Technologies and Potentials of Electro-chemical Energy Storage Systems for the Local Public Transport

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Electrochemical Energy Conversion and Storage Systems
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Motivation

Masterplan electro mobility of the German federal government:

→ 1 Million electric vehicles until 2020 (2,5 %)

What about the local public transport?

Source: APTS

The local public transport…

- …is visible!
- …has a “green” image (until now)
- …therefore particularly needs to reduce emissions and environmental impact
- …offers the chance to introduce E-mobility due to
  - Predictable operation range and known load profiles
- …needs suitable batteries!

Outline

- Motivation
- Demands to…
  - the battery system
  - infrastructure
- Overview on different technologies
- Summary

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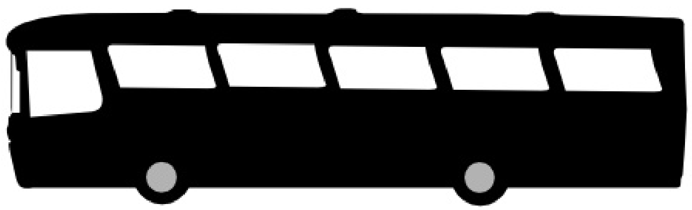
Automotive Sector – Demands to the Battery System

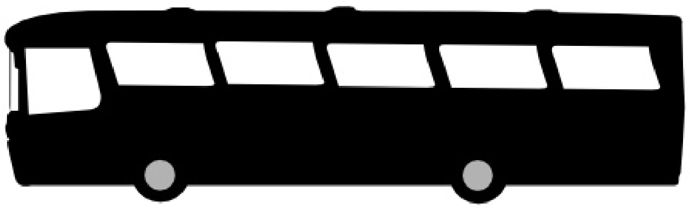
- Hybrid vehicles – battery usage



	Public transport	**Private cars**
Accelerating & braking	1 cyc./min. (~ 3 % cyc. depth)	0.6 … 0.9 cyc./min. (~ 3 % cyc. depth)
Hours of operation	5,000 /year	400 /year
15 years ➔	**4,500,000 cyc.** (~ 3 % cyc. depth)	**216,000 … 324,000 cyc.** (~ 3 % cyc. depth)

Automotive Sector – Demands to the Battery System

- Battery (full) electric vehicles – battery usage



	Public transport	Private cars
Distance per battery charge	80 km (~10% of total bus weight)	80 km
Hours of operation	5,000 /year	400 /year
Avg. speed	18 km/h	30 km/h
15 years ➔	**16,875 full cyc.**	**2,250 full cyc.**

Infrastructure Needs for Battery Electric Buses 1/3

- Starting point – 12 m-Bus:
  - Average speed: **18 km/h**
  - Electrical energy consumption: **2.7 kWh/km**

48,6 kWh consumed per hour

- Recharging at bus stops (overhead lines, induction systems, …)
  - Approx. time at bus stops: 20 min/h

146 kW charging power necessary…at every bus stop!


Source: Conductix-Wampfler

Infrastructure Needs for Battery Electric Buses 2/3

- 16 h of operation per day is an energy need of **778 kWh/day**
  - Full battery charge (250 kWh) "each morning" still means 33 kWh per hour left to recharge
  - For example, charging with 500 kW (!) allows to **"only"** recharge at every **5th bus stop**!

Recharge during operation is a must!

500 kW is more than 2x the max. power needed for operation (propulsion & aux.)

➔ Charge acceptance more critical than discharge power! (→ battery design)

<u>Here:</u>
For a 250 kWh-Battery, 500 kW is "only" 2 C

➔ No need for really "high" charge acceptance of the battery

Infrastructure Needs for Battery Electric Buses 3/3

➔ **Can battery exchange systems be a solution?**


Source: Better Place


Source: www.youtube.de

Demand for
battery packs per bus
> 1
(between 1.3 and 2)

Outline

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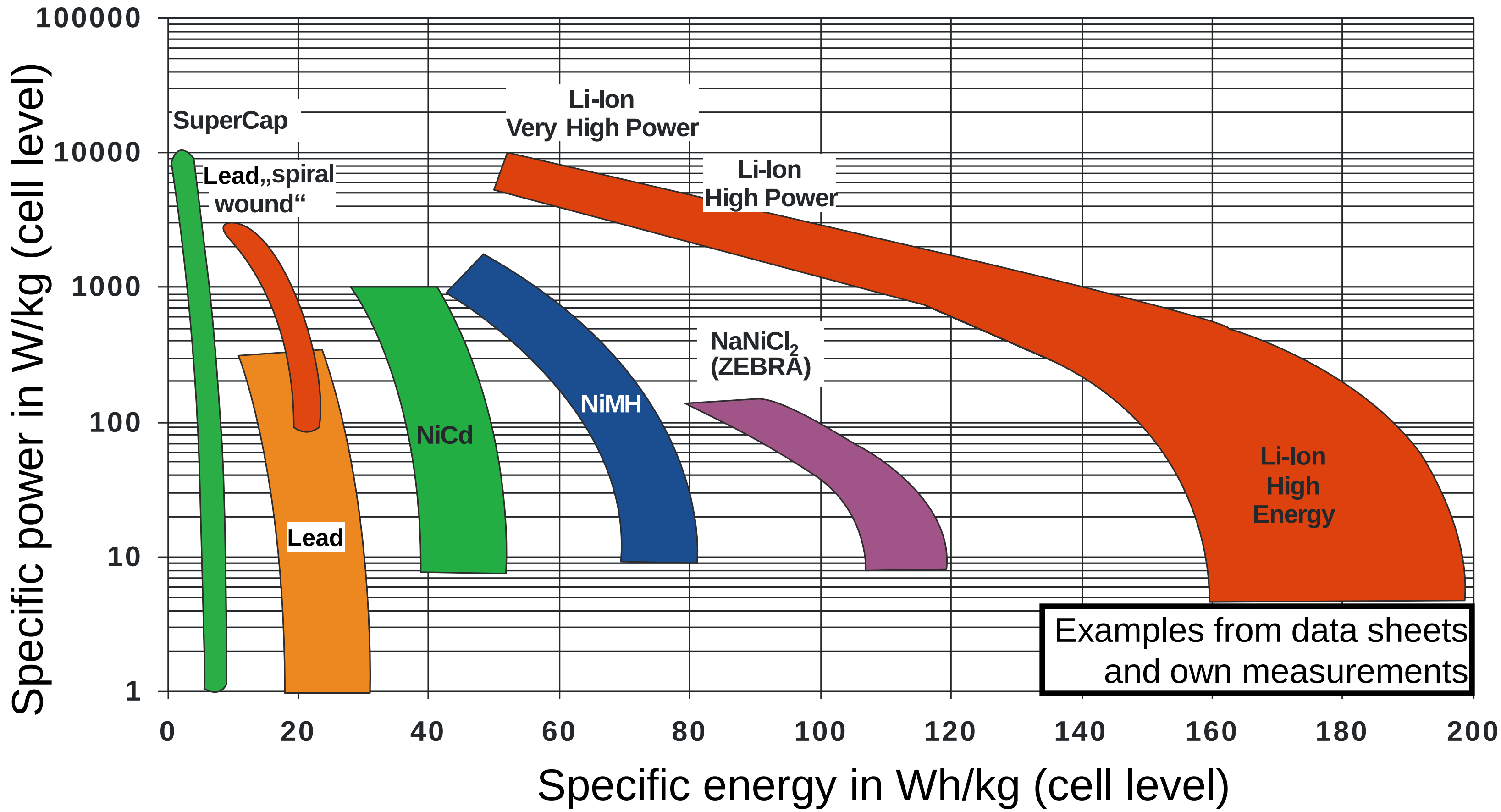
Performances of various battery technologies

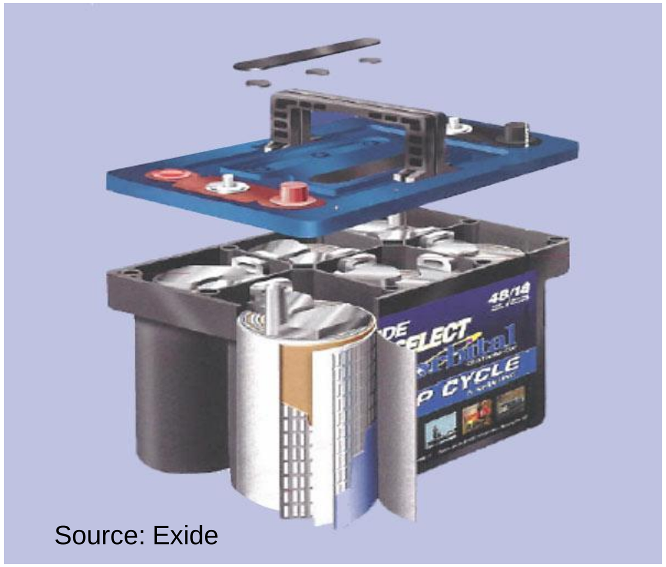
- Specific energy and power (cell level)



Lead acid batteries

+

- Low costs (production costs ~ 1/5 lithium ion batteries)
- Completely recyclable
- Safe



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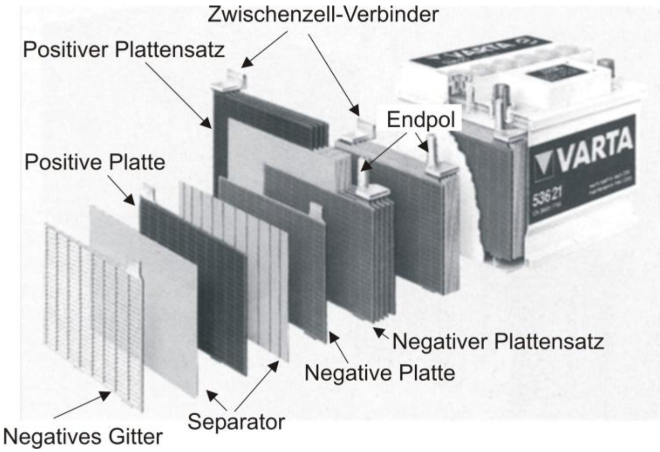
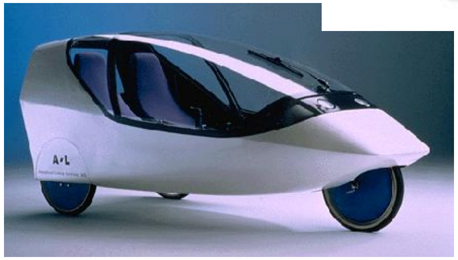
- Lifetime (limited to ~1000 full cycles)
- Weight (~320 kg for 80 km distance with compact car)
- Poor charge acceptance, peak power only @DCH

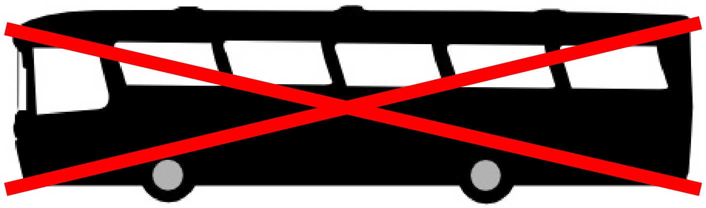


Lead acid batteries

- Already many products on the market with lead acid batteries (sub-compact cars, transporters, pedelecs, fork lifters, and so on)



- High possibility that a number of low cost vehicles with lead acid batteries are about to enter the market



- No real option for public busses due to poor lifetime and performance

Nickel Metall Hydrid (NiMH) Batteries

\+

- Already introduced ➔ lot of experience, mature
- Relatively good specific power (→ HEVs)
- High lifetime at shallow cycling depths
- Safe

- Relatively good specific energy, but not enough for EVs

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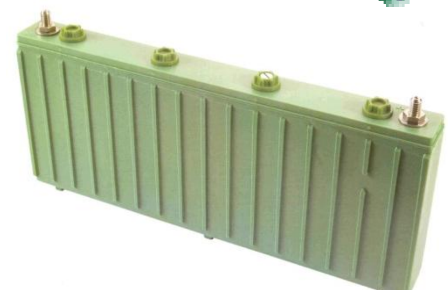
- High costs, limited cost-cutting potentials
- Only few suppliers throughout Europe

Quelle: Cobasys



Source: Johnson Controls

Nickel Metal Hydride (NiMH) Batteries

- NiMH is currently used in almost all available HEVs
  - Japan raises production within the next years
  - Sales are expected to increase until 2012
  - Only small margin for improvement, currently only little research activities
  - No long-term option for PHEV und EV

Source: APTS

Source: Siemens

Source: Toyota

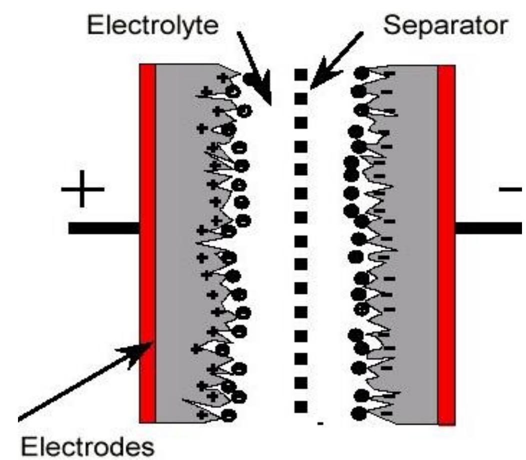
Electrochem. Double Layer Capacitors ("SuperCaps", "UltraCaps", "BoostCaps" etc.)

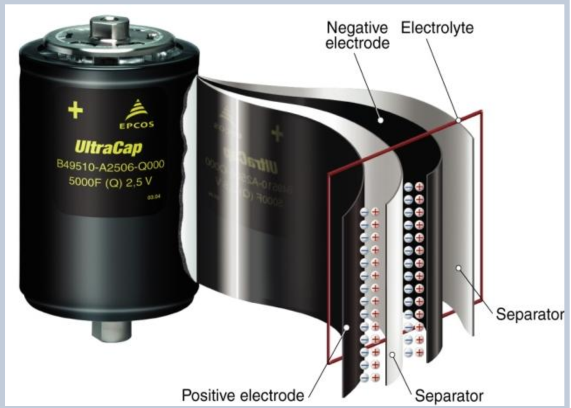
+

- High efficiency
- Very high specific power
- Excellent cycle life
  (1 million @75% cycling depth)

-

- Low specific energy (→ EV)
- High costs (~20,000 €/kWh)
- High self discharge
- Only 3 suppliers (Maxwell, Epcos, Nesscap)





Electrochem. Double Layer Capacitors (DLC, ("SuperCaps", "UltraCaps", "BoostCaps" etc.)

- Suitable for applications where high power over short time is needed (e.g. stop/start, certain hybrid electric applications, etc.)
- Already used in many HEVs → experience
- Too low energy density for EVs
- DLC wonder announced (high-permittivity barium titanate ceramic powder, EESTOR) ➔ technology and economics very vague

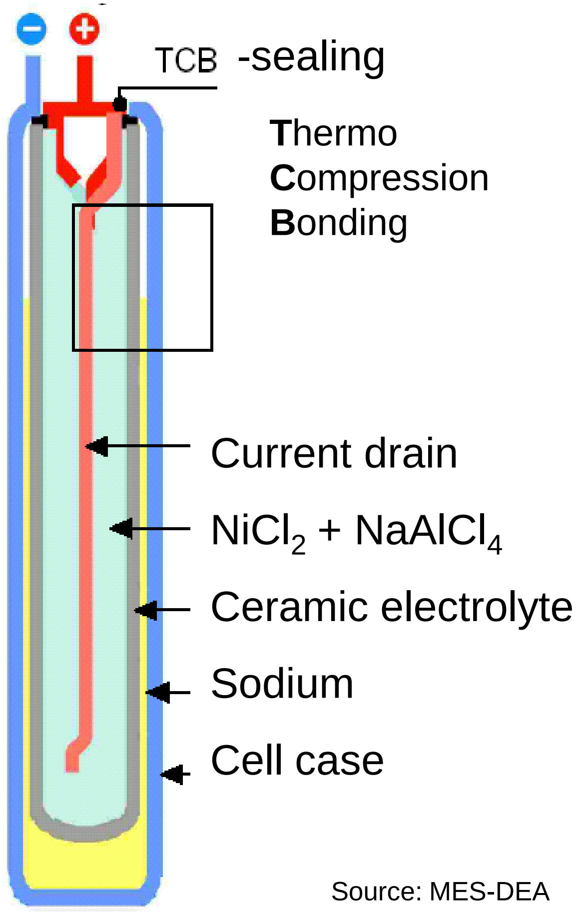
Sodium Nickel Chloride ($NaNiCl_2$, “ZEBRA“) Battery

+

- Reasonably priced (~500 €/kWh for system, today!)
- Nickel is the only limiting material
- Good lifetime

-

- Only one manufacturer (MES-DEA), limited production capacities
- Operating temperature 300 °C
- high thermal losses (~100 W for a 18 kWh-pack)



Source: MES-DEA

Sodium-nickel-chloride (ZEBRA)-battery

- Primarily used in EV (today: top-selling EV battery)
- Also used in stationary applications (NaS)
- Less suitable for private cars (retention of high temperature)
- Good solution for fleet operation

TH!NK City in Norway

Van for City Logistic in the Netherlands

Hybrid Bus in Italy

Electric Bus with 140 miles range in California

Source: MES-DEA

Lithium Ion Batteries (LIB)

+

- Very good performance (combination of high specific power and energy is possible)
- Many suppliers, a lot of activities in R&D
- Experience from consumer applications

- Sufficient lifetime seems to be achievable

-

- Still expensive
- Safety is an issue
- Demand for complex system electronics

Different cell concepts

Round cell

- A lot of experience in cell design (consumer products)
- High life expectancy
- Cooling more complex
- Suppliers: Saft, GAIA, A123, …

Pouch pack (“coffee bag“)

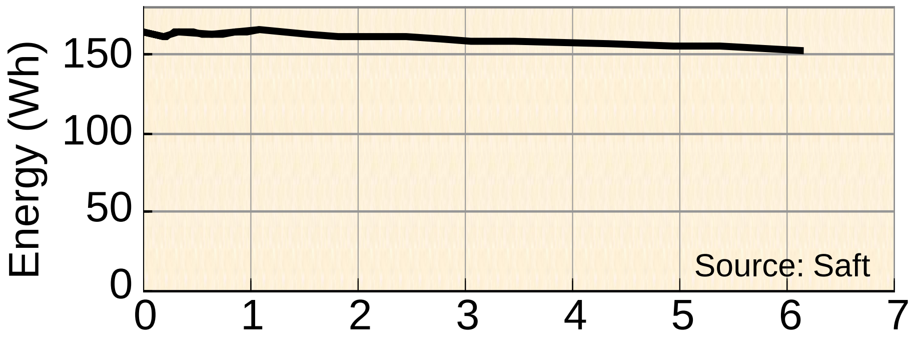
- Easy to cool
- High energy density
- Leak tightness is an issue
- Suppliers: Kokam, LiTec, …

Prismatic cell

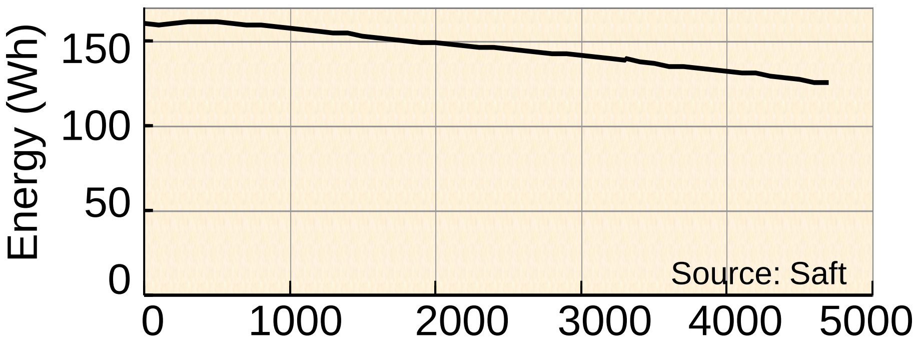
- Easy to install
- Combines some advantages of round and pouch cells
- Suppliers: GS Yuasa, Sanyo, Samsung…

Lithium Ion Cells for E-Mobility – high power and high energy

	High Energy	High Power
• Specific power (@25 °C)	200 – 400 W/kg	2000 – 4000 W/kg
• Specific energy	120 – 160 Wh/kg	70 – 100 Wh/kg
• Efficiency	~ 95%	~ 90%
• Self discharge (@25 °C)	< 5%/month	< 5%/month
• Cycle life	up to 5000 full cycles	10^6 (3,3% DOD)



Storage duration in years
@40 °C, 100 % SOC



Cycle numbers
@20 °C, 80 % cycling depth

Safety of LIB

Increase of passive safety (cell)

- Enhanced valves (overpressure), predetermined breaking points
- Ceramic separators, multi layer separators
- Use of inherently safe materials such as $LiFePO_4$
- Electrolyte additives for synthetic overcharge

Active safety measures

- Single cell voltage monitoring
- Precise charge and discharge management
- Temperature monitoring and advanced cooling concepts

Residual risk?

UN Transportation Tests could be a big (= expensive) problem for low quantities (→ local public transport)!

Costs of LIB

Today

- High energy at approx. 1000 to 1500 € / kWh (small batches), but quotation is difficult because there is no real (automotive) market yet

Prognosis & market claims for reachable prices by mass production:

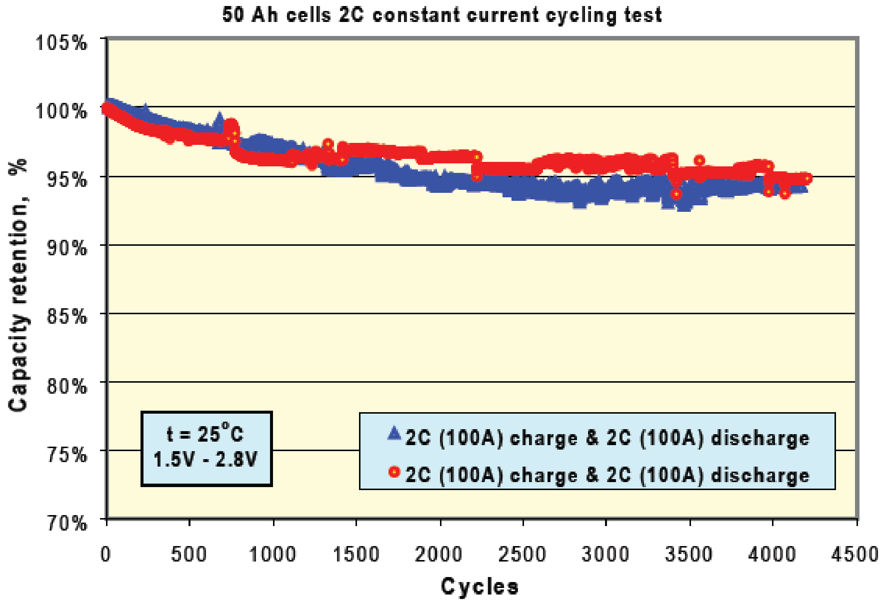
- 500 €/kWh for high power cells
- 300 €/kWh for high energy cells (There are estimates coming from Japan: 160 €/kWh)

Why?

- Already today, Kokam sells high quantities at < 500 €/kWh (HE)
- Today, there are HE cells from China (market for pedelecs, E-bicycles,…) sold for ~ 300 €/kWh (doubtful quality)
- Today, laptop batteries cost ~ 220 €/kWh (cost reduction between 1995 and 2005 by 5)

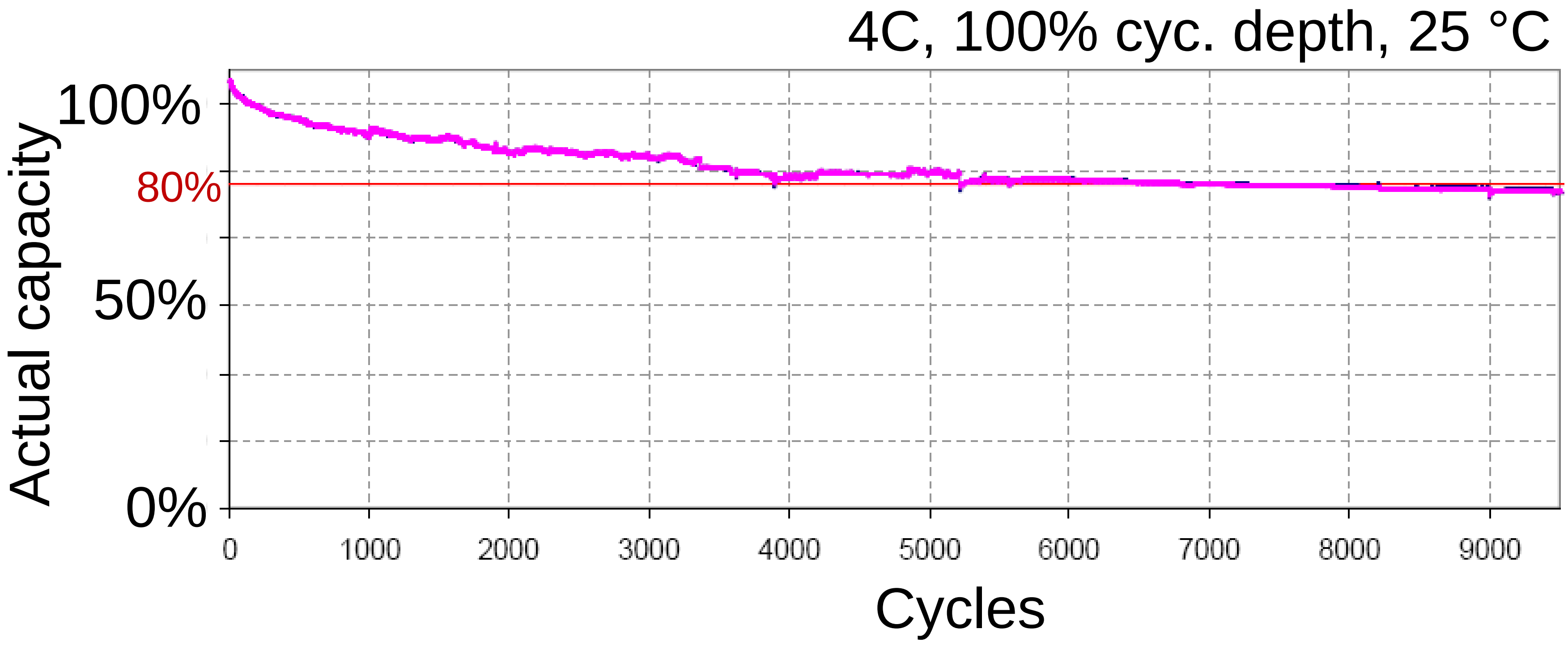
Lithium Titanate ($Li_4Ti_5O_{12}$) Anode – Solution for Local Public Transport?

- “Zero strain”, “2.2-Volt” material
- Claims of supplier:
  - 2.3V rated voltage
  - 6 C continuous current
  - 10 C peak current (10 sec)
  - 760 W/kg, 72 Wh/kg
  - **>12,000 full cycles**
  - **20 years calendar life (@25 °C)**



But: High Cycle Life possible even with "classic" Anodes

- Anode: Graphite, Cathode: NMC



Actual development of LIB

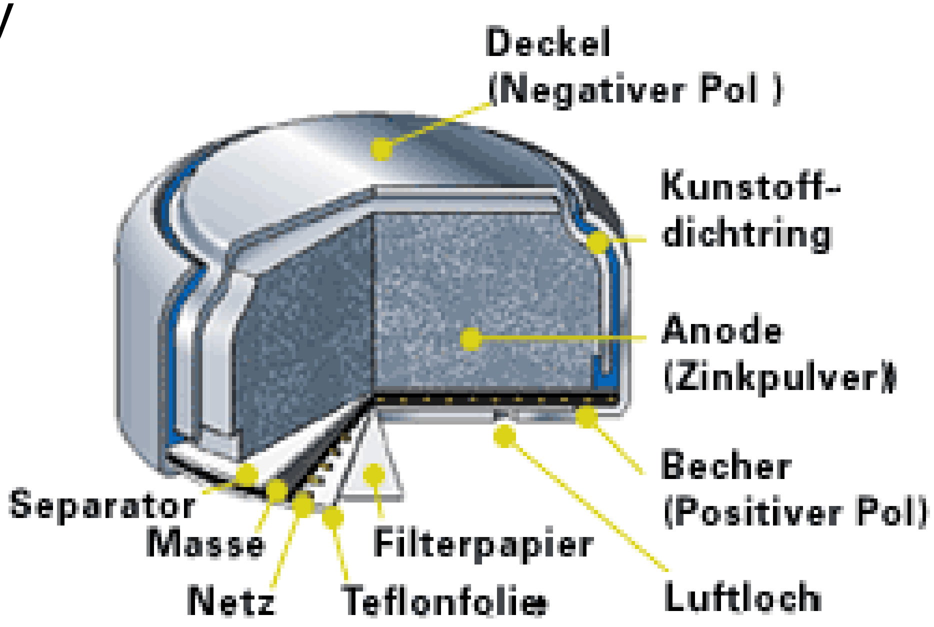
Higher specific energies possible

- “5-Volt” cathode material (e.g. $LiCoPO_4$, $LiNiPO_4$)
  - **+** High potential, high degree of safety
  - **–** Co expensive, cycle life not proven, electrolyte is a problem
- Silicon as anode material ($LiSi_5$)
  - **+** Theoretically 11x higher spec. energy than graphite anode
  - **–** Volume expansion very high ➔ cycle life is a problem

- 300 Wh/kg seems possible
  (2 t-battery: 80 km → 140 km driving distance)

Metal Air Batteries – an option for the future?

- Only theoretically realistic option for > 1000 Wh/kg
- As a rechargeable battery with > 1000 Wh/kg very unlikely within the next 10 years
- Might be interesting for battery exchange concepts with external regeneration (at energizing stations)
- Far from "ready for market"



Summary

	Hybrid electric busses	Pure battery busses
Lead Acid	X	X
NiMH	☺	X
SuperCaps	☺	X
$NaNiCl_2$	X	☺
Lithium Ion	☺	☺
Metal Air	→ ?	→ ?

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Thank you for your attention!

k Uwe Sauer

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Appendix

Land-Use caused by Bio Fuels vs. Electricity

➔ Harvest from 2nd generation of **biomass** BTL (expected):
60.000 km/ha/year

➔ Harvest from **photovoltaics** (in Germany):
1.000.000 km/ha/year

Assumption: Radiance in Germany: 1000 kWh/m^2/a,
Photovoltaics: 10% efficiency, area coverage: 1/3,
Vehicles‘ energy consumption: 20 kWh / 100 km,
Efficiency grid & vehicle: 60%

➔ **16x more driving distance with PV**

No question if electric vehicles will rule the market, the only question is: When how many...

- Masterplan electro mobility of the German federal government:
  1 Million electric vehicles until 2020 (2.5% related to all passenger cars in Germany)

McKinsey-Studie: Bis zu 16 Prozent Elektromobile in Megastädten schon 2015 (13.01.2010)

McKinsey&Company

In den Ballungszentren New York, Shanghai und Paris können sich Elektro- und Hybridfahrzeuge schon innerhalb der nächsten fünf Jahre als realistische Alternative zu Autos mit herkömmlichem Verbrennungsmotor etablieren. Den höchsten Marktanteil erreichen die Stromer nach einer neuen McKinsey-Studie in New York. Hier liegt der prognostizierte Anteil an den Neuzulassungen im Jahr 2015 bei bis zu 16 Prozent.

Source: internet portal CO_2-Handel.de

Energy Efficiency of Fuel Cell Vehicles vs. Battery Electric Vehicles

- Starting point: electrical energy (from CO_2-free sources)

Source: ATZ online

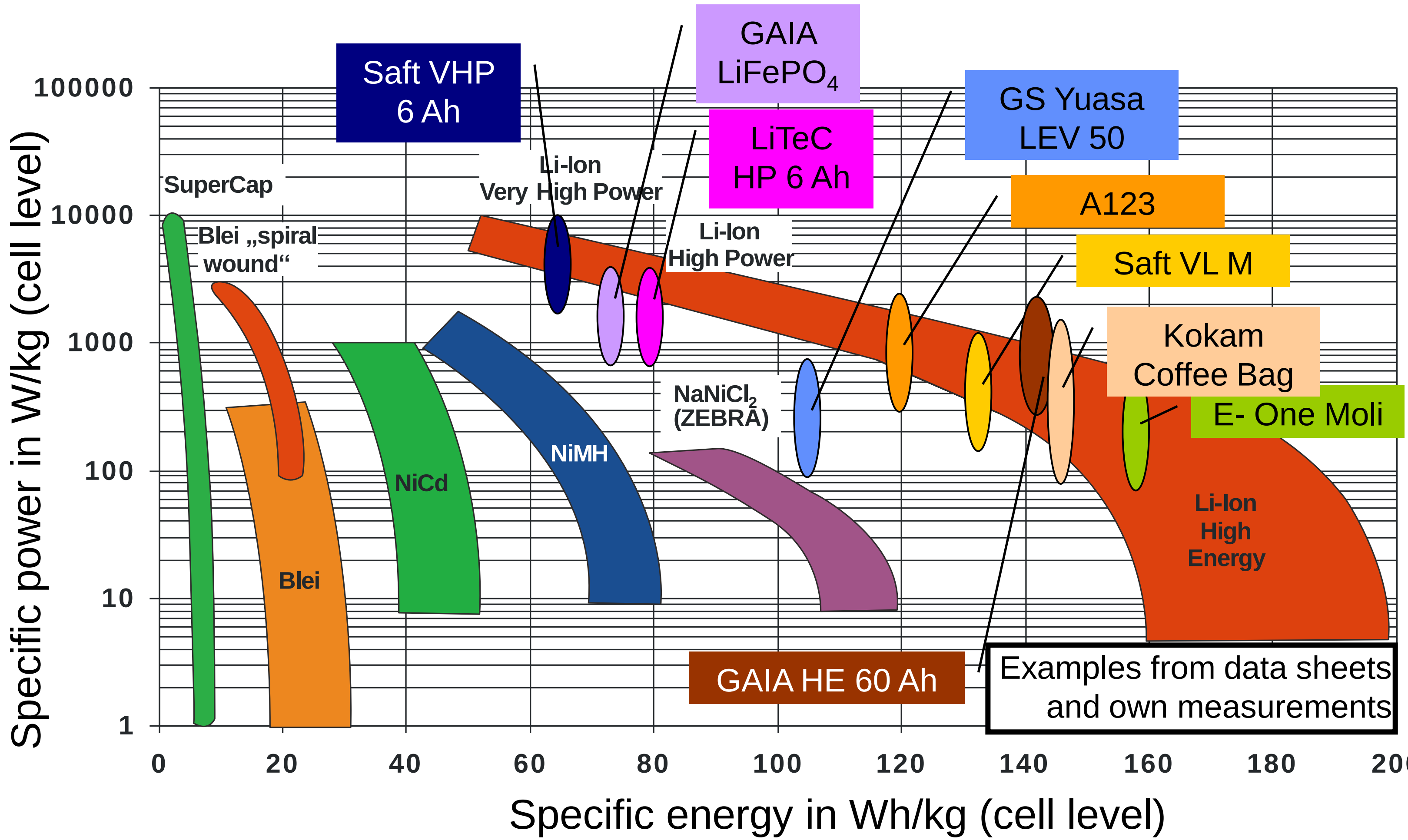

Source: minispace.com

- Energy use with fuel cell vehicles: **25 – 30%**
- Energy use with battery electric vehicles: **70 – 75%**

- **Energy consumption with hydrogen fuel cell is approx. 2,5x higher compared to battery electric vehicles**

Performances of various battery technologies

- Specific energy and power



Sodium-nickel-chloride (ZEBRA)-battery – characteristics of a typical module

Type		[illegible]	[illegible]5-557-ML-32
Ca[illegible]	[illegible]	64	32
[illegible]	kWh	17.8	17.8
[illegible]	V	278.6	557
[illegible]arge current	A	224	112
[illegible] Type/N° of cells		ML3 / 216	
Weight with BMI	kg	195	
Specific energy without BMI	Wh/kg	94	
Energy density without BMI	Wh/l	148	
Specific power	W/kg	169	
Power density	W/l	265	
Peak power 80% DOD, 2/3 OCV, 30s, 335°C	kW	32	
Ambient temperature	°C	-40 to +50	
Thermal loss at 270°C internal temperature	W	< 110	

BMI: Battery Management Interface

Source: MES-DEA

Summary

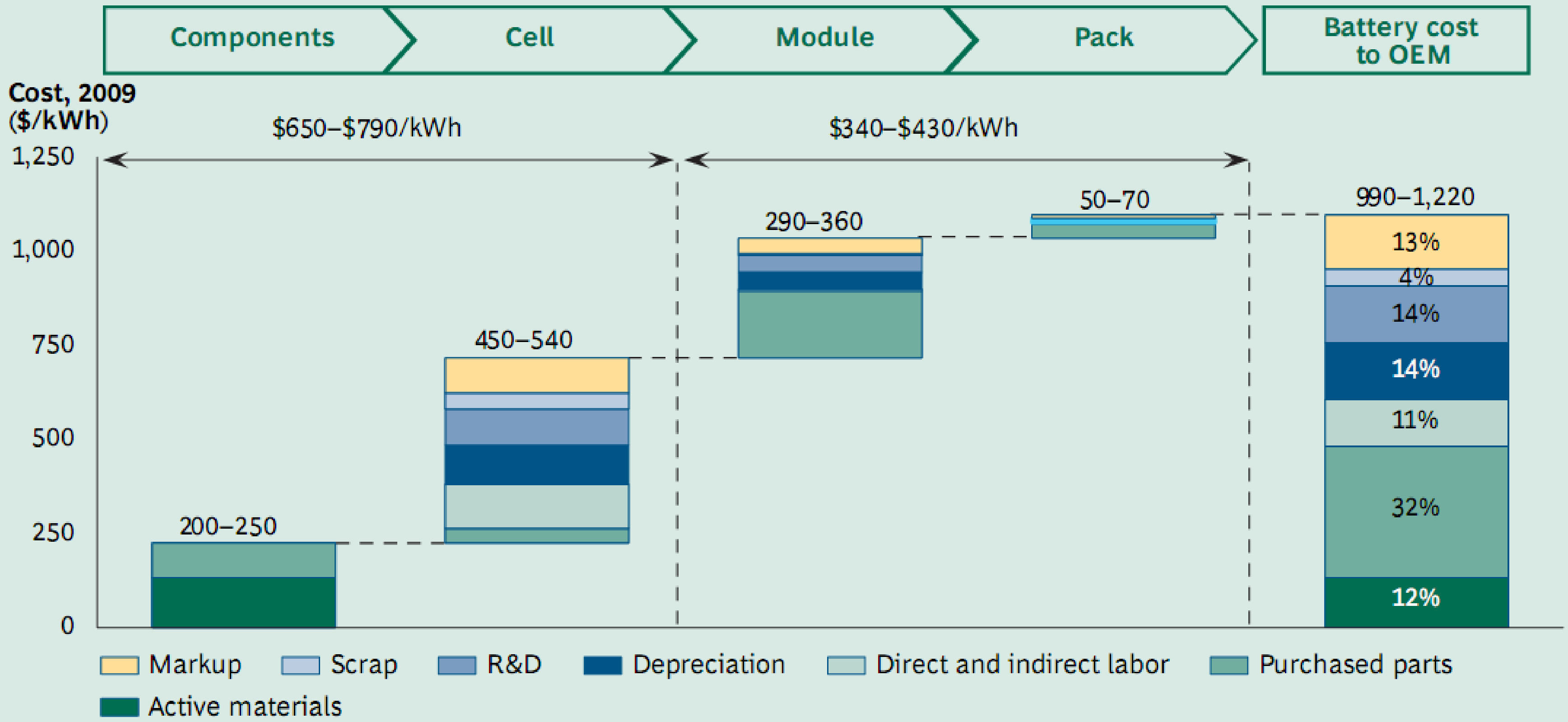
- Lithium-Ionen-Systeme verfügen über exzellente elektrische Eigenschaften.
- Alternativen sind bis 2015 nur in Nischen denkbar.
- Schwerpunkt der Entwicklungstätigkeiten in den kommenden Jahren:
  - Sicherheit
  - Kosten
  - Lebensdauer
  - Energie- und Leistungsdichte
- Infrastruktur

UN No.	Name and description	Class or division	Subsi-diary risk	UN packing group	Special provi-sions	Limited and excepted quantities		Packagings: Packing instruction
(1)	(2)	(3)	(4)	(5)	(6)	(7a)	(7b)	(8)
-	3.1.2	2.0	2.0	2.0.1.3	3.3	3.4	3.5	4.1.4
3028	BATTERIES, DRY, CONTAINING POTASSIUM HYDROXIDE SOLID, electric storage **NiMH**	8 ätzend (Anforderung nur an Verpackung)			295 304	2 kg	E0	P801
3480	LITHIUM ION BATTERIES (including lithium ion polymer batteries)	9 sonst.		II **"medium Danger"**	188 230 310 348	0	E0	P903
3481	LITHIUM ION BATTERIES CONTAINED IN EQUIPMENT or LITHIUM ION BATTERIES PACKED WITH EQUIPMENT (including lithium ion polymer batteries)	9		II	188 230 348	0	E0	P903

Ausnahme von Transporttests bei Stückzahl ≤ 100

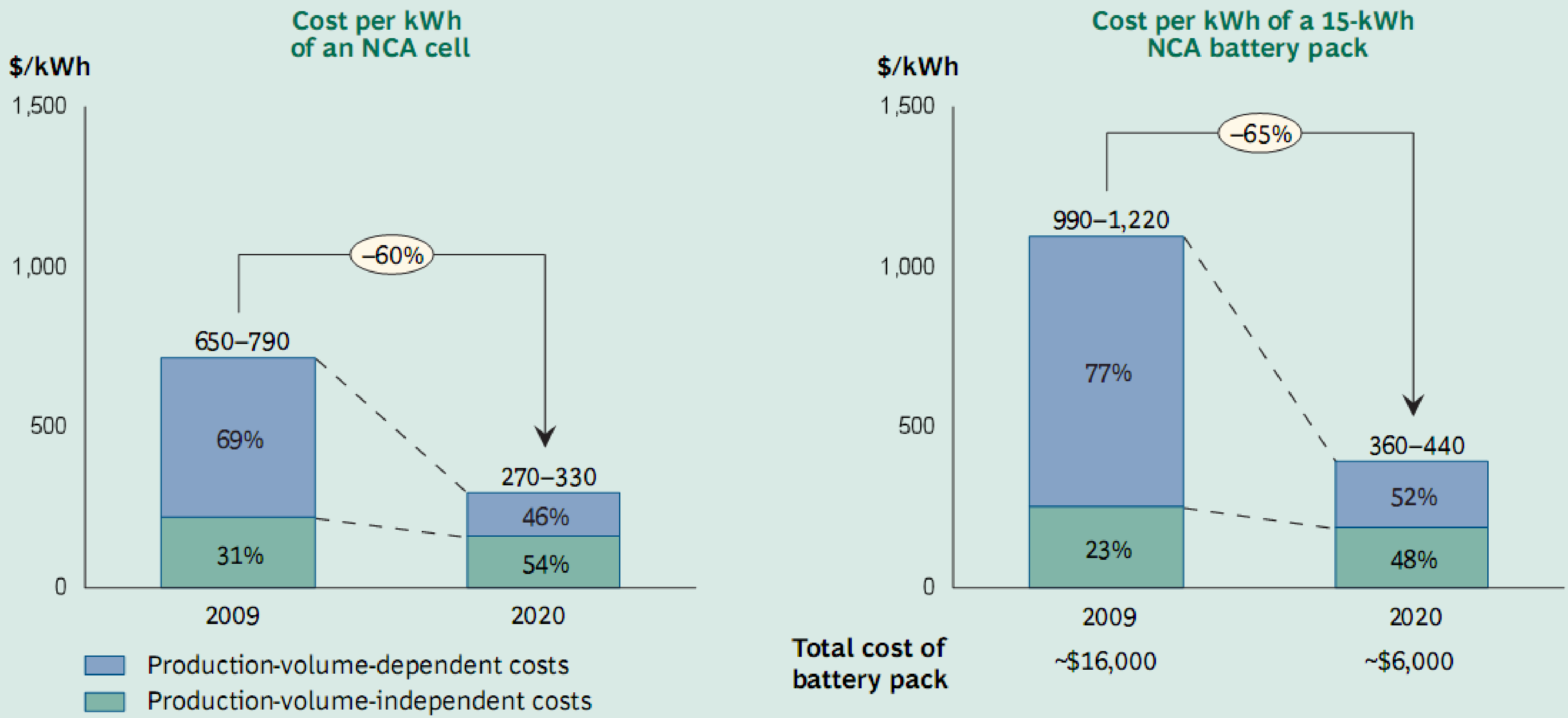
Wird diese Ausnahme auch so angewendet??

Exhibit 3. Batteries Cost OEMs About $1,100 per kWh at Low Volumes



Sources: Interviews with component manufacturers, cell producers, tier one suppliers, OEMs, and academic experts; Argonne National Laboratory; BCG analysis.
Note: Exhibit shows the nominal capacity cost of a 15-kWh NCA battery and assumes annual production of 50,000 cells and 500 batteries, as well as a 10 percent scrap rate at the cell level and a 2 percent scrap rate at the module level. Numbers are rounded.

Exhibit 4. Battery Costs Will Decline 60 to 65 Percent from 2009 to 2020



Sources: Interviews with component manufacturers, cell producers, tier one suppliers, OEMs, and academic experts; Argonne National Laboratory; BCG analysis.

Note: Exhibit assumes annual production of 50,000 cells and 500 batteries in 2009 and 73 million cells and 1.1 million batteries in 2020. Numbers are rounded.