Workshop of the

The Dutch Royal Institute of Engineers

The battery – Bottleneck for the E-mobility?

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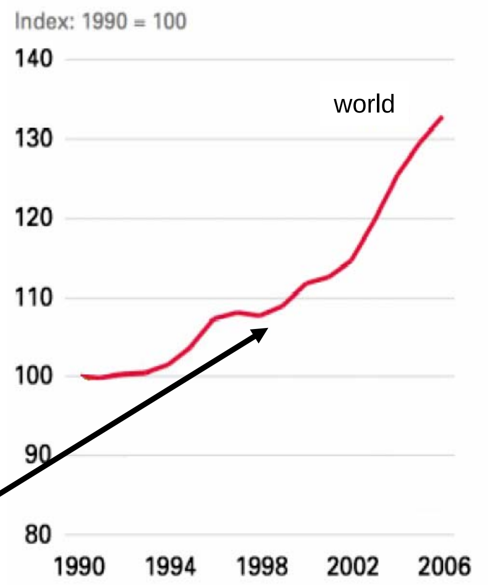
Why electrification of vehicles?

1. Limited resources – oil is limited and can get very expensive as seen in 2008

2. **Climate change – CO_2 emissions must be reduced worldwide by 70% until 2050 (in Germany by 90%)**

World-wide CO_2 emissions



This is, what the world is currently doing

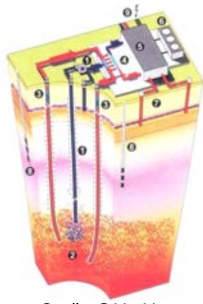
Why electrification of vehicles?

1. Limited resources – oil is limited and can get very expensive as seen in 2008

2. **Climate change – CO_2 emissions must be reduced worldwide by 70% until 2050 (in Germany by 90%)**

Electricity is available in the long-run in almost unlimited quantities from

- ➔ renewable energy sources,
- ➔ nuclear power plants, or
- ➔ fossil power plants with carbon capture!



Quelle: GtV e.V.

Land requirement for bio fuels vs. electricity for mobility

➔ Harvest from **bio mass** of 2nd generation (BTL) expected:
60,000 km/ha/year

➔ Harvest from **photovoltaics** in Germany:
1,000,000 km/ha/year

Assumptions: Solar energy in Germany 1000 kWh/m²/a, photovoltaics with 10% efficiency, land use factor 1/3, vehicle energy consumption 20 kWh / 100 km, efficiency grid & vehicle 60%

➔ **16x more driving with electricity from PV compared with bio fuels**

Energy efficiency fuel cell vs. electric vehcile

➔ Starting point: electrical power (from CO_2-free sources)

Quelle: ATZ online


Quelle: minispace.com

➔ usable energy with fuel cell vehicles: **25 – 30%**

➔ usable energy with electric vehicles: **70 – 75%**

➔ **Energy needs for fuel cell vehicles with clean hydrogen is 2.5 x higher compared with electric vehicles**

Electric- and hybrid electric vehicles are „under construction“ - everywhere


Quelle: Volvo


Quelle: Daimler

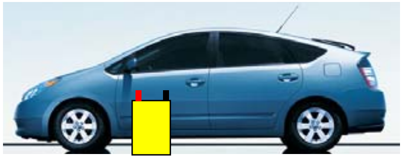

Quelle: Think


Quelle: Daimler


Quelle: minispace.com

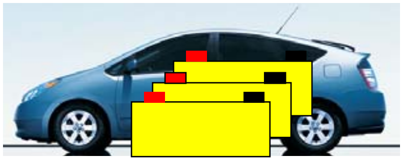

Quelle: Tesla Motors

Electrification concepts for passenger cars



Hybrid electric vehicle (HEV)
Storage capacity approx. 1 kWh, charging only during driving, fuel reduction max. 20%

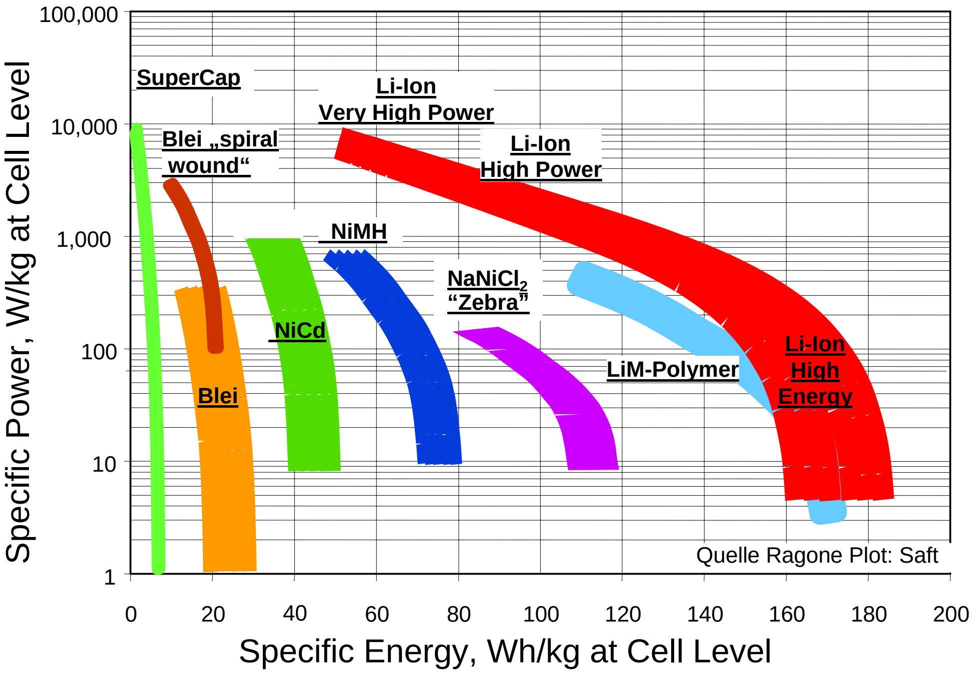
Plug-in Hybrid electric vehicle (PHEV)
Storage capacity 5 – 10 kWh, charging from the grid, 30 to 50 km electrical driving range, full driving range with conventional engine or fuel cell, driving with empty battery possible



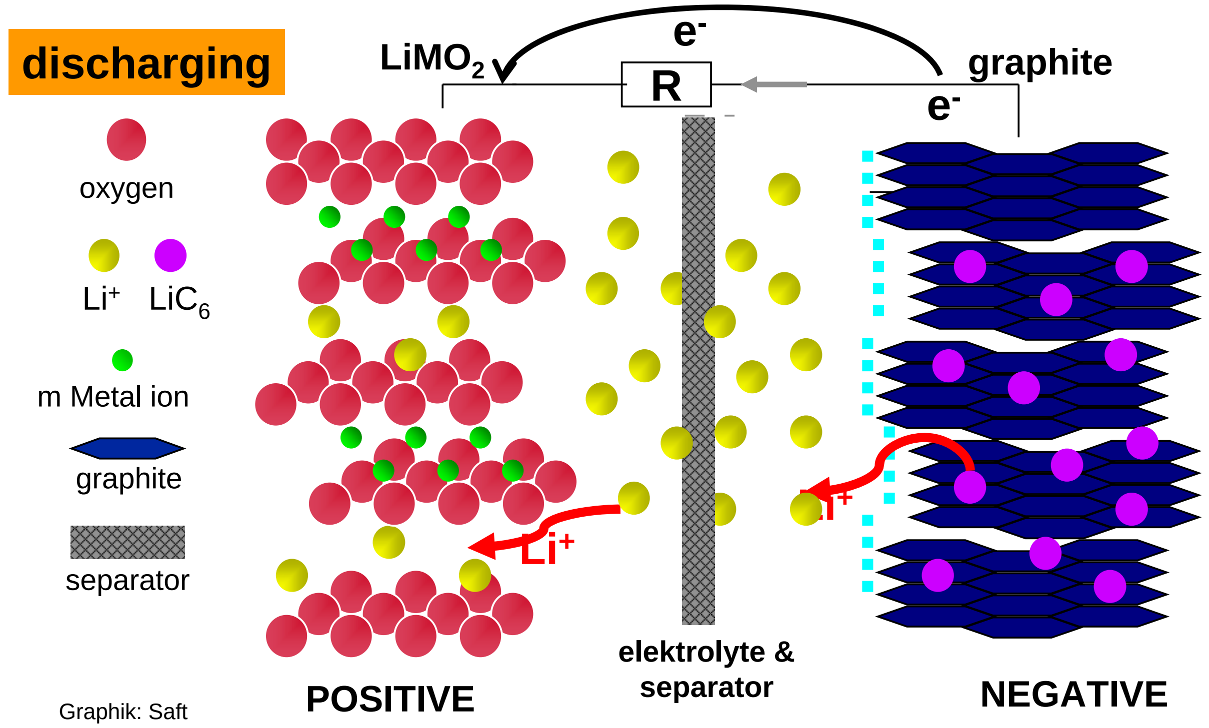
Electric vehicle (EV)
Storage capacity 15 – 40 kWh, charging from the grid, 100 to 300 km electrical driving range

Gravimetric power density vs. energy density

(power and energy density of specific products taken from data sheets and measurements)



The lithium ion system („Rocking Chair“)

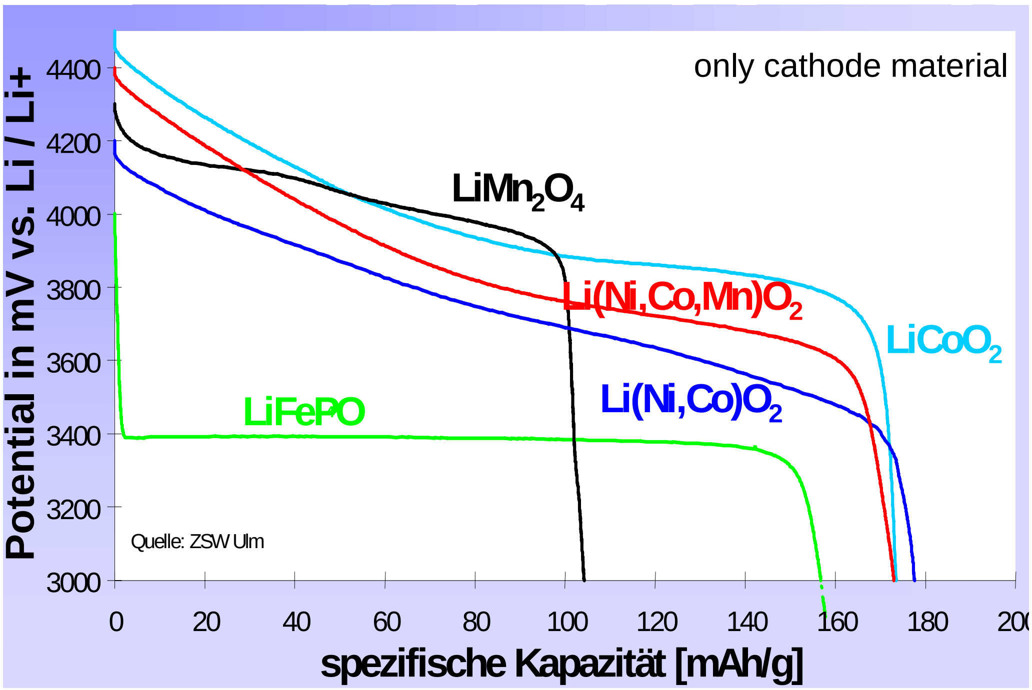


Main technologies in the focus for lithium-ion batteries

Li-ion liquid

cathode material		anode material	
Good lifetime, high safety risk	$LiCoO_2$	Hard Carbon LiC_6	“3.7 V material”, low number of full cycles
Highest safety risk, good electrical performance	$LiNiO_2$	Graphit LiC_6	“3.7 V material”, expensive good cycle lifetime (EV)
Short lifetime, safety better compared with Co & Ni	$LiMn_2O_4$	Titanat $Li_4Ti_5O_{12}$	“2.2 V Material”, safe, low energy density
Popular mixed material with optimum of different features	$LiCo_{1/3}Ni_{1/3}Mn_{1/3}O_2$	Silizium $Li_{22}Si_6$	“3.7 V material”, high energy denstiy, under investigation
High variability of mixed materials (e.g. additional Al)	$LiCo_xNi_yMn_zO_2$		
“3.3 V material”, cheap & safe, lower energy density	$LiFePO_4$		

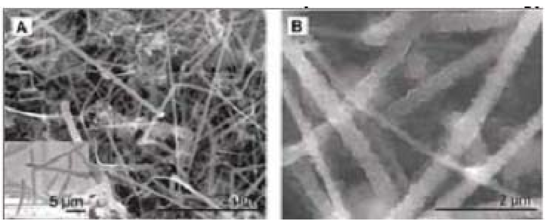
Lithium-ion batteries – Performance of different materials



Important technology innovations under development

Improved energy density by

- „5 Volt" cathode materials e.g. $LiCoPO_4$
  - Advantage: high potential, high safety
  - disadvantage: costs of cobalt, sufficient cycle lifetimes not confirmed
- Silicon anode materials ($LiSi_5$)
  - Advantage: theo. 11x higher energy density of the anode compared with graphite
  - Disadvantage: high volume expansiun, severe lifetime problems



Quelle: Stanford University – Silicon Nano Wires

- Energy densities up to a maximum of 300 Wh/kg might be possible

Actual main R&D topics for Li-ion batteries

Li-ion liquid

Separators

General: very expensive component in Li-ion cells — **„standard“**

Multi-layer separator with a melting layer (→ turns to high resistance at overheating) — **„Shut-Down“**

Ceramic separator minimizes the risk of short circuits at high temperatures — **Separion®**

Electrolyte and binders are major components with regard to deep temperature performance and lifetime.

Electrolyte

„standard“ — **Electrolyte**: EC, PC, DMC, DEC, EMC; **salts**: $LiPF_6$, $LiCF_3SO_3$, $LiN(CF_3SO_2)_2$; **Additives**

LIBOB — Higher security

Polymere — safe, low conductivity at room temperature

Ionic liquids — Possible electrolyte for 5 Volt cells

Different cell concepts

Round cells

- Long years of experience with cell design
- High lifetime expectations
- Cooling difficult

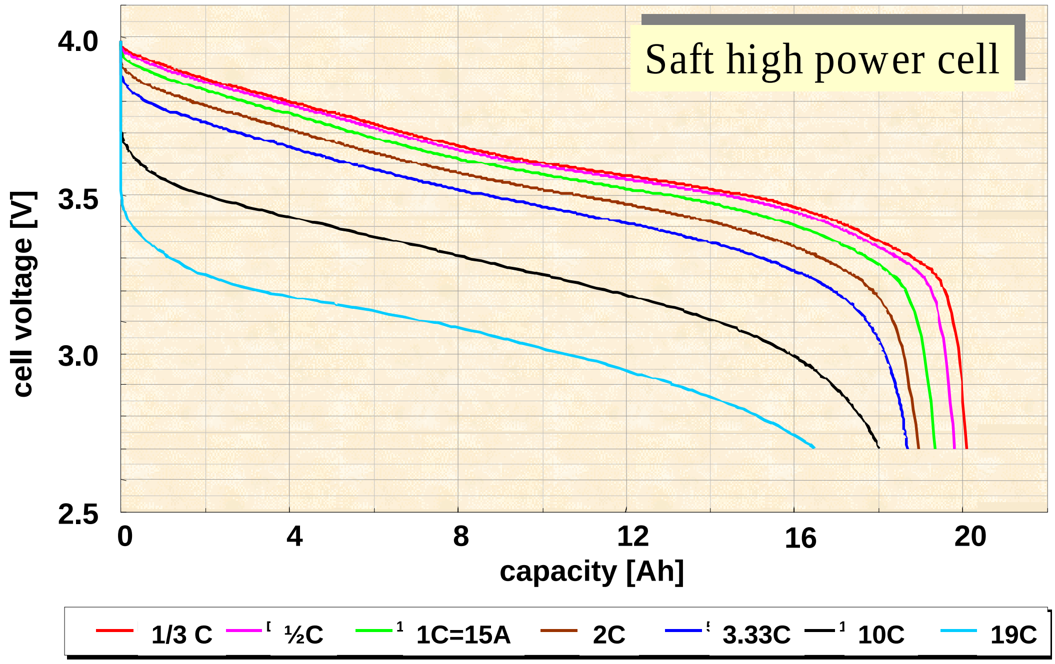
„Coffee bag“ cells

- Very good cooling properties
- High energy density
- Tightness of foils still in question

Prismatic cells

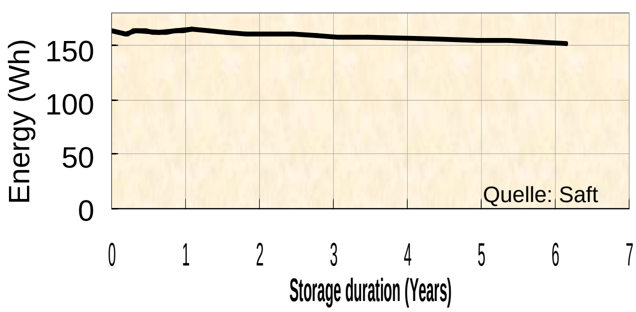
- Simple system design
- Combines several advantages of round cells and coffee-bag cells

Discharge characteristic of Li-Ion „High Power“ batteries

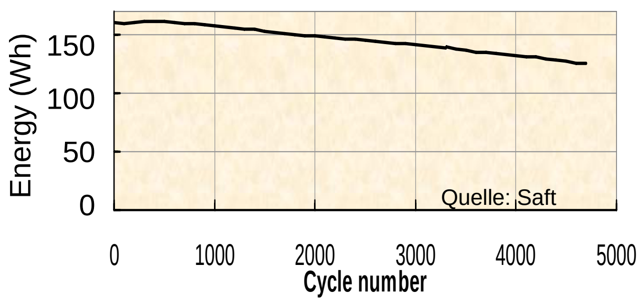


Electrical performance (cell level)

	high energy	high power
• Power density	200 – 400 W/kg	2000 – 4000 W/kg
• Energy density	120 – 160 Wh/kg	80 – 100 Wh/kg
• Efficiency	~ 95%	~ 90%
• Self discharge	< 5%/month (25°C)	< 5%/month (25°C)
• Cycle lifetime	up to 5000 full cycles	10^6 (3.3% DOD)



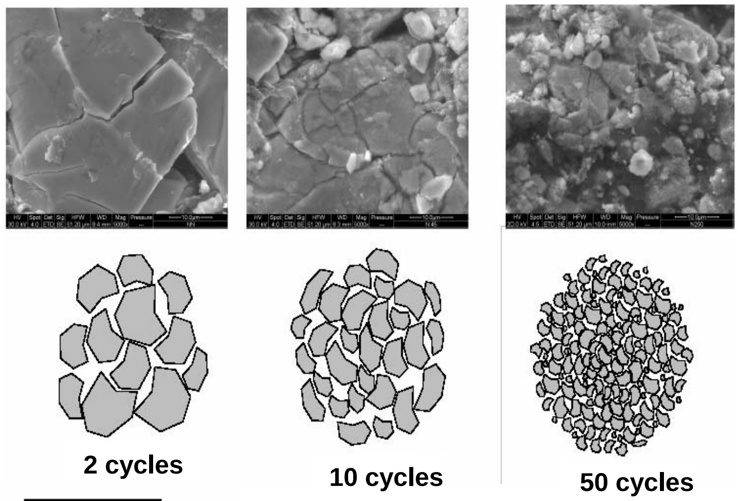
Calendar life assessment at 40°C and 100 % SOC



Cycle life assessment at 20°C at 80 % DOD cycle

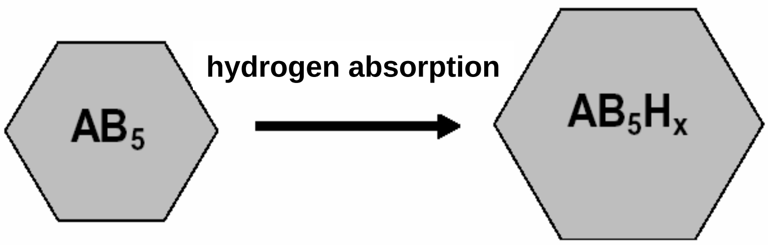
Ageing effects by cycling NiMH-batteries

- Grid expansion during emplacement of hydrogen leads to mechanical stress and thereby destroys crystals of metal alloy



volumeexpansion

$LaNi_5 \rightarrow LaNi_5H_6$ approx20%



Life time as a function of c

(Generally similar for lithium-ion-, NiMH
absolute numbers varying depending on th

There is a lot of additional battery cycle lifetime to support grid stability or doing energy trading !

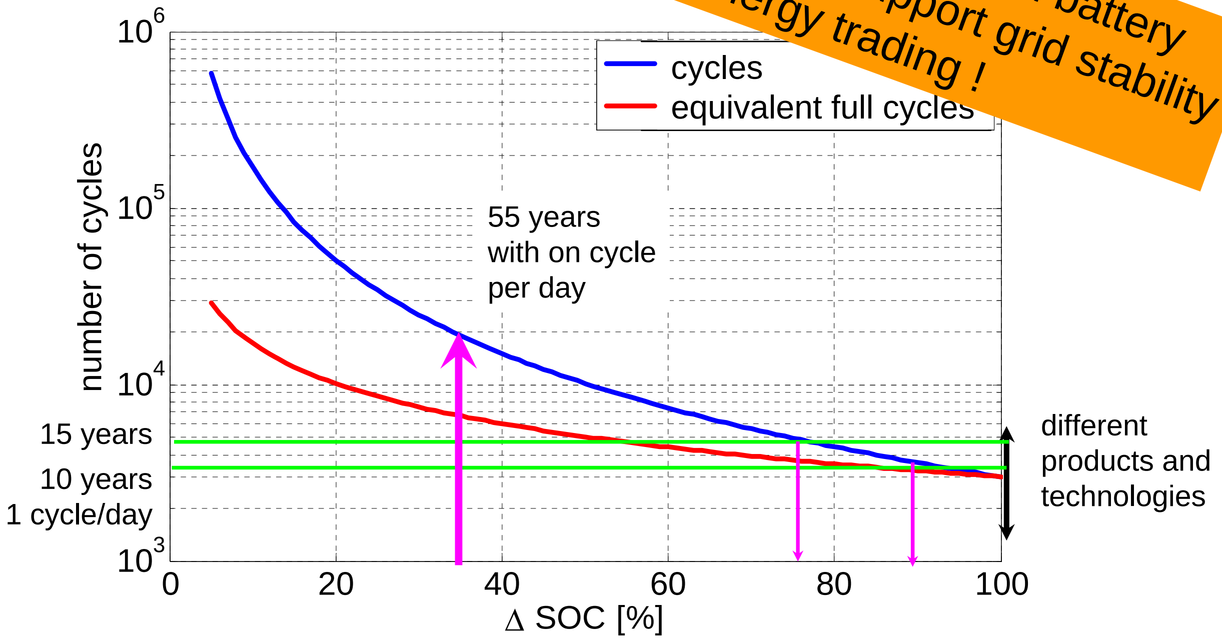
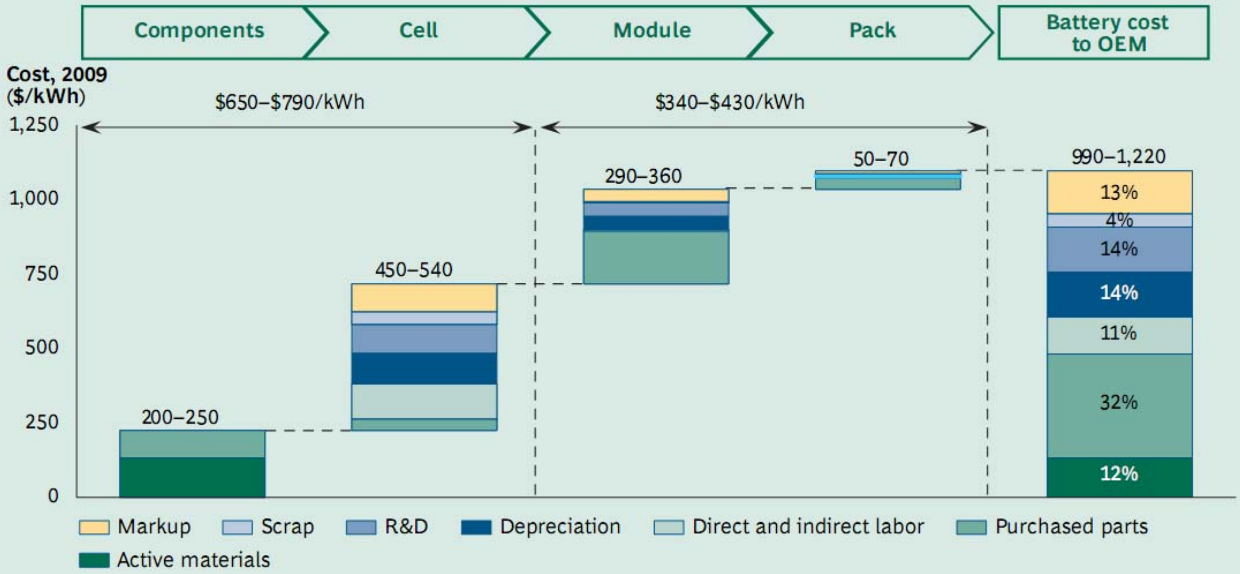


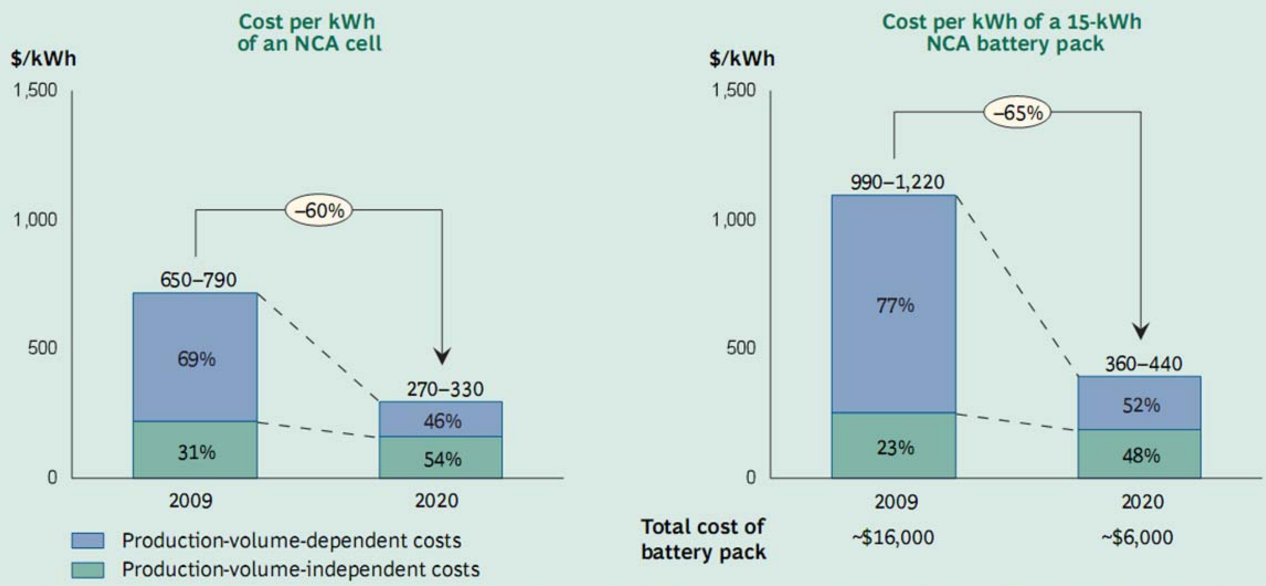
Exhibit 3. Batteries Cost OEMs About $1,100 per kWh at Low Volumes



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.

Quelle: Boston Consulting Group, 2009

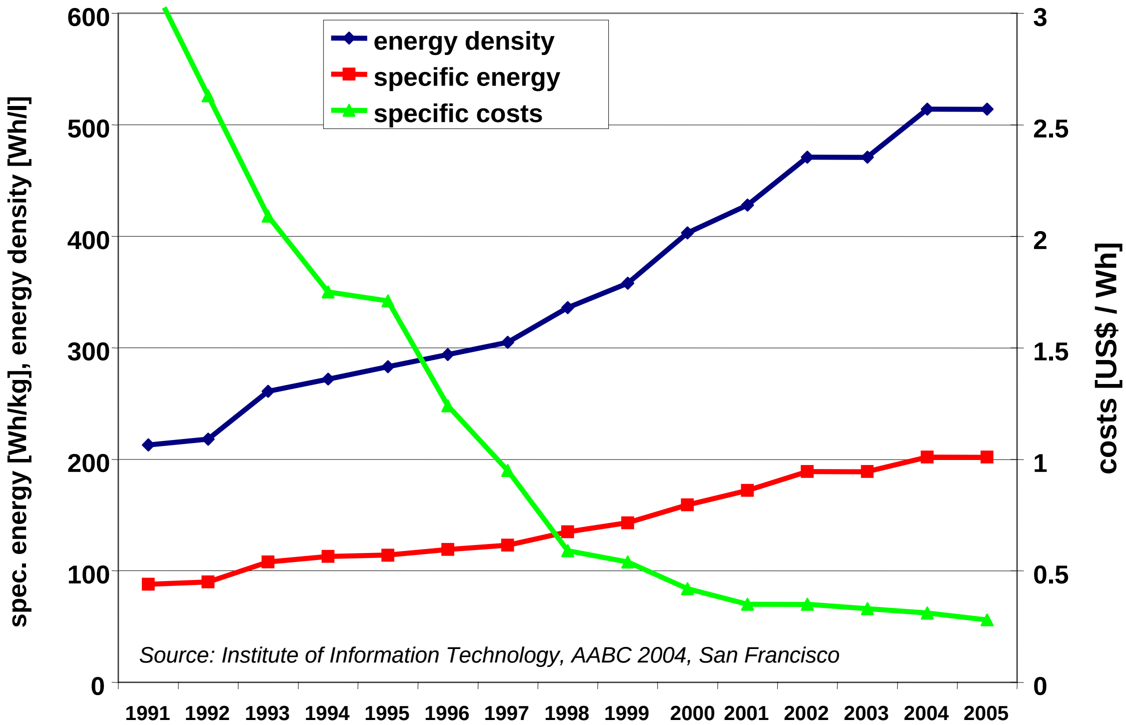
Exhibit 4. Battery Costs Will Decline 60 to 65 Percent from 2009 to 2020



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.

Quelle: Boston Consulting Group, 2009

Cost development of consumer cells of the type 18650 (standard cell e.g. used in battery packs of laptops)



Most important battery manufacturers of lithium-ion consumer batteries (type 18650 cell)

Battery manufacturer	Country	Production in million cells
Sanyo	Japan	588
Samsung	Korea	386
Sony	Japan	359
Panasonic	Japan	237
LG Chem	Korea	ca. 200

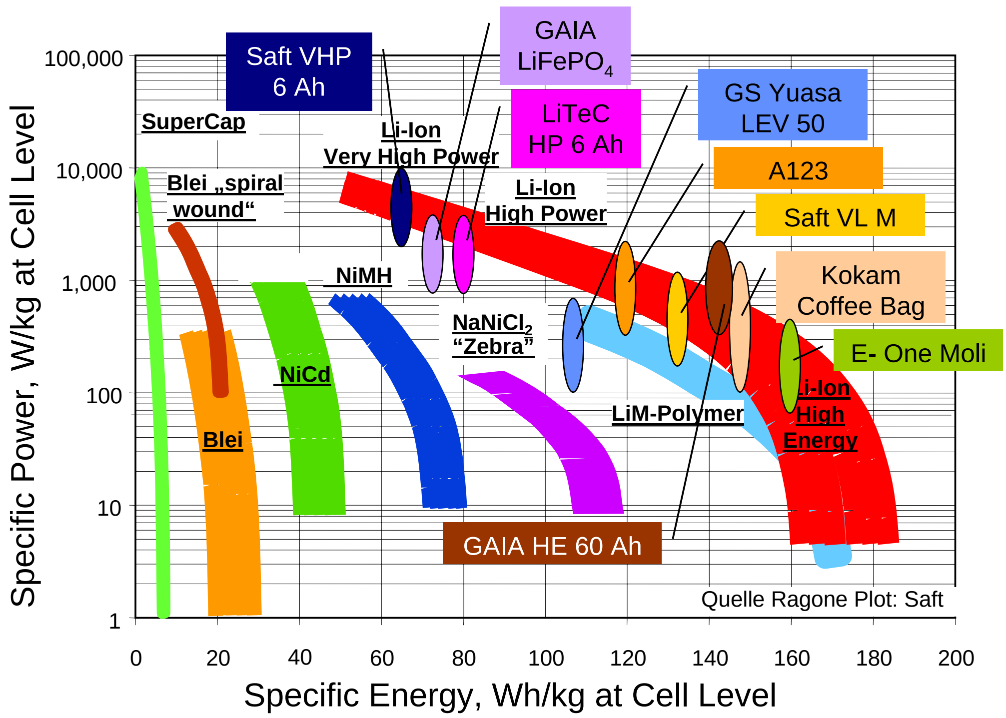
source: Institute Information Technology, data for 2007

Main tracks of current R&D activities on Li-ion batteries

- Maximising safety and reliability
- Reduction of costs by material selection and economcy of scale
- Transferring life cycle results from the lab to the field
- Improving the usable DOD while maintaining the lfietime
- Optimisation of system technology (mainly costs)
- Improving the energy density

Consolidation of the technology and preparing for mass production is in the focus.
Improving of energy density improves the market penetration only slightly.

Products are available on the market



What follows from costs and performance of lithium-ion batteries?

Batteries are expensive

- 15 kWh/100km x 300 €/kWh = 4,500 €/100km
  (selling price to the car manufacturer, after (!) cost reduction)

Batteries for electric vehicles cost as much as the total remaining car

- Costs for a small to medium size vehicle (all parts and manufacturing) are in the order of 5,000 €/vehicle

Lithium-ion batteries achieve many more cycles than typically used, but the battery will die even without cycling after a certain time

Why long-ranging full electric vehicle are not economic for the mass market … . An example.

Size of the battery for 200 km full electric driving: approx. 30 kWh (ranges from 24 kWh for very efficient small vehicles to 40 kWh)

Costs for battery purchase (selling from battery manufacturer to car manufacturer): approx. 30 x 300 € = 9,000 €

Selling price to the user: approx 9,000 € x 1,8 = 16,200 € for the battery only

➔ Weight at 100 Wh/kg ➔ 300 kg

➔ **Battery dies after 10 to 15 years anyway, even if it wouldn‘t be used at all..**

Average usage of vehicles in Germany: 37 km/day

➔ **80% of the battery dies unused.**

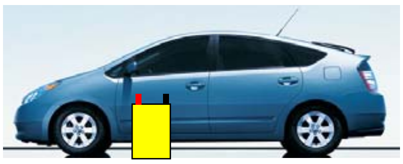
A full electric vehicle as a mass product remains a short ranging vehicle.

100 km full electric driving range seems to be an appropriate sizing.

Fast charging and exchangeable battery concepts try to make the full electric vehicle a one-by-one replacement of today's conventional vehicles.

This is nonsense from an economical and from an ecological point of view.

Electrification concepts for passenger cars



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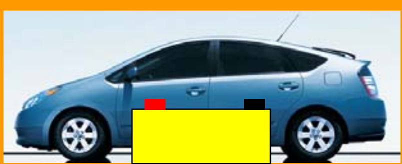
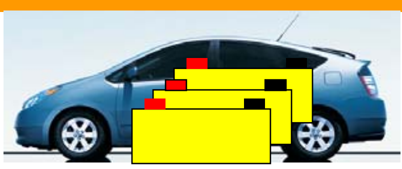


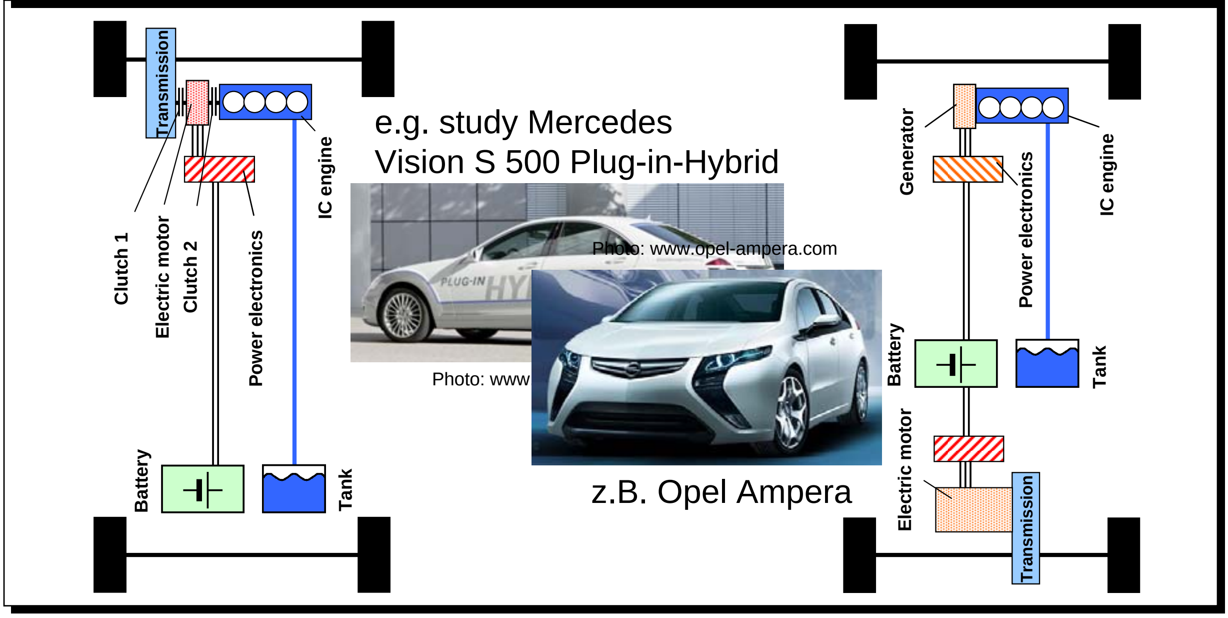
Plug-in Hybrid electric vehicle (PHEV)
Storage capacity 5 – 10 kWh, charging from the grid, 30 to 50 km electrical driving range, full driving range with conventional engine or fuel cell, driving with empty battery possible



Electric vehicle (EV)
Storage capacity 15 – 40 kWh, charging from the grid, 100 to 300 km electrical driving range

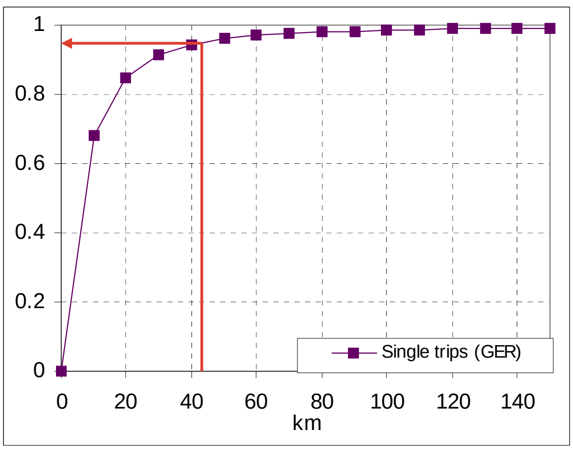
Topology of hybrid- (HEV) and Plug-in hybrid vehciles (PHEV)

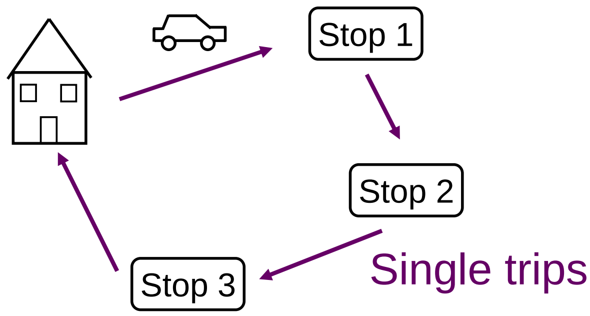
Parallel hybrid	Series hybrid (incl. range extender)



Graphik: Dr. Kube, Volkswagen Konzernforschung, 2007

Statistical Driving Behaviour

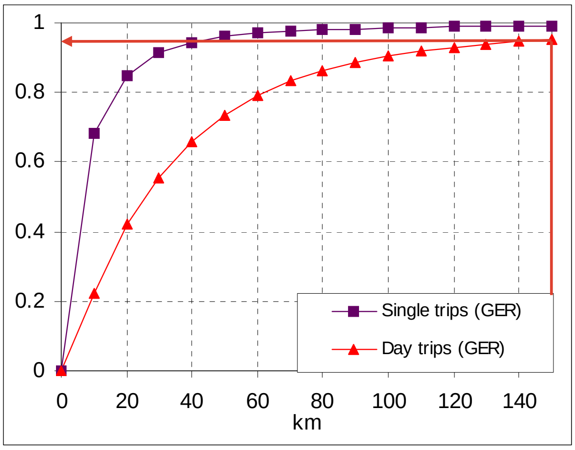


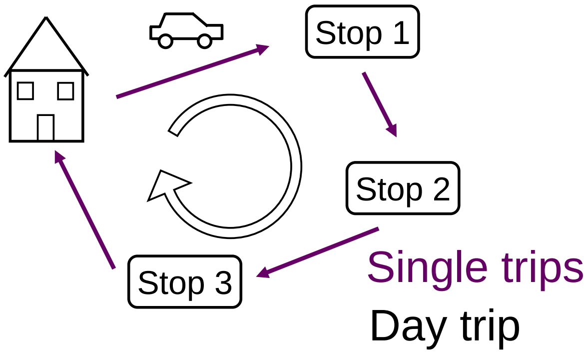


Data source: Mobilität in Deutschland, Bundesministerium für Verkehr, Bau und Stadtentwicklung

- 95 % of single trips shorter than 42 km

Statistical Driving Behaviour





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- 95 % of single trips shorter than 42 km
- 95 % of day trips shorter than 150 km

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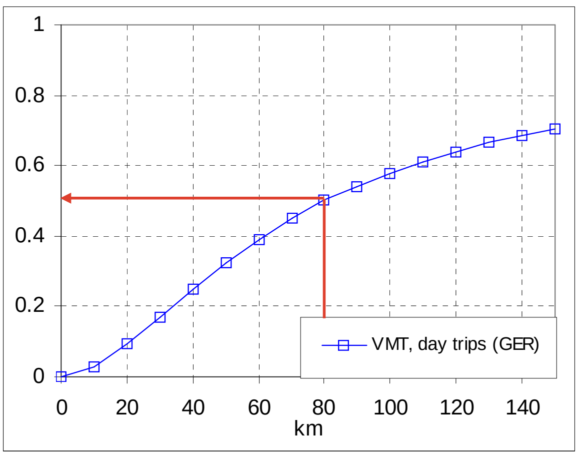

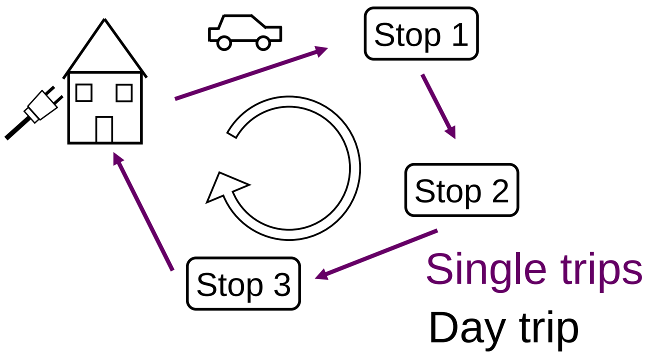

VMT: Vehicle miles travelled

Data source: Mobilität in Deutschland, Bundesministerium für Verkehr, Bau und Stadtentwicklung

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- 95 % of day trips shorter than 150 km
- 50 % of VMT can be driven with a battery for 80 km

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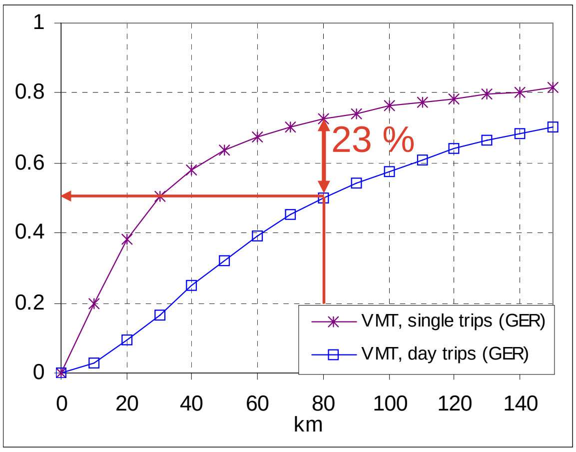

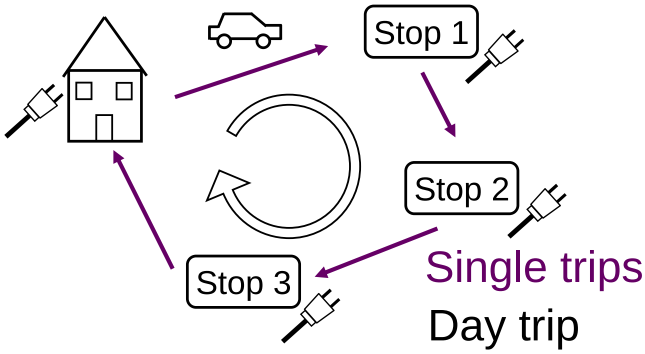

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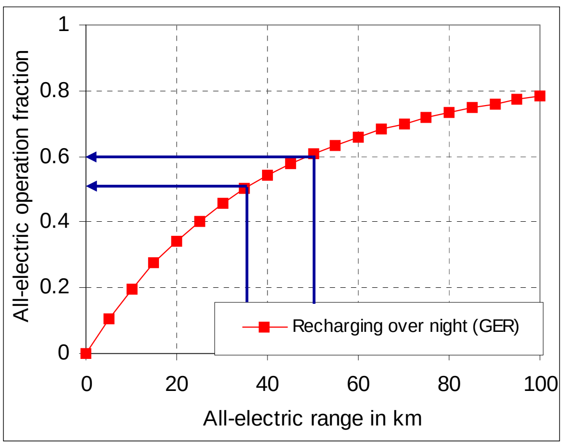
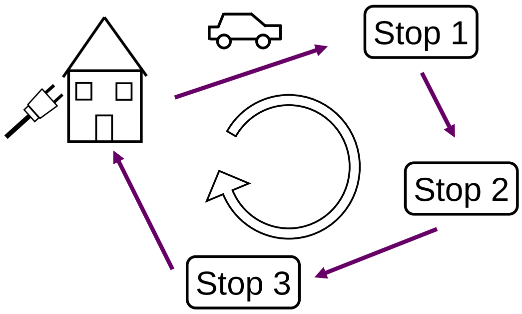
- 95 % of day trips shorter than 150 km
- 50 % of VMT can be driven with a battery for 80 km
- Recharging after every single trip increases fuel substitution by 23 %

All-electric operation fraction of PHEVs





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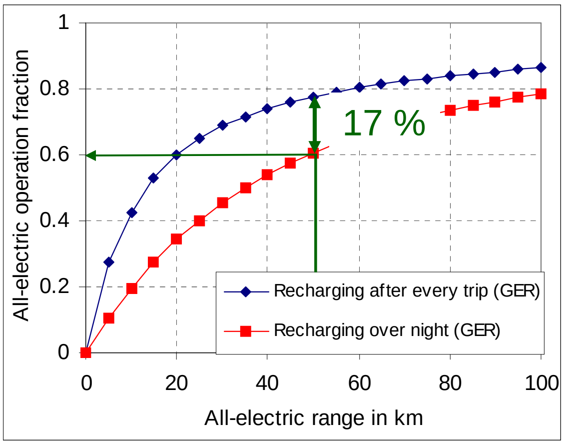
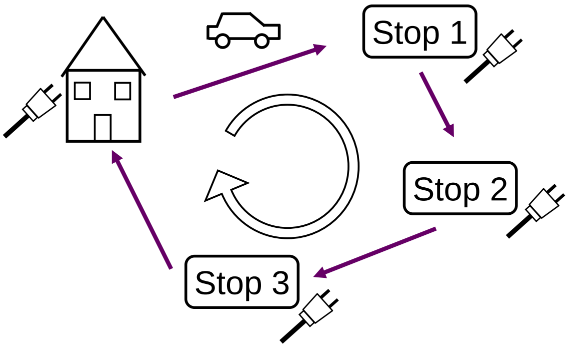
- PHEV-35: fuel substitution of 50 % (same as EV-80)
- PHEV-50: Over night charging sufficient for 60 % of VMT (and more than 70 % of days for pure electric driving)

All-electric operation fraction of PHEVs





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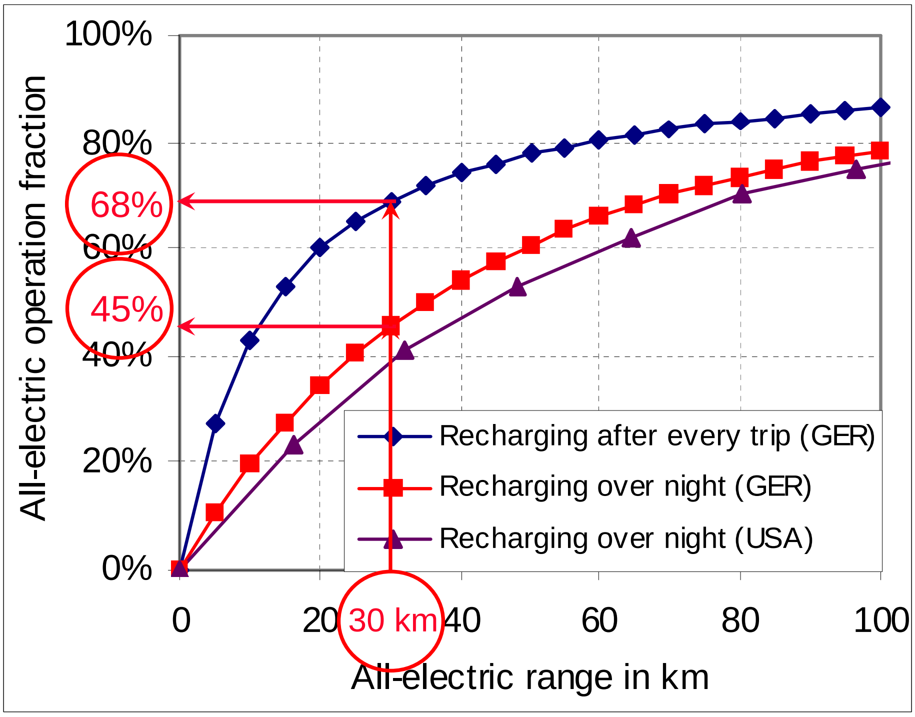
- PHEV-50: Over night charging sufficient for 60 % of VMT (and more than 70 % of days for pure electric driving)
- Recharging after every trip increases fuel substitution by 17 %

Sizing of the battery of Plug-in hybrids
➔ very high fuel saving potential with small battery



Electro mobility concepts need to be intelligent :

➔ **Full electric vehicles for short distances („second family car“, urban delivery, craftsmen, etc.)**

or expensive upper class cars where costs are not a major issue, or for user with a very high daily mileage

➔ **Plug-in hybrid electric vehciles is the replacement technology for today‘s universal cars with a high degree of fuel substitution**

Workshop of the

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