Mitglied der Helmholtz-Gemeinschaft

Perspektiven und Limitierungen elektrochemischer Energiespeicher

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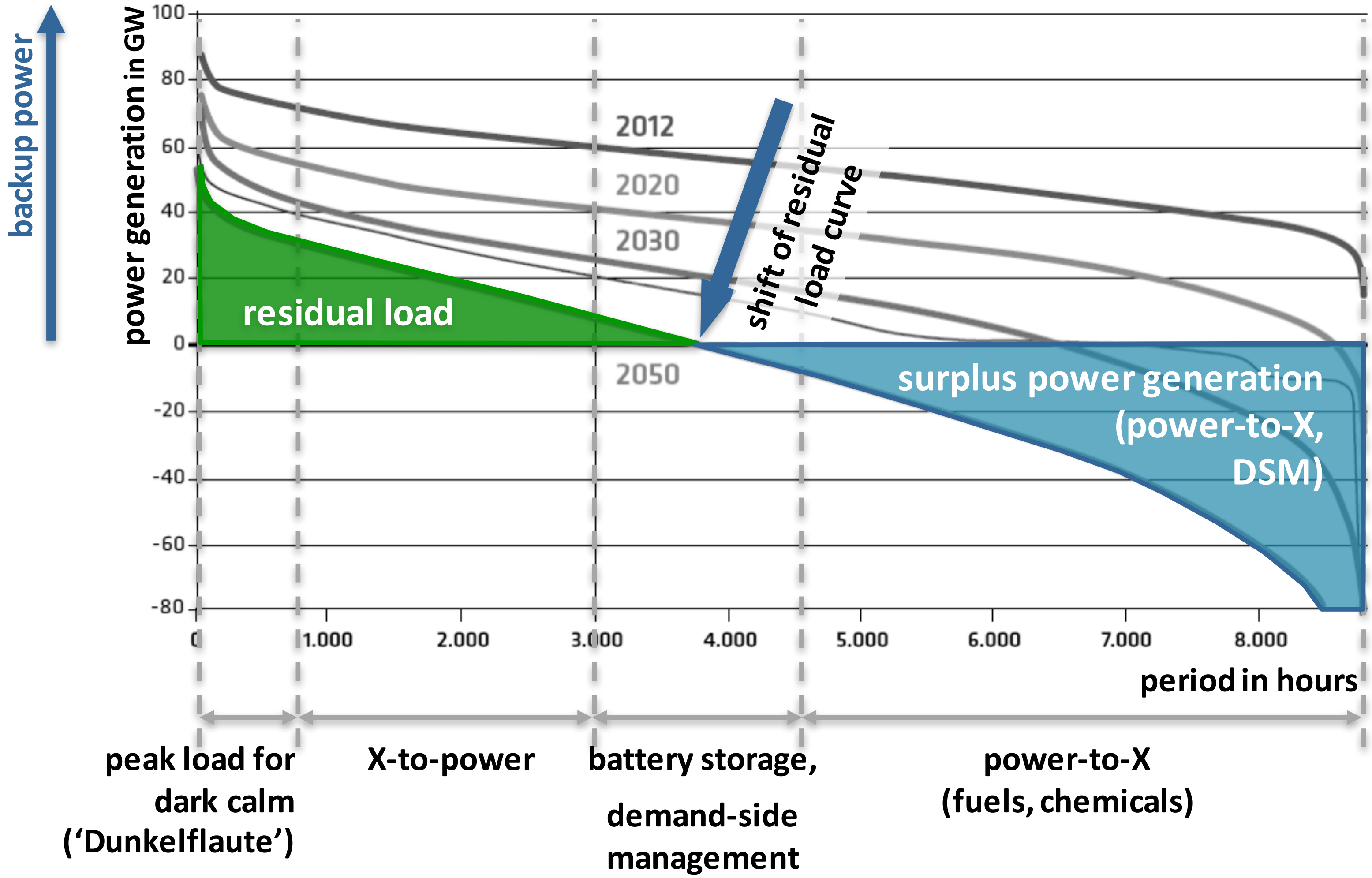
AK-Energie, DPG-Frühjahrstagung, Regensburg | 7. 3. 2016

‚Energiewende‘ –
prognostizierte Residuallast & ‚Überschussstrom‘



source: Fraunhofer ISE – Energiesystem Deutschland 2050

Szenarien und Technologien zur stationären Energiespeicherung

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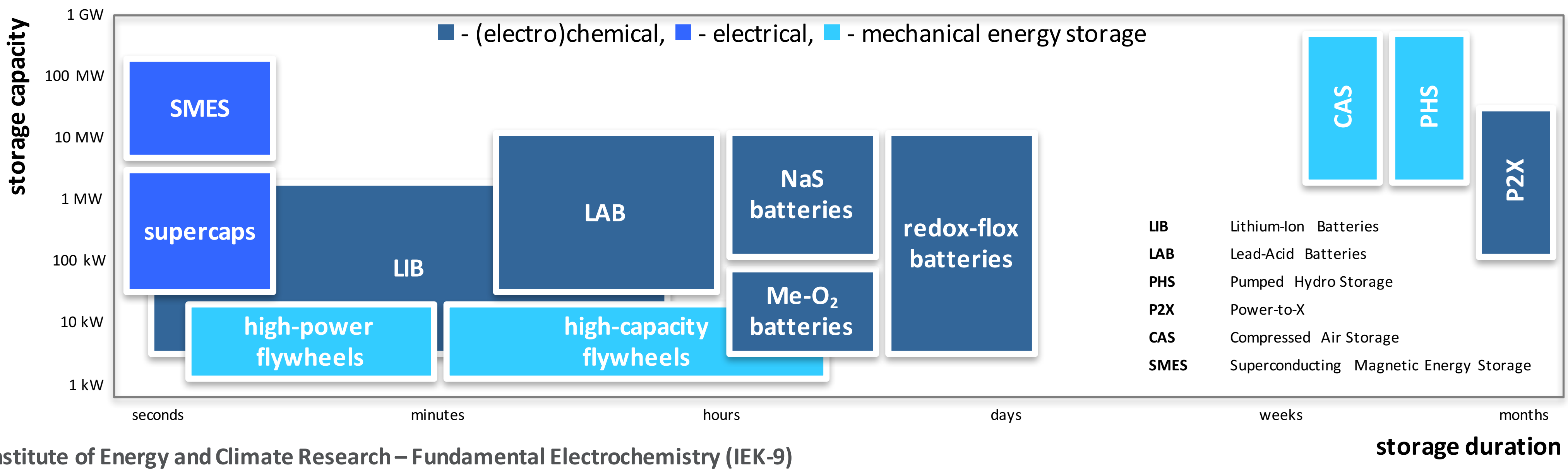
power management	energy management		
milliseconds - seconds: ▪ power quality: frequency stabilization ▪ un-interruptible power sources (UPS)	**minutes:** ▪ island systems / off-grid stand-alone ▪ emergency power ▪ black start	**minutes - hours:** ▪ arbitrage trade ▪ generation & load smoothing (peak shaving, load leveling) ▪ island systems / off-grid stand-alone ▪ emergency power	**weeks - months:** ▪ seasonal energy storage

high cycle efficiency ⟷ moderate cycle efficiency

moderate capacity ⟷ **high capacity**



outline –
storage-related issues for a transition of the energy system

power management

1. short-term power regulation
   - lithium-ion batteries

energy management

1. mid-term decentralized energy storage
   - advanced lithium-ion
   - post-lithium ion & post-lithium
2. long-term seasonal energy storage – power-to-gas
   - electrolysis (alk., PEM, SOEC)
3. power-to-X: e-fuels & e-chemicals
   - power-to-fuels (co-electrolysis)
4. X-to-power
   - fuel cells (PEM, SOFC)

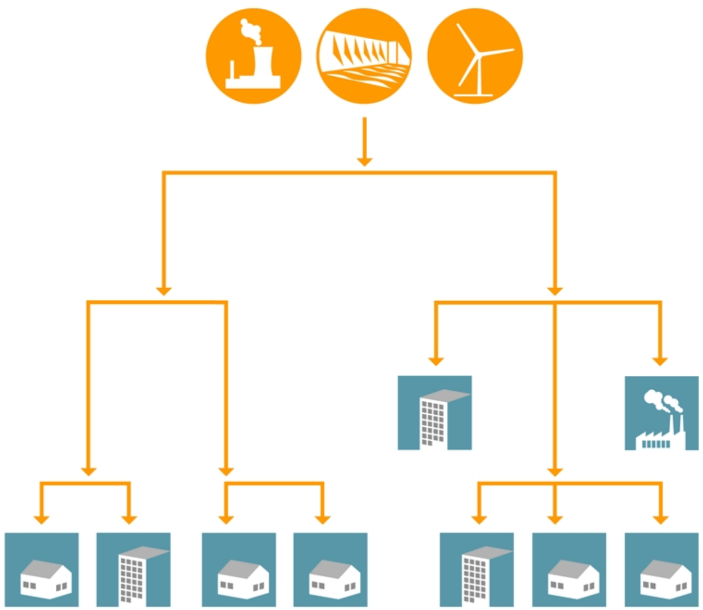
electro mobility

1. battery electric vehicles
2. fuel cell electric vehicles


short-term grid storage
5 MW / 25,000 LIBs, YOUNICOS

future grids with renewables

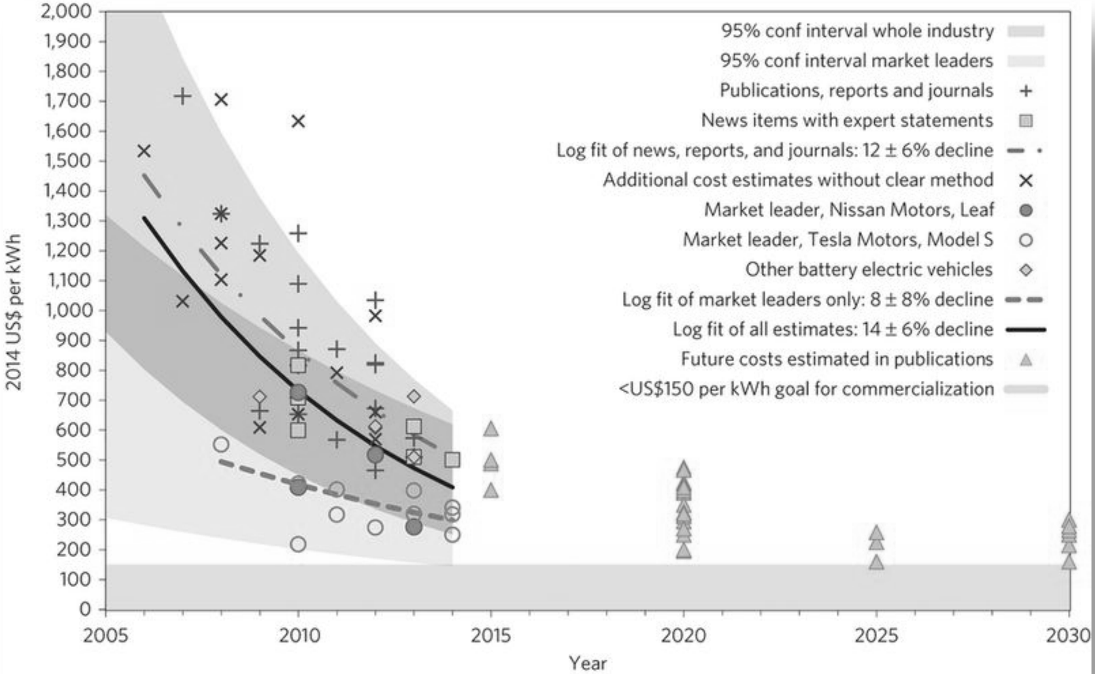
zentrale Stromversorgung



dezentrale Stromversorgung

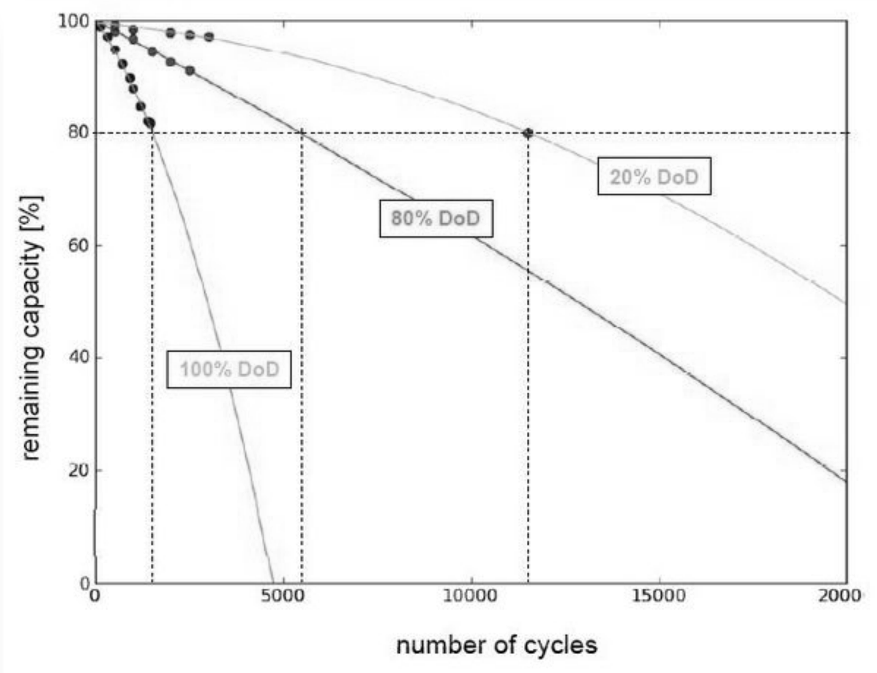
stationary grid storage – key requirements

cost ('economy of scale')



source: Nykvist and Nilsson (2015)

cycle life ('aging')

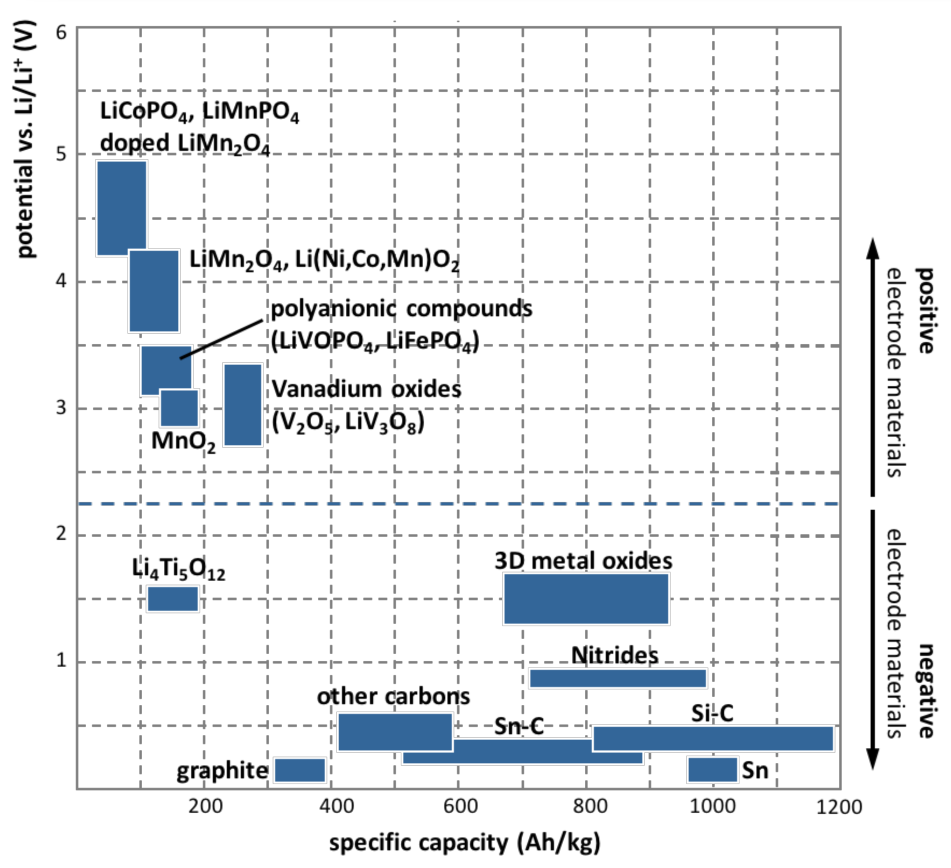


target costs grid storage: **100 $/kWh**

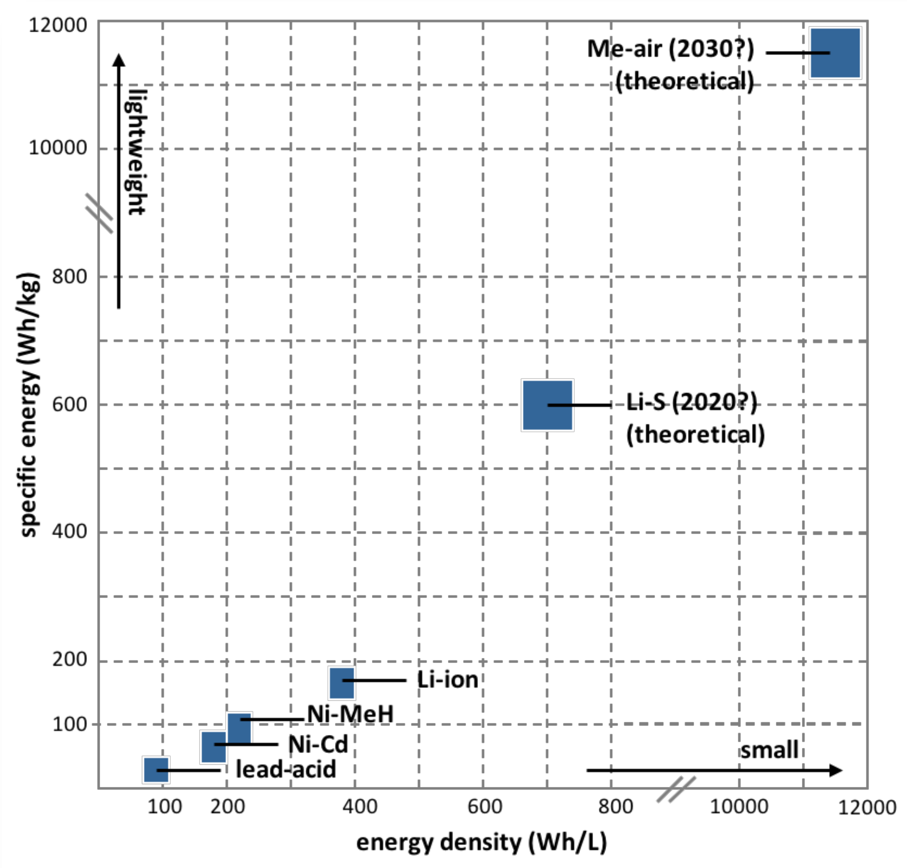
target lifetime grid storage: **7000 cycles**

ansatz for improvement – enhanced energy density

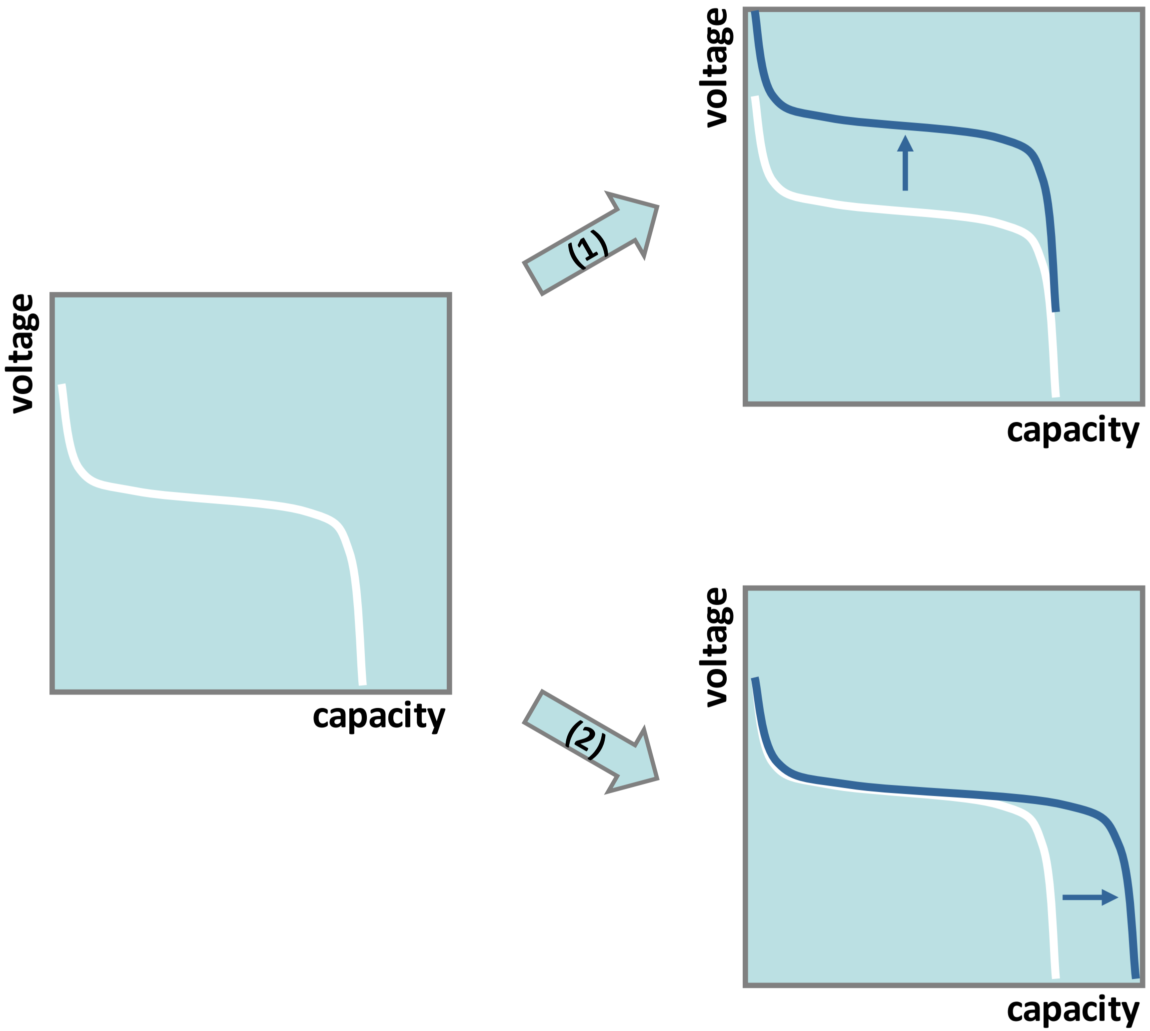
ansatz 1: novel materials



ansatz 2: novel concepts



strategies for next-generation lithium-ion batteries: improved energy density



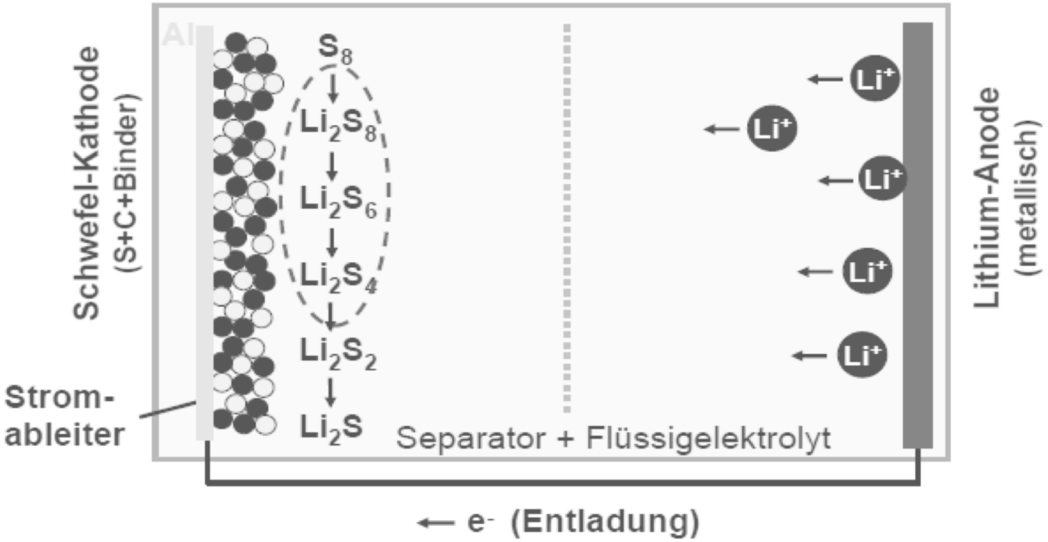
high-voltage cathode materials:

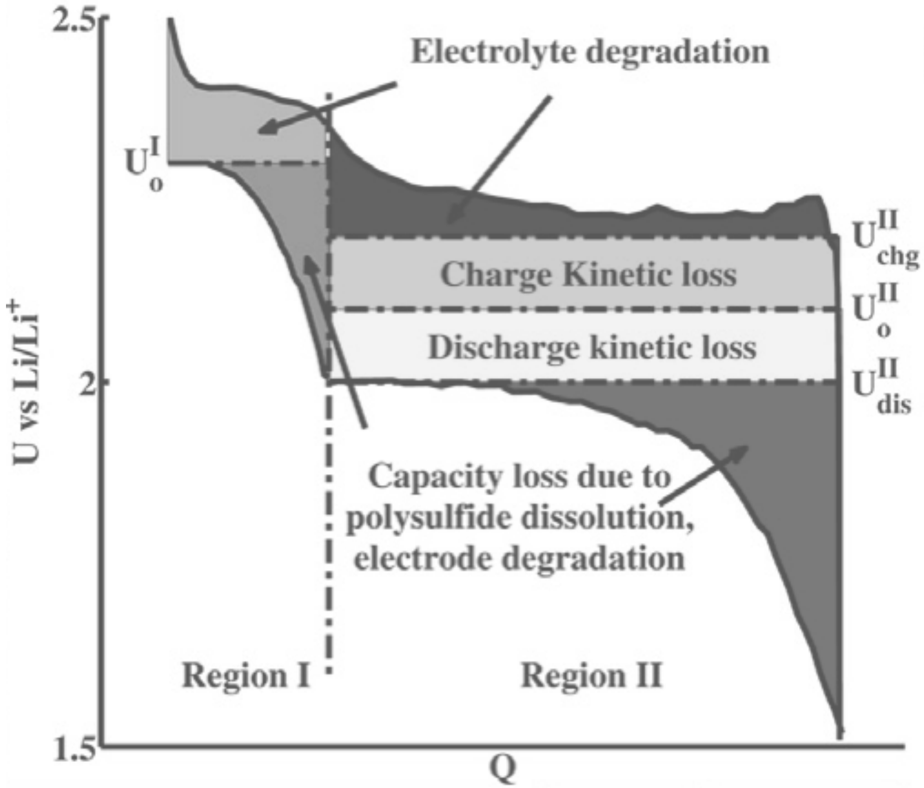
- $LiNi_{0.5}Mn_{1.5}O_4$
  (3D framework structure)
- voltage: **5 V**
- capacity: 140 mAg^{-1}

high-capacity cathode materials:

- $Li_2MnO_3 – Li(Ni_{1/3}Co_{1/3}Mn_{1/3})O_2$
  (2D layered structure)
- voltage: 4 V
- capacity: **250 $mAhg^{-1}$**

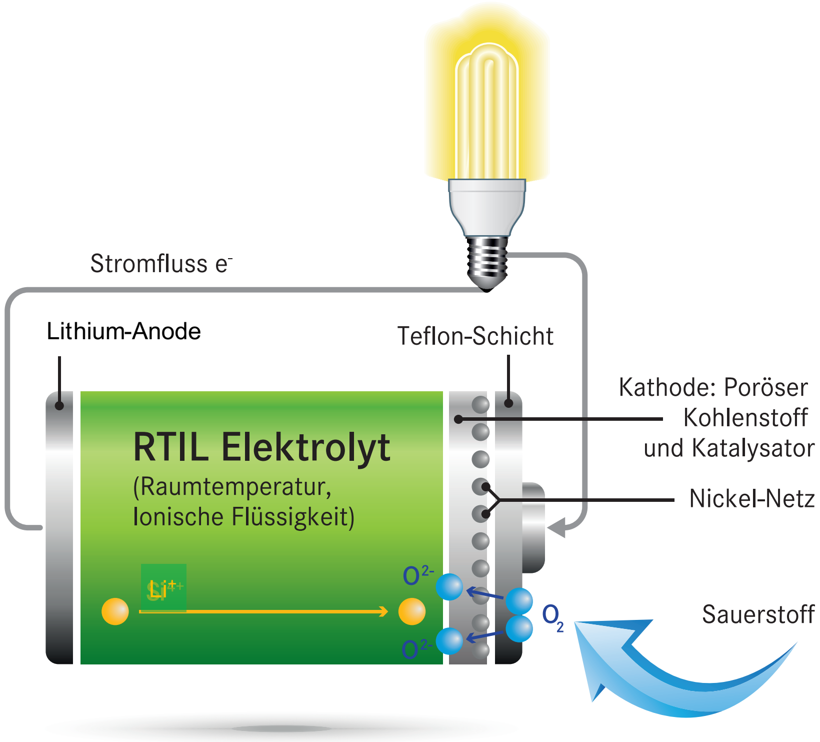
post lithium-ion batteries – Li-S_8

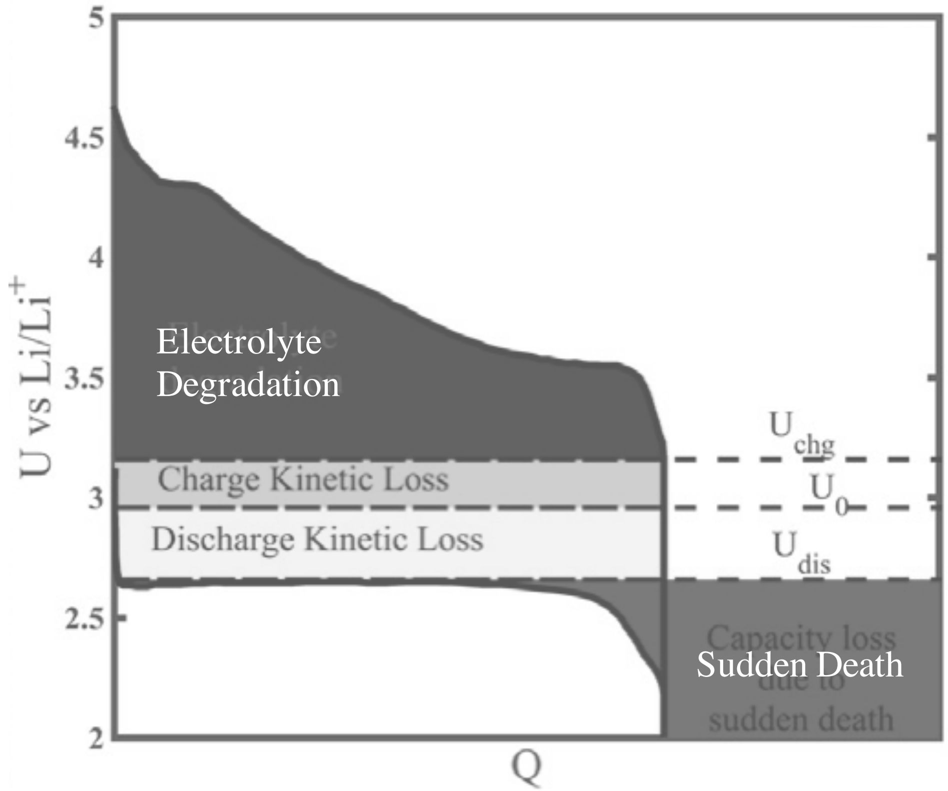




- electrically insulating redox pair (S_8/Li_2S)
- sulfur/polysulfide leaching into electrolyte
- instability of (available) electrolytes
- limited cycle life

post lithium-ion batteries – Li-O_2

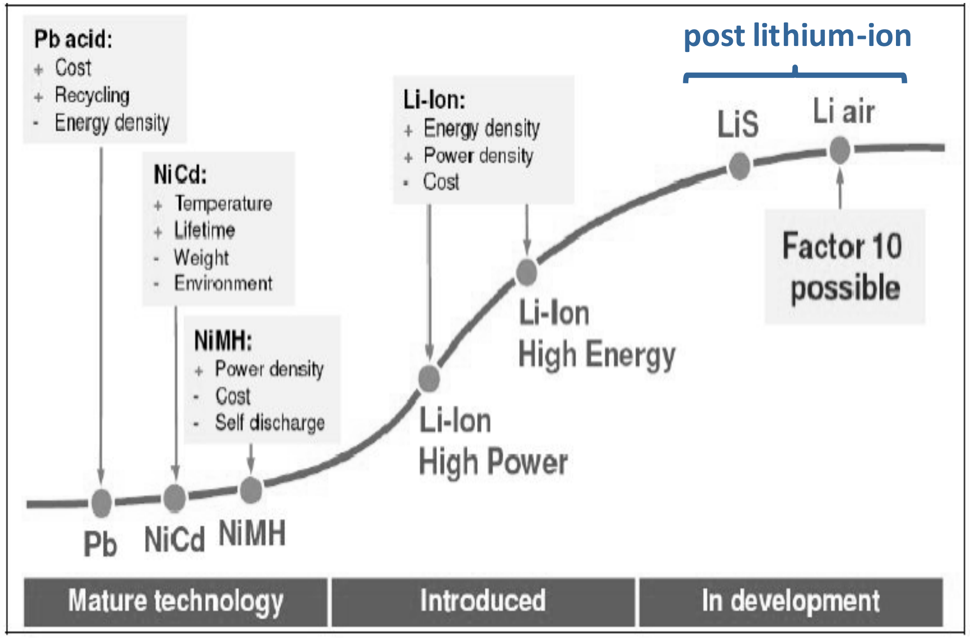




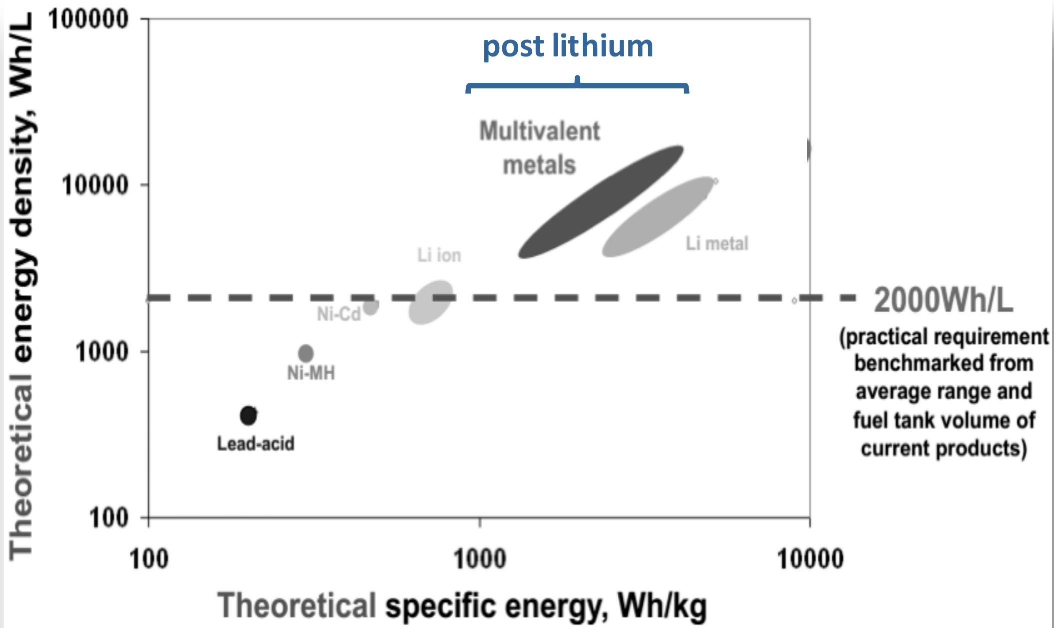
- reactivity of the O_2^--radical major obstacle:
  - common electrolytes decompose
  - catalysts enhance decomposition
  - reactivity with common binders such as PVDF
  - reactivity with carbon matrix to form Li_2CO_3
- formation of atomic oxygen during recharge (Li_2O_2 decomposition)
- limited cycle life, efficiency

post Lithium-ion & post-Lithium batteries

post lithium-ion technologies



post lithium technologies



post Lithium-ion concepts:

- enhanced energy density
- challenge: improve cycle life

post Lithium concepts:

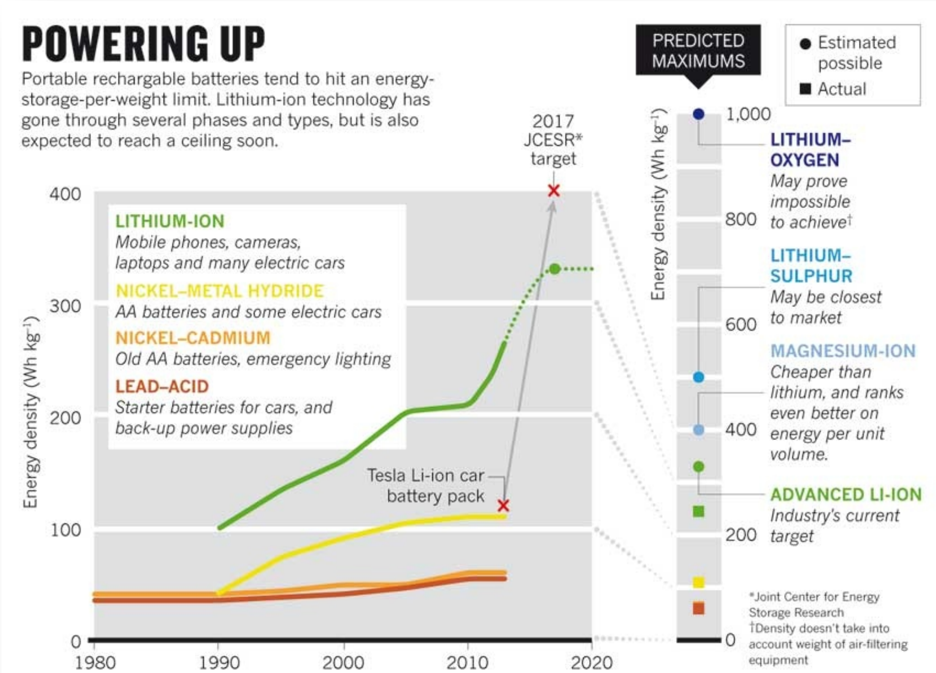
- use of earth-abundant raw materials
- processing under ambient conditions
- challenge: improve cycle life

post-lithium battery options – Me-O_2

	Fe-O_2	Zn-O_2	Li-O_2	Al-O_2	Si-O_2
specific energy	80 Wh/kg (theo. 1000 Wh/kg)	150 Wh/kg (theo. 1084 Wh/kg)	600 Wh/kg (theo. 11246 Wh/kg)	500 Wh/kg (theo. 8146 Wh/kg)	400 Wh/kg (theo. 8470 Wh/kg)
cycleability (@ 80% DOD)	> 1000 cycles	< 500 cycles (limited by Zn dendrites)	< 100 cycles (limited by disproportionation reactions)	10 cycles	---
cost	< 100 € / kWh	< 200 € / kWh	500 € / kWh	< 200 € / kWh	< 200 € / kWh
safety	good	good	risks associated to Li-metal	good	good
complexity of design	medium / low	medium / high	high	medium / high	medium / low

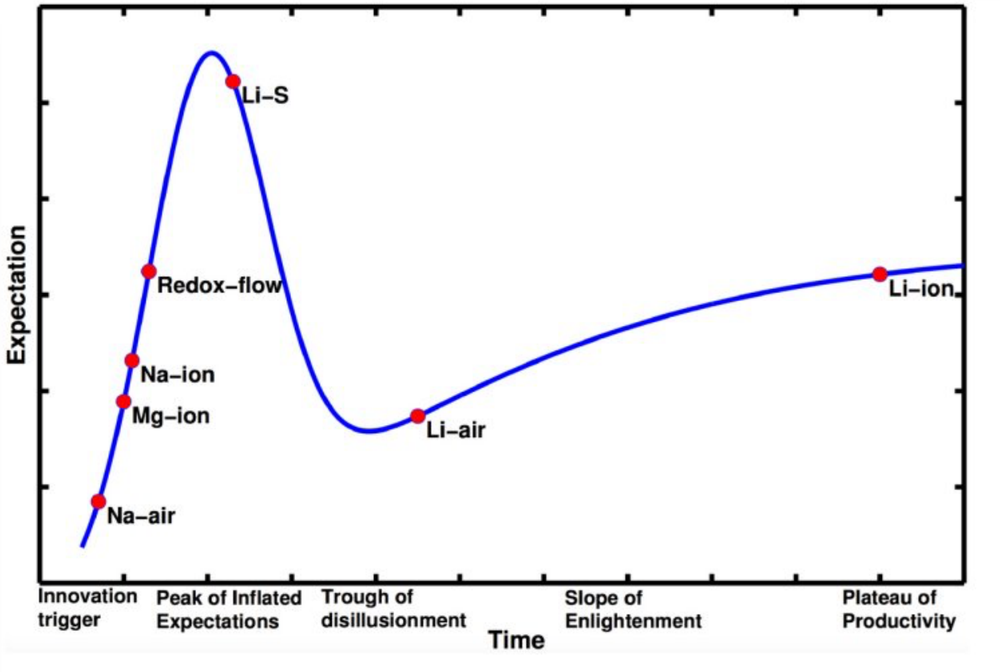
post lithium technology – roadmap & 'hype chart'

roadmap for post-lithium batteries



courtesy of IBM Almaden

different iterations of product cycles ('hype chart')

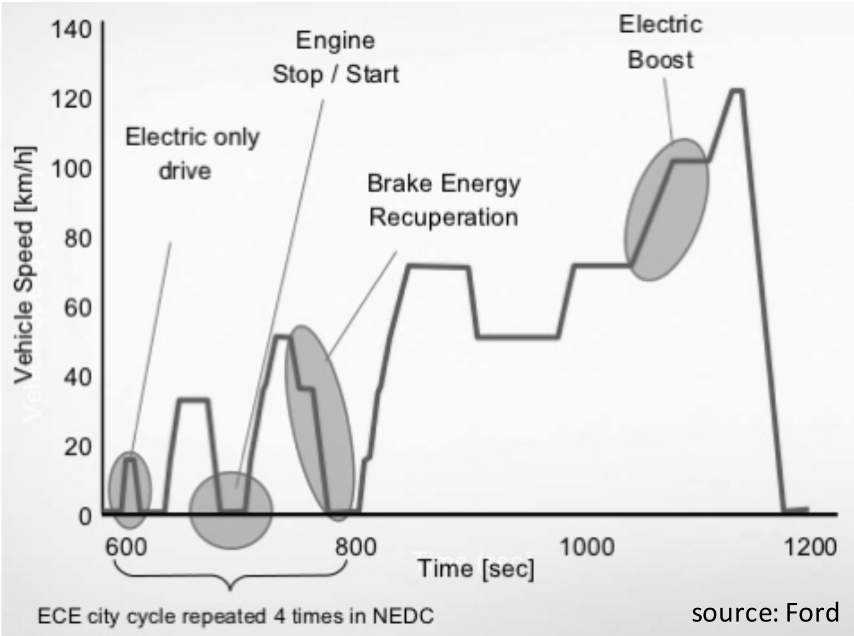


O. Sapunkov et al., Transl. Mater. Res. **2** (2015) 045002.

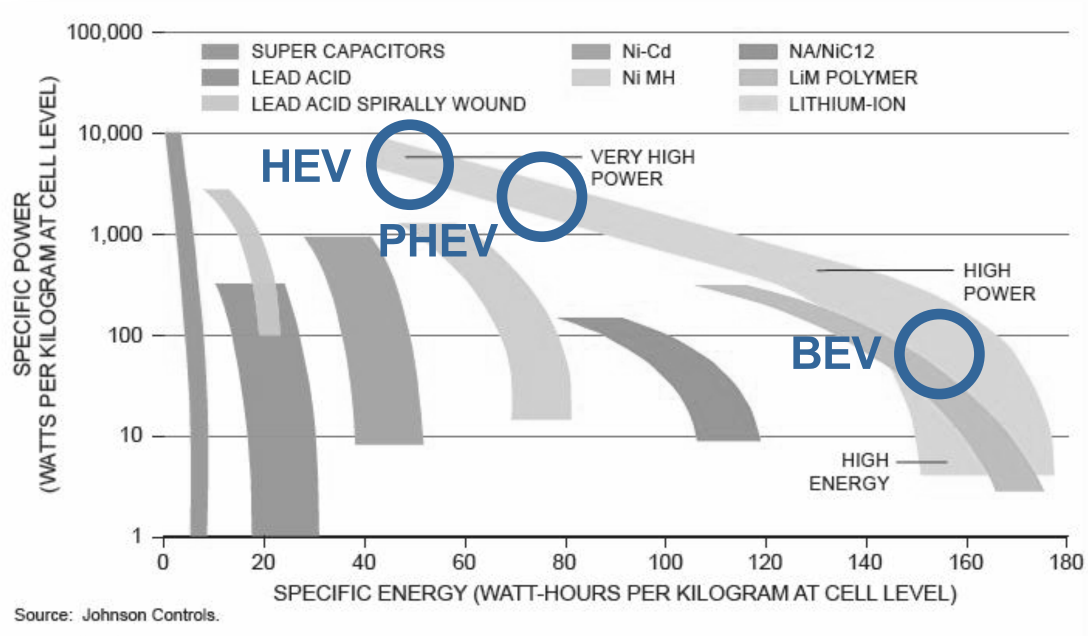
electromobility

electromobility – technical key requirements

basic functions of electrified powertrains



energy vs. power density (Ragone plot)



tradeoff between power- and energy density

electro-mobility – objectives

high safety & reliability

- status: ‘thermal runaway’
- goal: safe operation

low cost

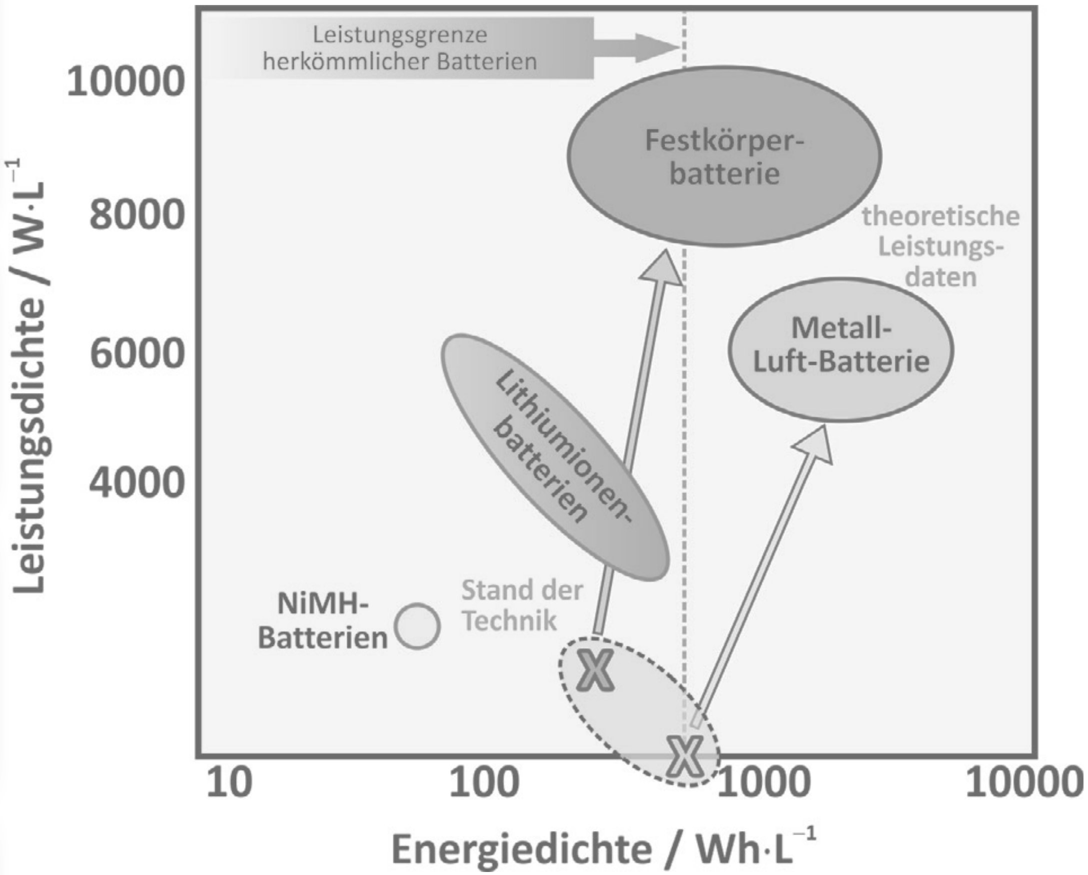
- status: 150-200 EUR / kWh
- goal: < 100 EUR / kWh

high energy **&** power density

- status: 520 Wh/L
- goal: ~ 800 Wh/L

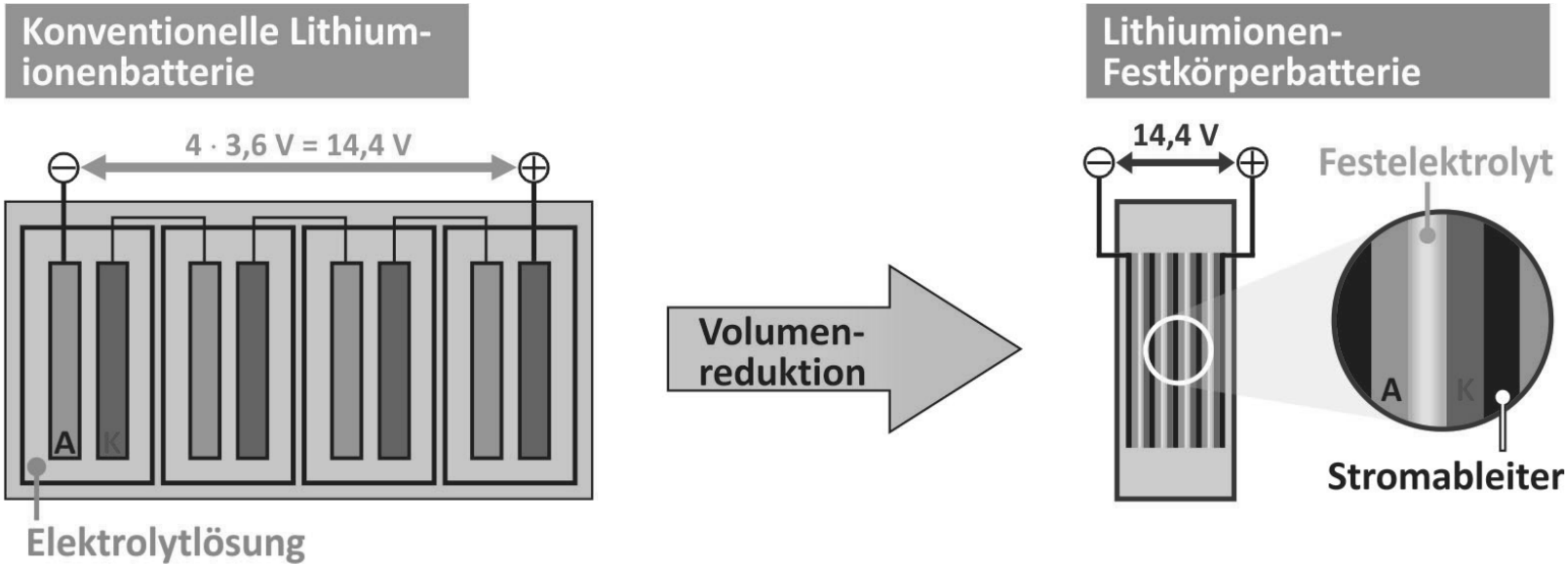
long lifetime

- status: < 10y
- goal: > 10y



source: Toyota Pressemitteilung (2011);
Stefan Berendts, Technische Universität Berlin

all solid-state batteries – improved energy density

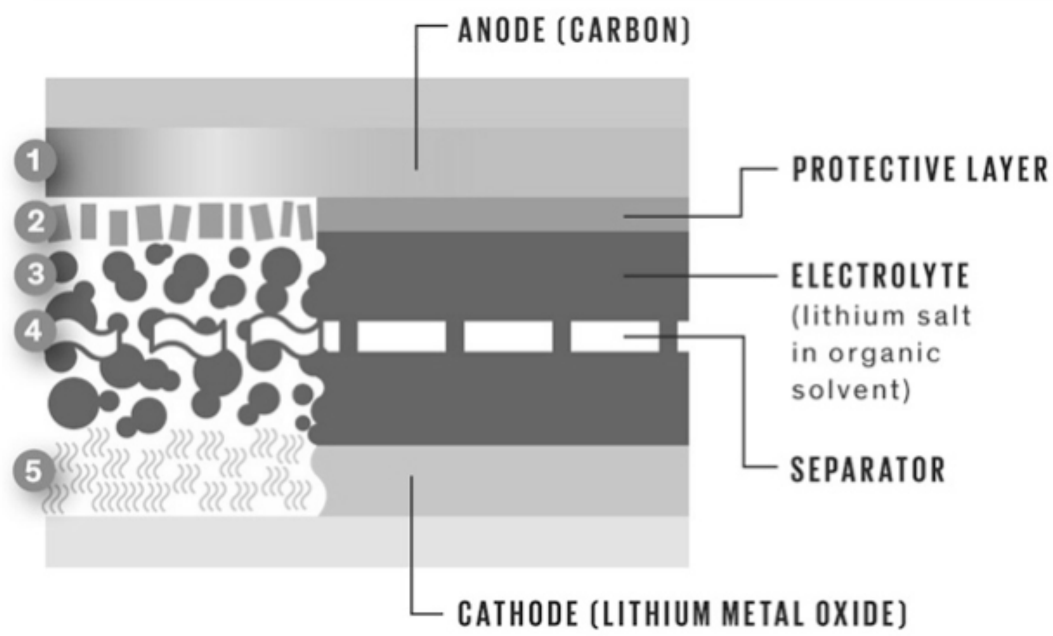


- kompaktere Bauweise bei gleicher Kapazität
- reduziertes Volumen der Batterie auf ein Fünftel

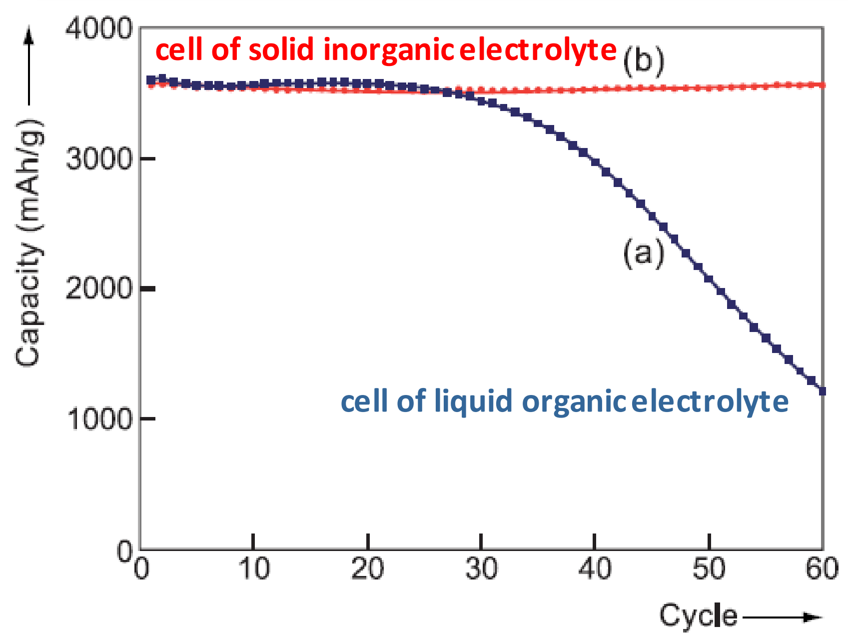
source: Toyota Pressemitteilung (2011)
Stefan Berendts, TU Berlin

all solid-state batteries – safety & reliability

safety (‚thermal runaway‘)



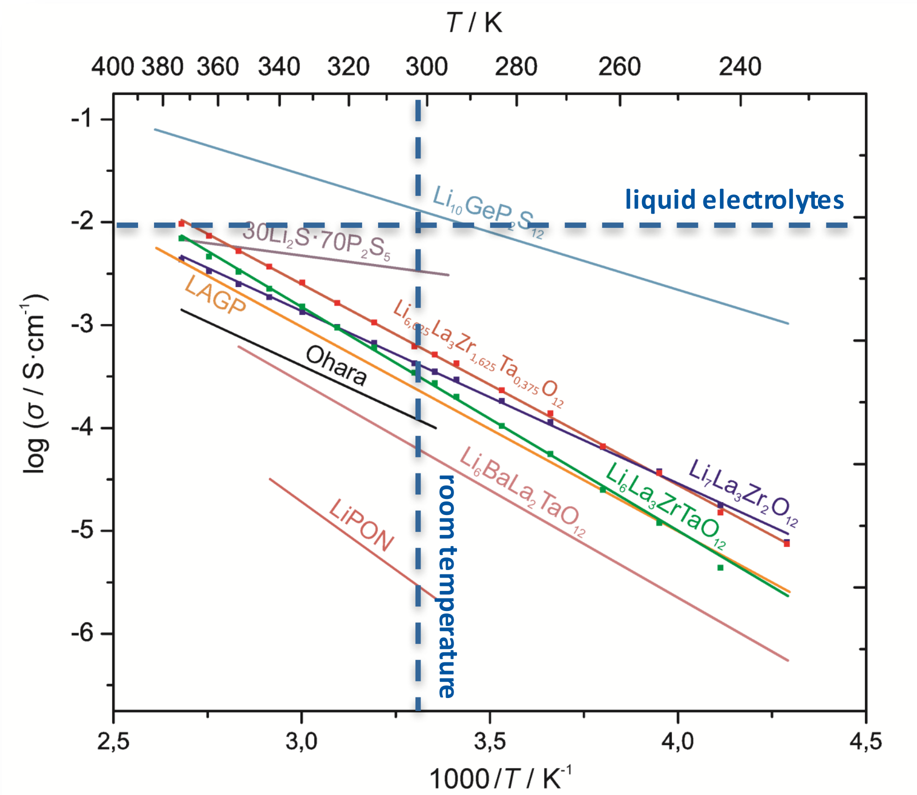
reliability (cycle life)



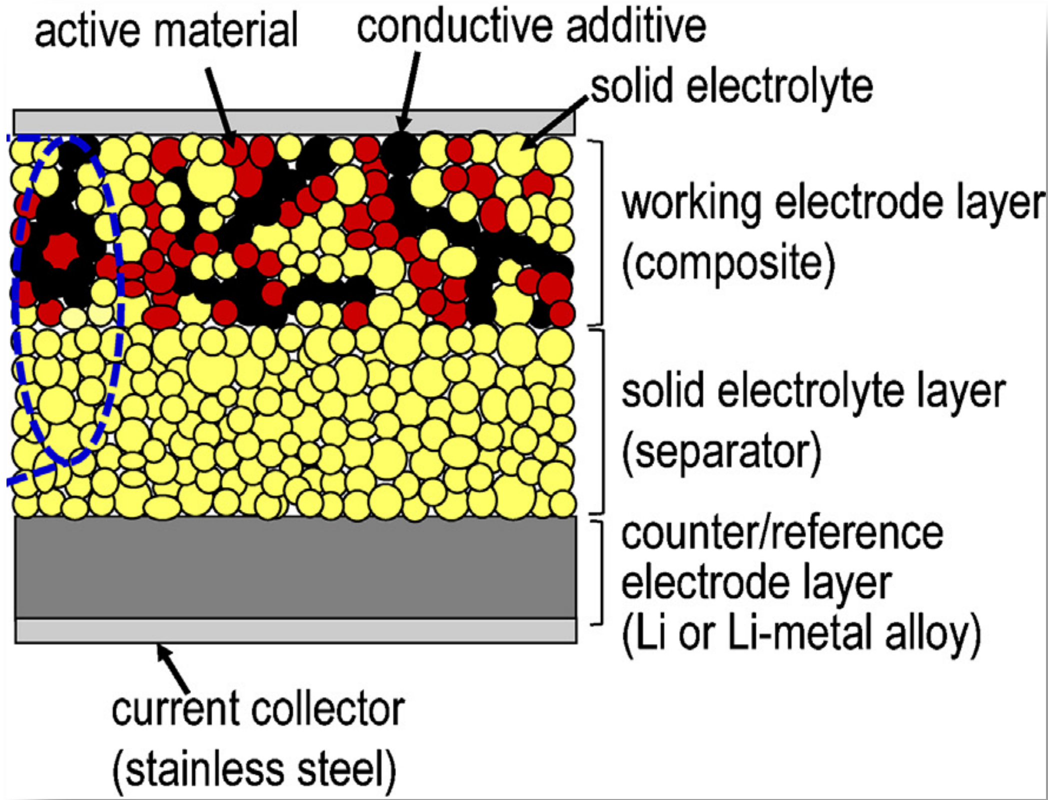
P. Notten et al., Adv. Energy Materials (2008)

all solid-state batteries

ionic conductivity



composite electrodes (transition resistance)



Tatsumisago et al., J. Asian Ceramic Soc. 1 (2013) 17

TESLA patent – metal-air battery as range extender

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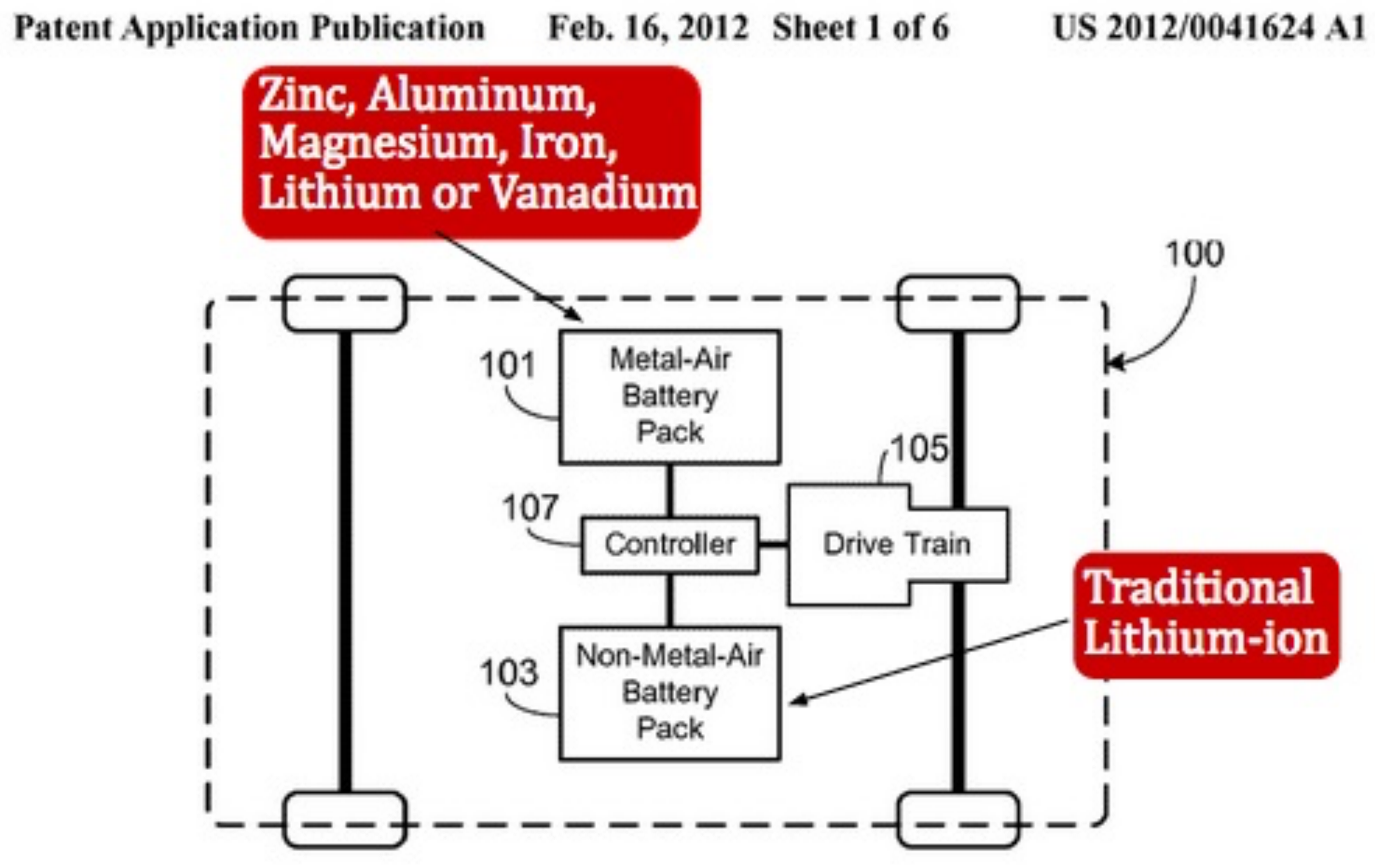


FIG. 1

Moore ‘s law and battery performance

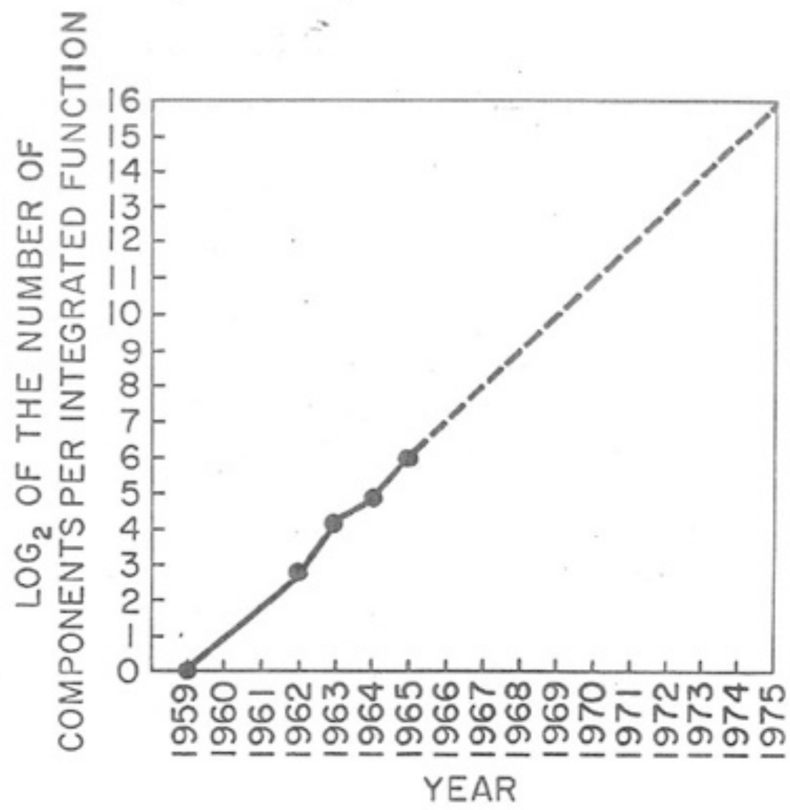
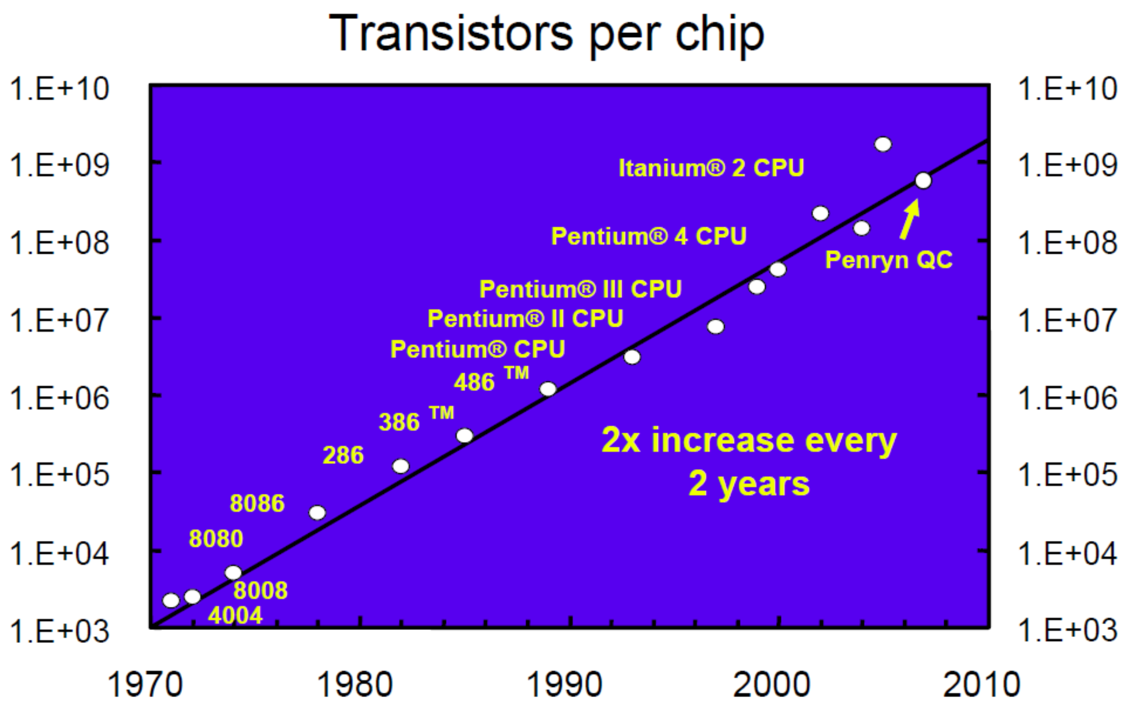
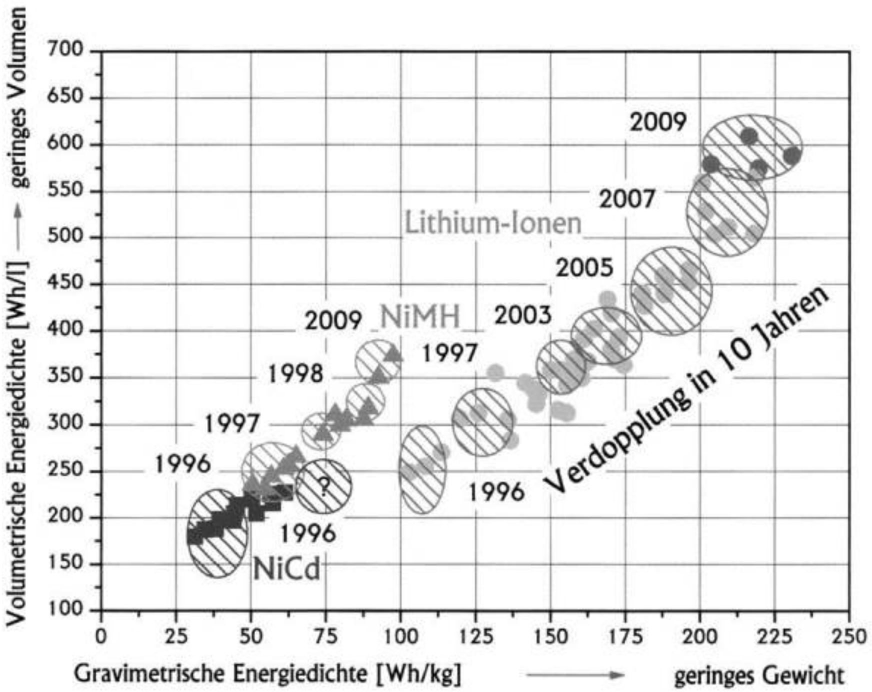


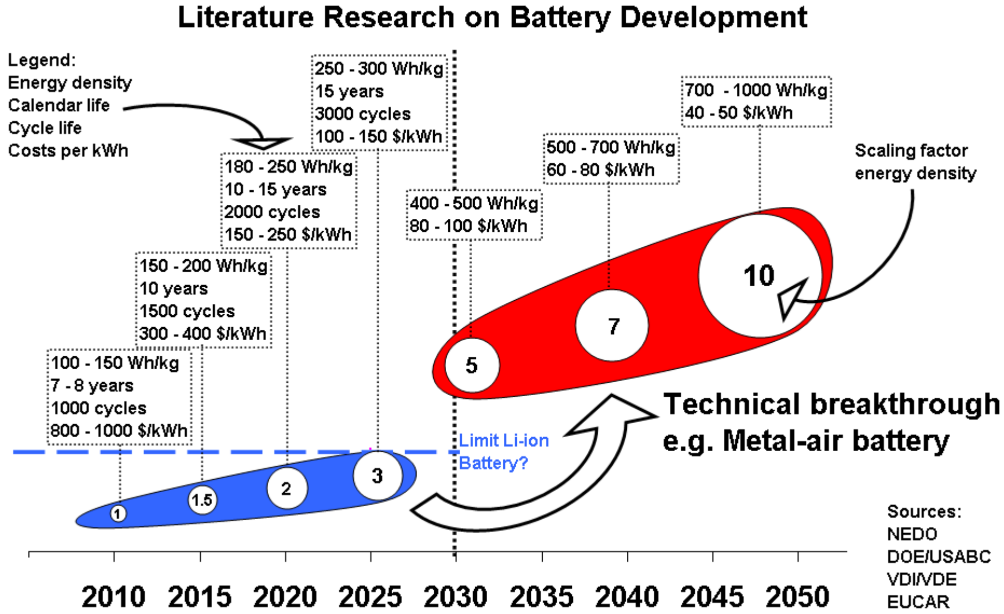
Fig. 2 Number of components per integrated function for minimum cost per component extrapolated vs time.



- **‚Moore’s Law‘**: performance in integrated circuits doubles about every two years (Gordon Moore, co-founder of Intel, 1967)
- today: public has become accustomed to rapid progress in mobile phone technology, computers, and access to information

Moore's law and battery performance





B. Schott, C. Günther, A. Jossen: *Batterie-Roadmap 2020+*, ZSW-Studie, April 2010

- Moore's Law not applicable to battery technology: doubled performance in energy density in ten years (courtesy of Panasonic)
- Improvements in battery development are almost entirely based on higher energy density and that's limited by physics.
- necessety of developing revolutionary new battery design