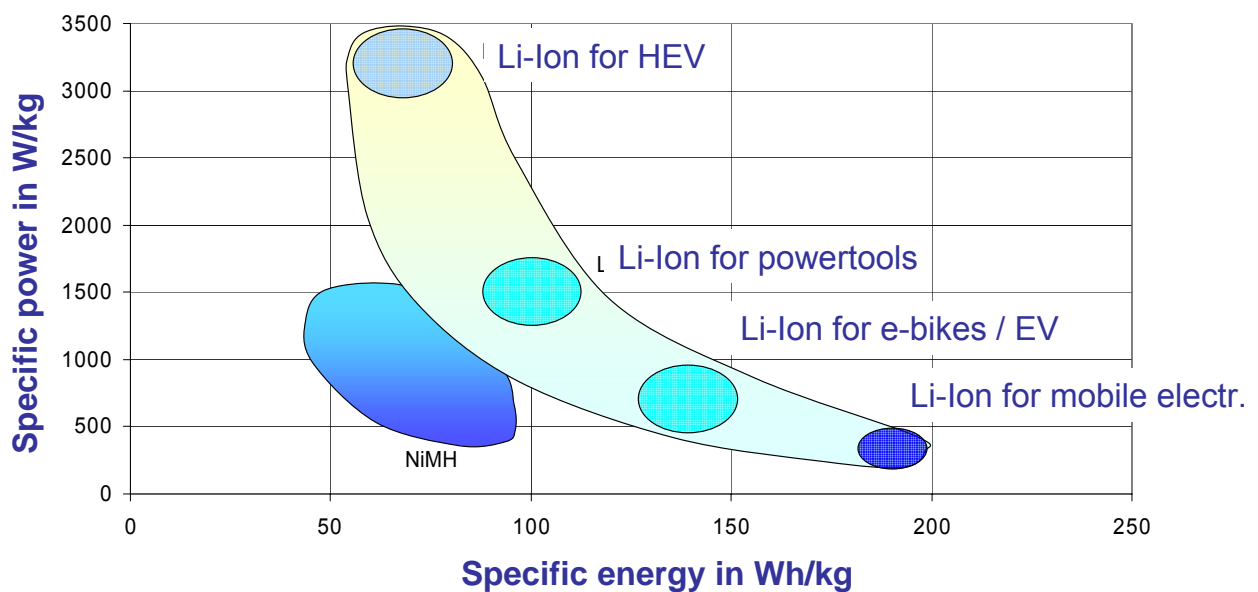
high specific power,
low cost, safety,
>12 years lifetime@ shallow cycling

Plug in Hybrid Electric Vehicle (PHEV) // 5-20 kWh

medium specific power,
high specific energy
low cost, safety,
> 12 years lifetime@ deep cycling (4000 cycles)



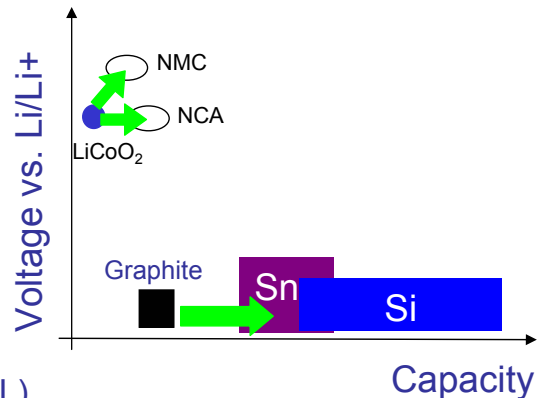
Power and Energy of Li-Ion Batteries for different target applications



Technology Trends for Mobile Electronics

Increase of Cell capacity

- New anode materials
 - Si (Panasonic) based materials
 - Sn (Sony) based materials
- New Cathode Material to achieve higher cell voltage/higher capacity
 - NCA (Panasonic, Sony)
 - NMC (Sanyo)



Increase of battery safety

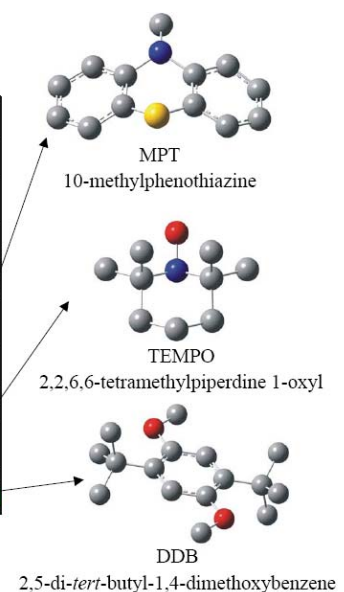
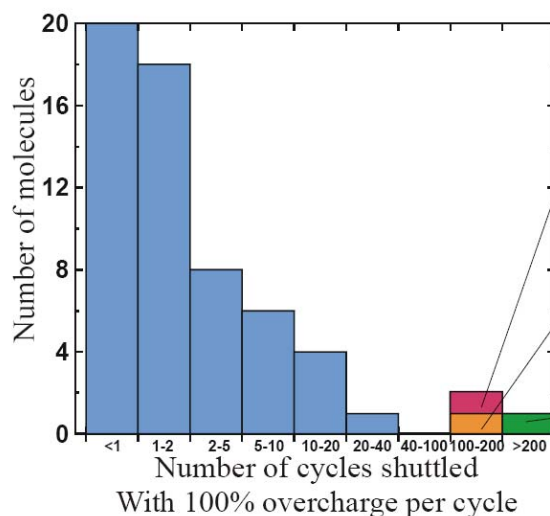
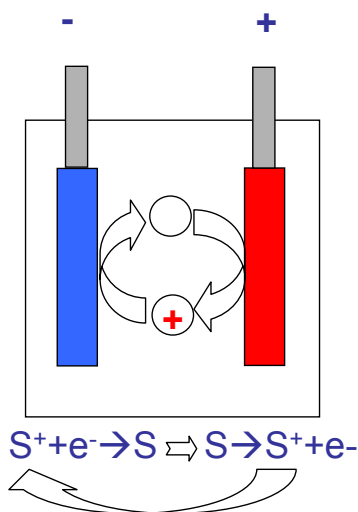
- Development of **heat resistance layer (HRL)**
 - Ceramic coated anode or cathode
 - Heat resistance polymer
 - Ceramic coated Separator

Lifetime is no critical factor

The increase of cell capacity will **reduce lifetime**

- 2 years calendar life
- 200 cycles

Additive for Shuttle-Process in Li-Ion Batteries as substitute for electronic charge equalization systems



J.R. Dahn, *The Electrochemical Society Interface*, Winter 2005

Technology Trends for Hybrid Electric Vehicles

Increase in power

- Increase of conductivity
Coating of Active material with carbon
- Increase of active area
Smaller particles and nano size particles

Increase in low temperature performance

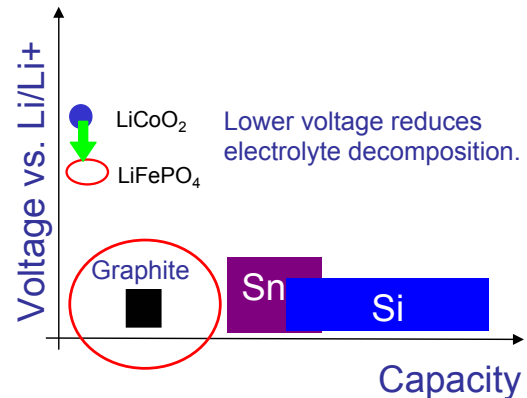
- New electrolytes
- smaller particle size

Increase in battery safety

- New cathode materials (LiFePO_4)
- New separator
- Safer electrolyte

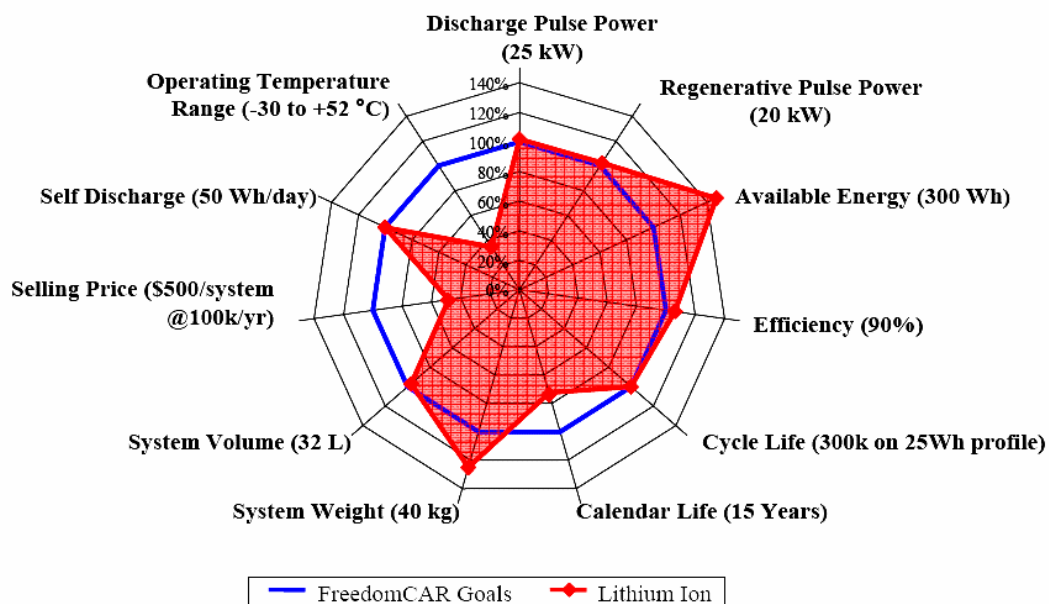
Increase in Lifetime

- Stable cathode (LiFePO_4)
- Improved electrolyte
- Optimized control strategy
- Calendar life at high SOC maybe critical



Li-Ion Batteries for Power Assist HEV

Status: Comparison with FreedomCar targets



Requirements for Stationary Li-Batteries

Increase of power → low priority

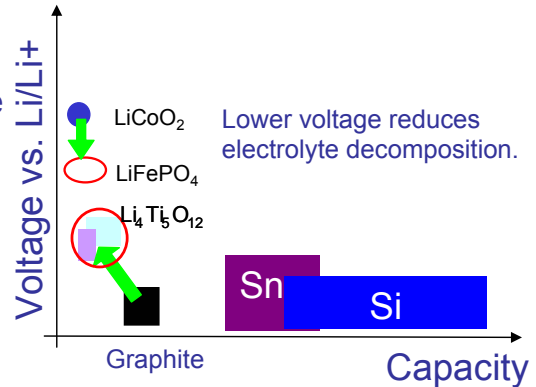
Increase of low temperature performance → low priority

Increase of battery safety → important

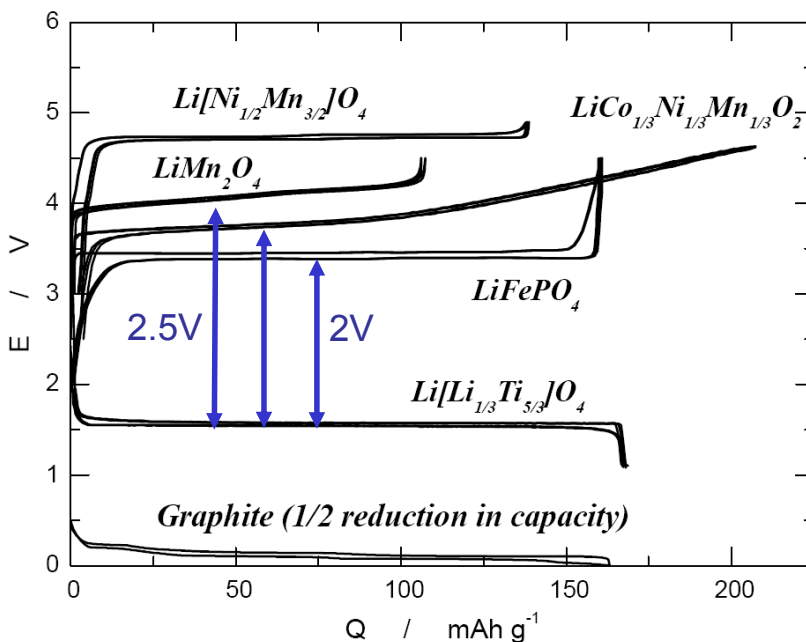
- New cathode materials (LiFePO_4)
- New separator
- Safer electrolyte

Increase of Lifetime → important

- Increase in cycle life
 - Zero strain anode? Gives low cell voltage!
- Increase in calendar life at high state of charge
 - Stable cathode (LiFePO_4)
 - Improved electrolyte
 - Optimized control strategy



Long Life 2V Lithium Battery



Long cycle life possible
(10 000 cycles + ?)

Long calendar lifetime
at high state of charge
(10 years + ?)

But

- only 50% of energy
- higher costs per Wh
- more resources necessary
- more cells necessary

Battery Safety



The safety of Li-batteries can be critical. Million of batteries were recalled in the last 2 years.

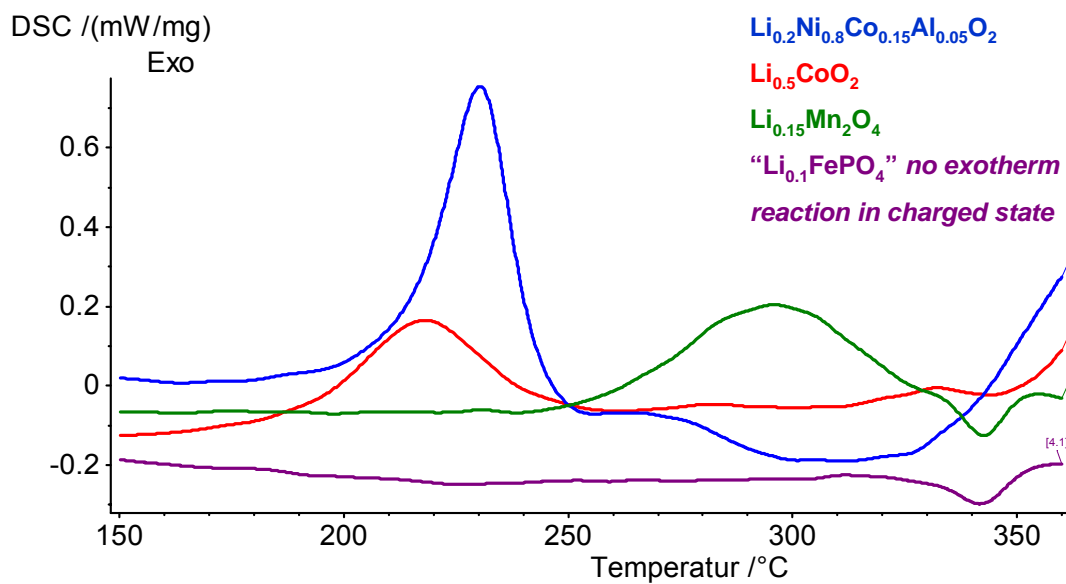
For large stationary systems safety is more critical.

Must be solved by

- new cathode materials
- new electrolytes
- Battery / cell design

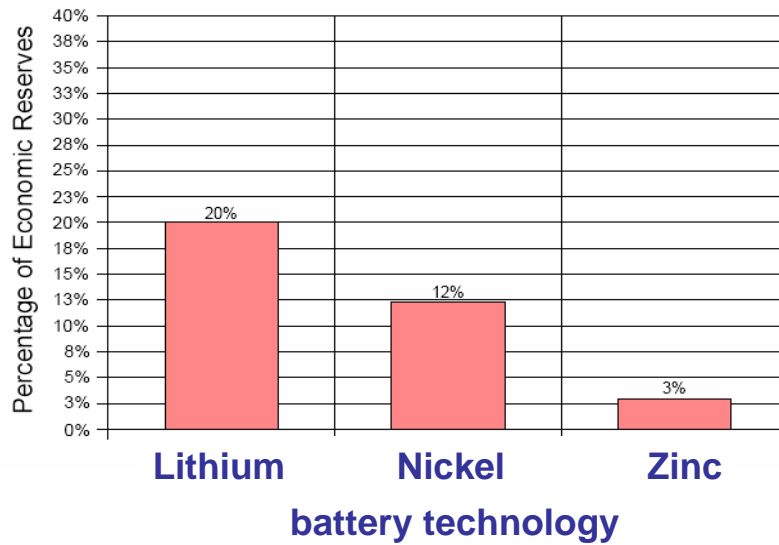


Thermal Stability of different Cathode Materials



A lithium-economy has some limitations

Percentage of Resource Reserves Required to Manufacture 1 Billion 5kWh PHEV Batteries

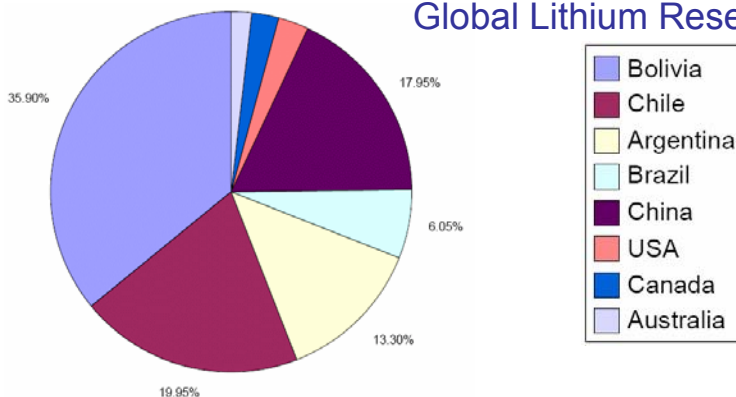


Source: Meridian International Research



The trouble with Lithium

Global Lithium Reserve Base



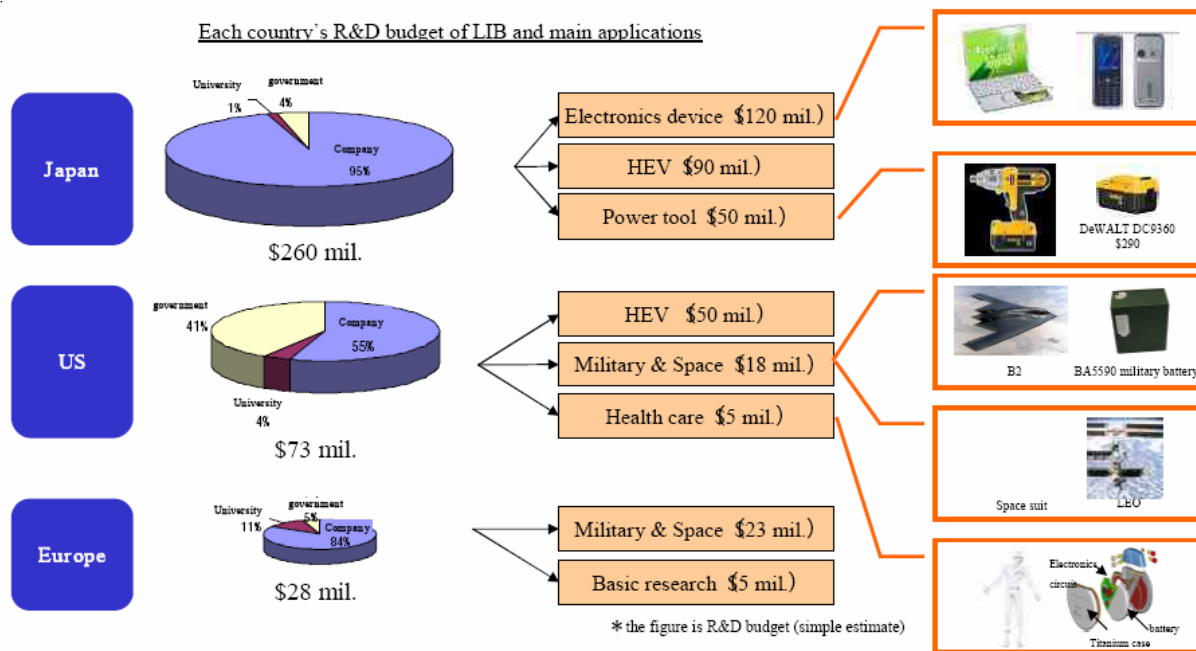
If Li batteries will enter automotive an stationary applications in relevant Market share we have to work on:

- Recycling of Li from used batteries
- Activating of Li resources
- Developing of Li batteries with high cell voltage
- Looking for none Li battery technologies

Source: Meridian International Research



R&D in Li-Batteries



Source: Namura-Report 2006

R&D required for large stationary Li-Batteries

- Further improvement of intrinsic battery safety by use of new cathode materials and improved electrolytes and separators.
- Cost reduction, by new cathode materials, improved engineering and finally mass production.
- Development of Li-batteries that are optimized for stationary applications. Today most R&D is concentrated on mobile electronics and automotive applications.
- Development of new, long-life generation of lithium batteries (2V types are maybe an option).
- Control strategy for lithium ion batteries is totally different from that of other battery technologies.
- Battery state determination methods for LiPFO_4 and other systems with flat discharge voltage curve.

Summary

- Li-batteries show the highest specific energy (up to 200 Wh/kg) of available rechargeable battery systems.
- Today Li-batteries are market leader in portable power sources
- Li-batteries have a high technology potential for further improvement. Today >90% of battery R&D is done on Li-batteries.
- Upscaling of lithium batteries from 100 Wh storage to large stationary systems requires further R&D with the targets:
 - lower costs
 - improved battery safety
 - longer lifetime
- New Li-battery technologies optimized for stationary applications will show excellent performance, but some technologies will have higher specific costs.
- A “Lithium economy” is maybe limited by the available Li-resources.
- Lithium battery R&D in Europe low
- Worldwide no Li-battery R&D focus on stationary applications