Újgenerációs akkumulátorok

Molnár Károly

PowerQuattro Zrt.

Fejlesztési igazgató

C. Egyetemi docens

performance in electronics

Unsere Energie für Ihren Erfolg

HOPPECKE Lithium-Ionen

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19.03.2013

René Linke

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www.hoppecke.com

Motive Power Systems | Reserve Power Systems | Special Power Systems | Service

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What is Lithium?

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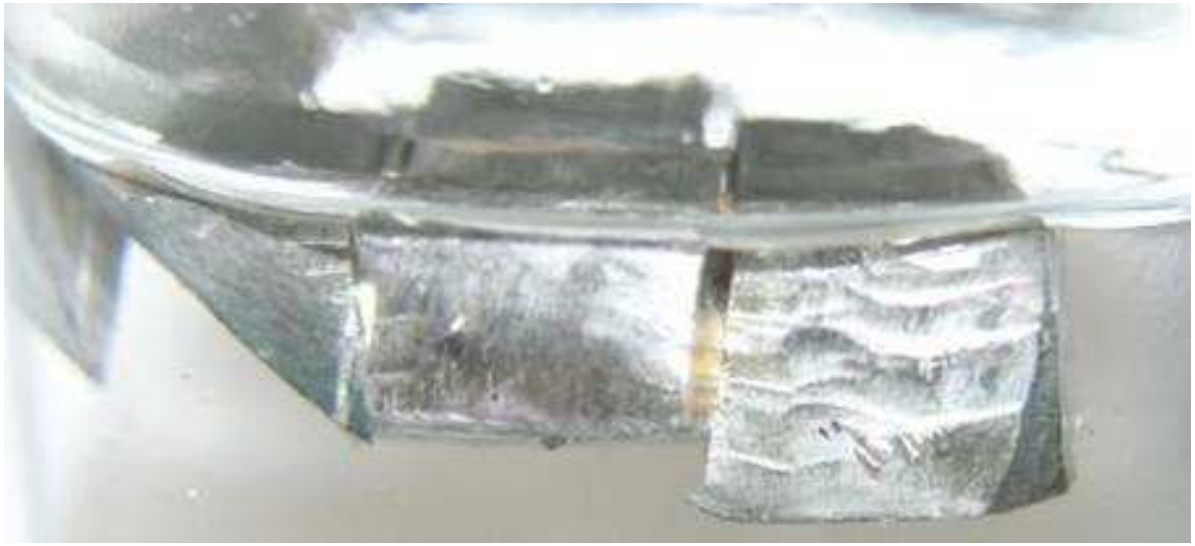
- **Metal**, element no. 3 in periodical system of chemical elemets
- **3rd lowest atomic weight of all elements** behind the gases hydrogen and helium
- Smallest density of solid elements
- **The solid element with the lowest weight**
- From Greek *líthos* „Stone“
- Silver-white, soft
- Reactive with humidity



Lithium in paraffin oil

Why Lithium for batteries?

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1. **Strong negative electrode potential**

extraordinarily high cell voltages possible!

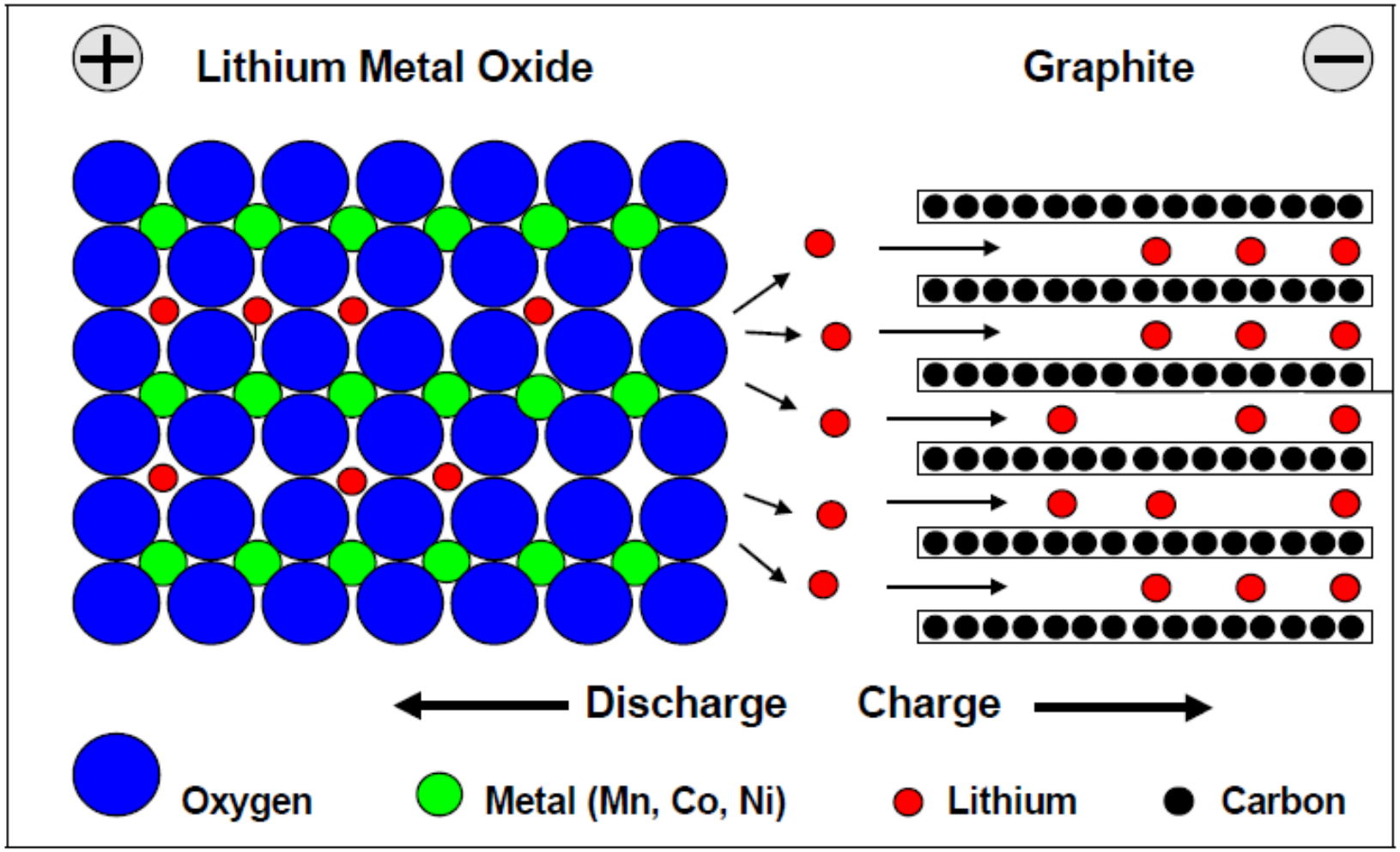
2. **Low weight!**

Li/O_2 (saure Lösung): ~4,3V

reduzierte Form	⇄	oxidierte Form	e^-	Standardpotenzial E° in V
Li	⇄	Li^+	$+1\ e^-$	-3,04
K	⇄	K^+	$+1\ e^-$	-2,92
Ba	⇄	B^{2+}	$+2\ e^-$	-2,90
Ca	⇄	Ca^{2+}	$+2\ e^-$	-2,87
Na	⇄	Na^+	$+1\ e^-$	-2,71
Mg	⇄	Mg^{2+}	$+2\ e^-$	-2,35
Al	⇄	Al^{3+}	$+3\ e^-$	-1,68
Mn	⇄	Mn^{2+}	$+2\ e^-$	-1,19
Zn	⇄	Zn^{2+}	$+2\ e^-$	-0,76
Cr	⇄	Cr^{3+}	$+3\ e^-$	-0,74
S^{2-}	⇄	S	$+2\ e^-$	-0,48
Fe	⇄	Fe^{2+}	$+2\ e^-$	-0,41
Cd	⇄	Cd^{2+}	$+2\ e^-$	-0,40
Co	⇄	Co^{2+}	$+2\ e^-$	-0,28
Sn	⇄	Sn^{2+}	$+2\ e^-$	-0,14
Pb	⇄	Pb^{2+}	$+2\ e^-$	-0,13
Fe	⇄	Fe^{3+}	$+3\ e^-$	-0,036
$H_2 + 2\ H_2O$	⇄	H_3O^+	$+2\ e^-$	0
Sn^{2+}	⇄	Sn^{4+}	$+2\ e^-$	+0,15
Cu^+	⇄	Cu^{2+}	$+1\ e^-$	+0,15
$SO_3 + 6\ H_2O$	⇄	$SO_4^{2-} + 4\ H_3O^+$	$+2\ e^-$	+0,17
Cu	⇄	Cu^{2+}	$+2\ e^-$	+0,34
Cu	⇄	Cu^+	$+1\ e^-$	+0,52
$2\ I^-$	⇄	I_2	$+2\ e^-$	+0,54
$H_2O_2 + 2\ H_2O$	⇄	$O_2 + 2\ H_3O^+$	$+2\ e^-$	+0,68
Fe^{2+}	⇄	Fe^{3+}	$+1\ e^-$	+0,77
Ag	⇄	Ag^+	$+1\ e^-$	+0,80
Hg	⇄	Hg^{2+}	$+2\ e^-$	+0,85
$NO + 6\ H_2O$	⇄	$NO_3^- + 4\ H_3O^+$	$+3\ e^-$	+0,56
$2\ Br^-$	⇄	Br_2	$+2\ e^-$	+1,07
$6\ H_2O$	⇄	$O_2 + 4\ H_3O^+$	$+4\ e^-$	+1,23
$2\ Cr^{3+} + 21\ H_2O$	⇄	$Cr_2O_7^{2-} + 14\ H_3O^+$	$+6\ e^-$	+1,33
$2\ Cl^-$	⇄	Cl_2	$+2\ e^-$	+1,36
$Pb^{2+} + 6\ H_2O$	⇄	$PbO_2 + 4\ H_3O^+$	$+2\ e^-$	+1,46
Au	⇄	Au^{3+}	$+3\ e^-$	+1,50
$Mn^{2+} + 12\ H_2O$	⇄	$MnO_4^- + 8\ H_2O$	$+5\ e^-$	+1,51
$3\ H_2O + O_2$	⇄	$O_3 + 2\ H_3O^+$	$+2\ e^-$	+2,07
$2\ F^-$	⇄	F_2	$+2\ e^-$	+2,87

Li/O_2 (alkalische Lösung): ~3,4V

Electrochemical functioning of Li-Ion battery



A Li-Ion cell consists of an anode containing carbon / graphite and a cathode of lithium metal oxide. During charging, Lithium ions move from the cathode to the anode. During discharging, the Lithium ions move from the anode back to the cathode. During both processes, of course, electrons move outside.

Numerous electrode materials

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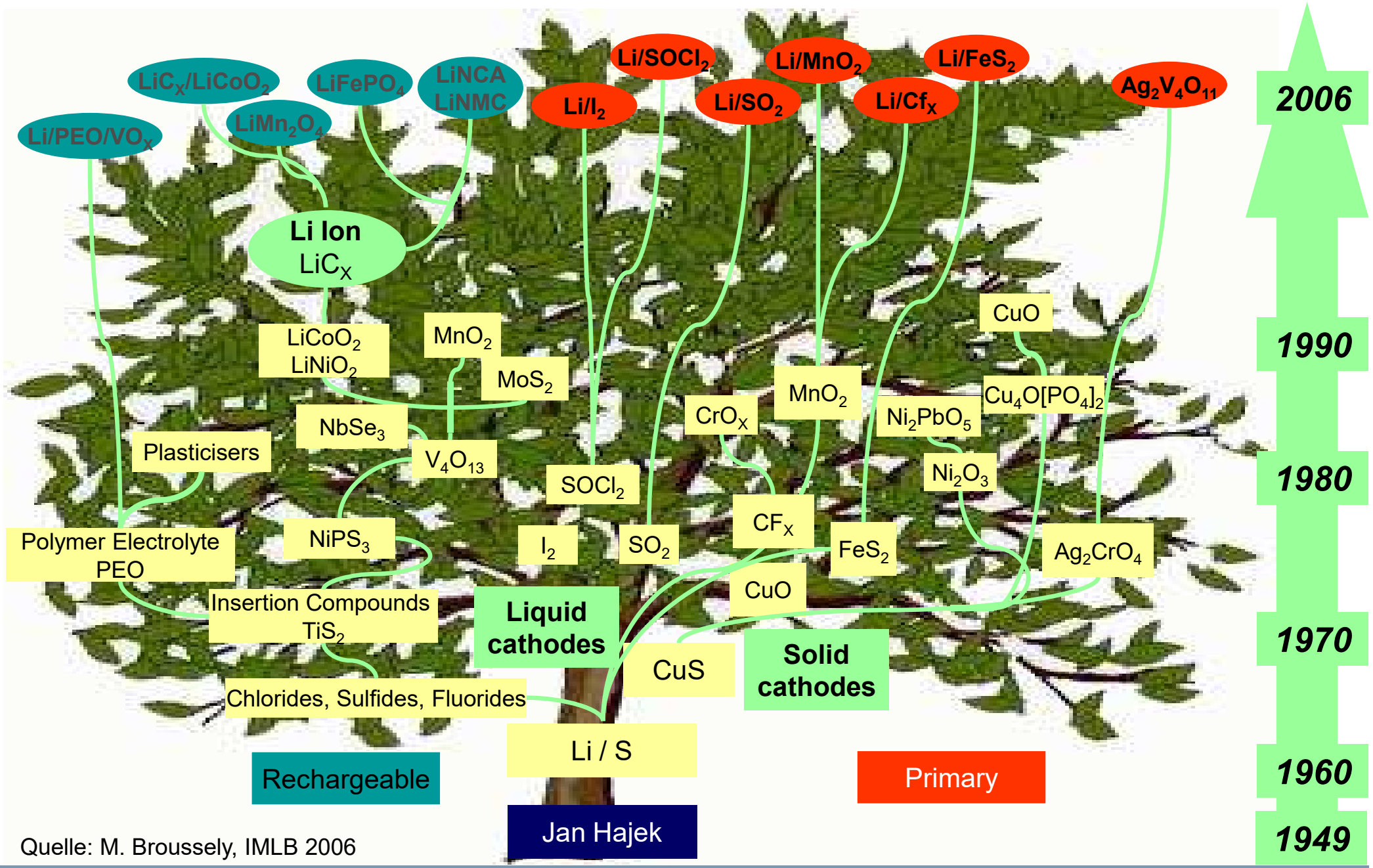

Quelle: M. Broussely, IMLB 2006

Development trends of electrode materials

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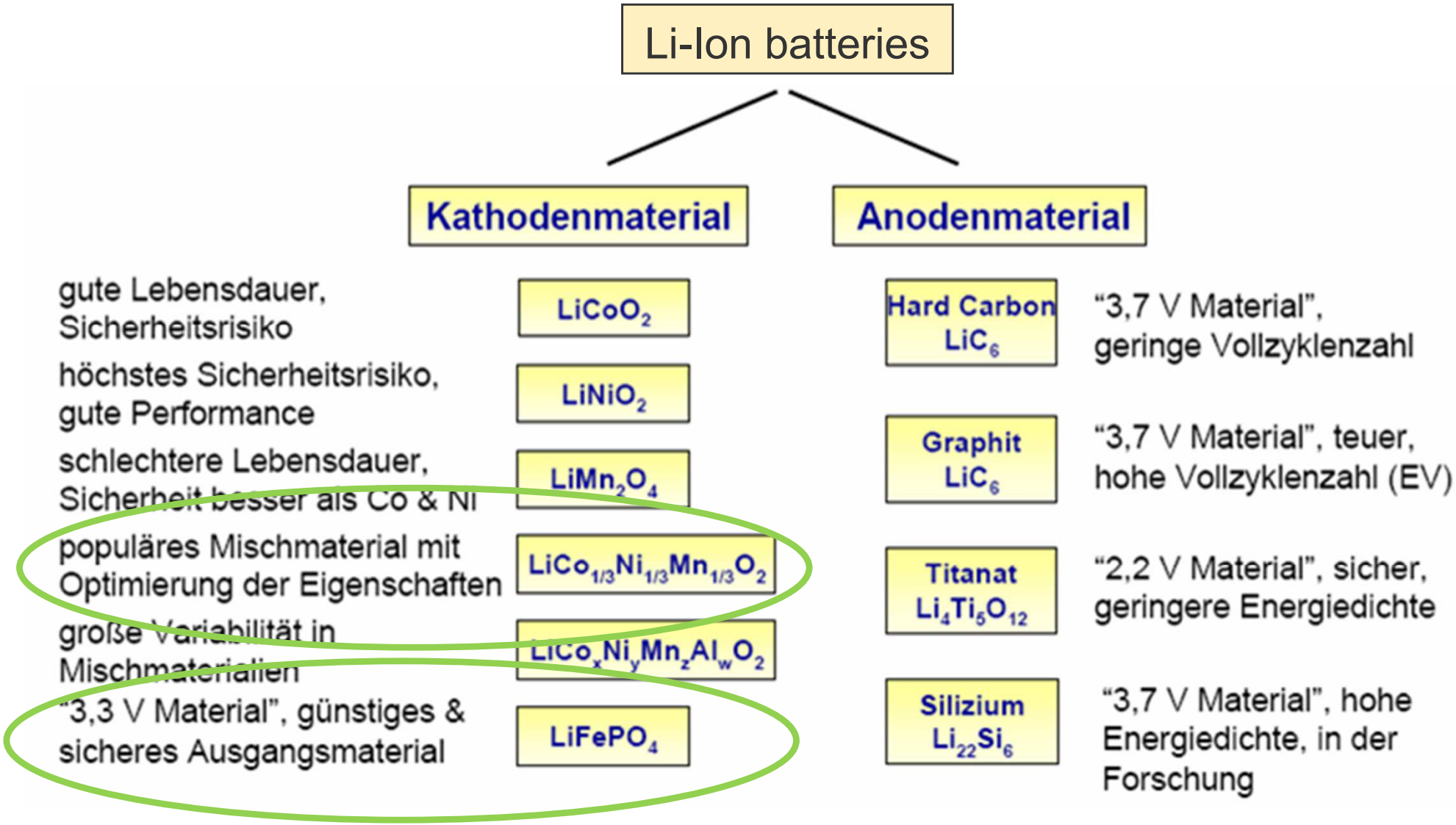

Quelle: Prof. Dr. Dirk Uwe Sauer, RWTH Aachen, „Technologie und Auslegung von Batteriesystemen für Elektromobilität“, FGLA-Kolloquium, 15.1.2010.

Cathode materials

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NCA (Nickel-Cobalt-Aluminium; Kathode)

- HP cells for hybrid applications with high currents; e.g. JohnsonControlSaft-Zellen (HighPower, 6.5Ah) in Mercedes S400 Hybrid verbaut, currents of 30C possible
- Typically cylindrical cells, relatively well developedt

NMC (Nickel-Mangan-Cobalt; Kathode)

- HO current cell technology -> for years in operation, well developed (1500 full cycles @ 100% DoD, 4000 cycles @ 80%DoD, good mixture of characteristics, high cell voltage 3.7V, stable quality

LFP (Lithium Iron Phosphate; Kathode)

- Material focused on in Asia (Ressources better available there than in Europe), cheap; tests in Zwickau
- Lower cell voltage 3.2V than NMC
- Very plain voltage curve in medium SoC area -> SoC detection very difficult

LTO (Lithium Titanium Oxide; Anode)

- Extremely high cyclability (>10.000 full cycles), but low cell voltage, low energy density; very expensive; also in tests in Zwickau

Trends of material development

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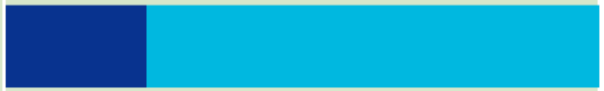
Development Strategy	Time frame	Tasks	Potential	2015 2020 2025 2030
Lithium-Ion Improve existing Chemistries	5 years	**Development, Engineering** (NCA, NMC, LFP)	10 - 15%	
Lithium-Ion Develop New Materials	10 years	**Research & Development** (Advanced cathodes, Li alloys, Si-C compounds)	20 - 40%	
New Energy Storage Systems	20 years	**Explorative Research** (Advanced Lithium Systems, Oxide Systems, Others (?))	> 100%	

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Cost

Energy

Life time

Availability

Safety

Comparison of battery technologies

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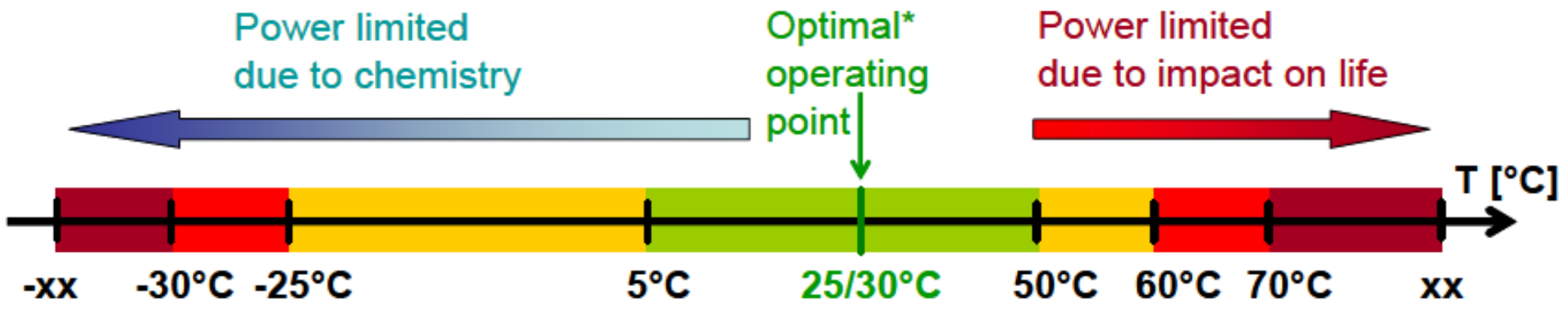
	Pb-acid	Ni-Cd	Ni-MH	Li-ion
Commercialized	1890	1956	1990	1992
Nominal Cell Voltage	**2.0V**	**1.2V**	**1.2V**	**3.2- 3.7V**
Positive Active Material	PbO2	NiOOH	NiOOH	**LiCoO2/LiMn2O4/LNMC/ LiFePO4**
Negative Active Material	Pb	Cd	MH	Graphite
Electrolyte	Aqueous (Acid)	Aqueous (Alkaline)	Aqueous (Alkaline)	Organic
Energy density (Cell level)	**100 Wh/l <30Wh/kg**	**150 Wh/l 50Wh/kg**	**250 Wh/l 60-80Wh/kg**	**350-400 Wh/l 100-150Wh/kg**
Power density [W/kg] (Cell level)	200 - 700* (*Thin Film Batteries)	200 - 1,000* (*HP System)	500 - 1,000* (*HP System)	Up to 2,000* (*HP System)
Life Time (years)	5-25	10-15	10-15	10-15
Cycle Life Time (100% DoD)	300	1000	1000	>1500
Cycle Life Time (80% DoD)	**750 – 1,600**	**2,000 – 3,000**	**2,000 – 3,000**	**4,000**
Rechargeability	**Several hours**	**Minutes to hours**	**Minutes to hours**	**1h up to 100% SOC; >10C pulse depending on SOC**
Efficiency [%]	80 - 85	90	90	90 - 95
Operation temp. [°C]	-20 / +45	-40 / +50	-40 / +50	-20/ +50
Cost (Battery Level)	**<0.2 €/Wh**	**0.5 €/Wh**	**0.5-1 €/Wh**	**1.0-1.5 €/Wh**
Environmental Concerns	Pb on disposal	Cd on disposal	None identified	None identified

Operation temperature

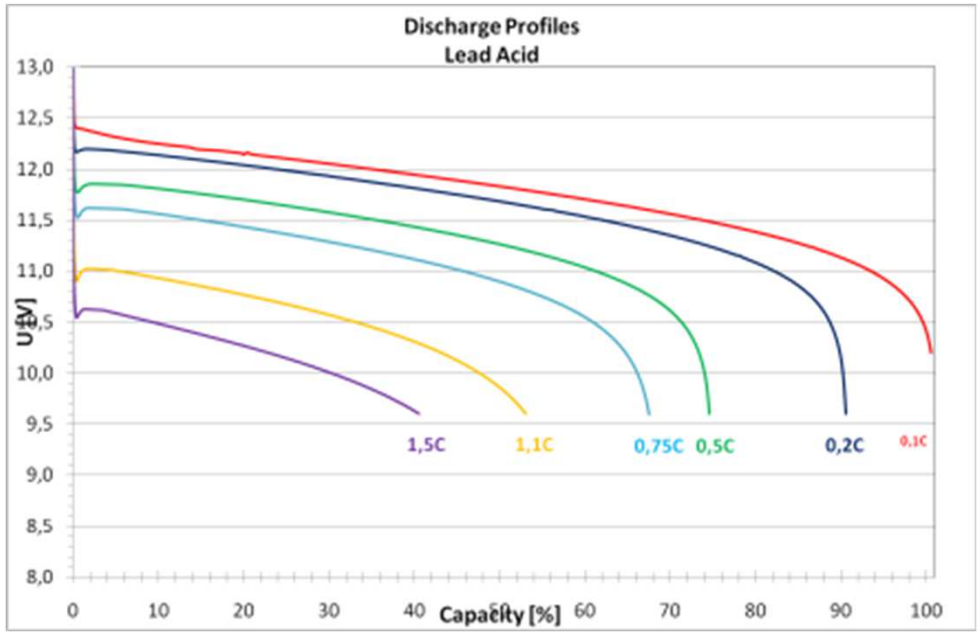
Temperature Operating Range

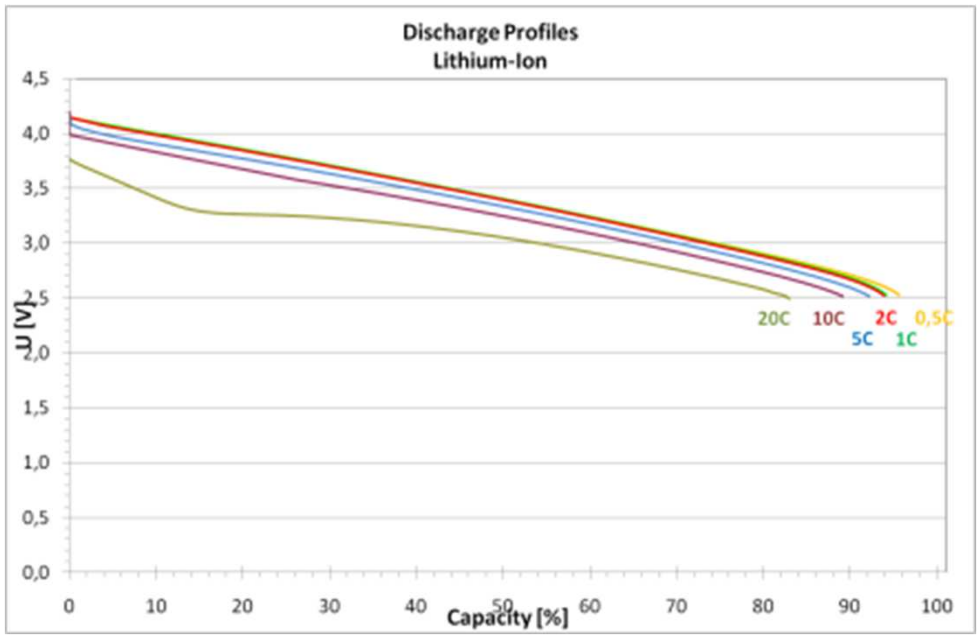


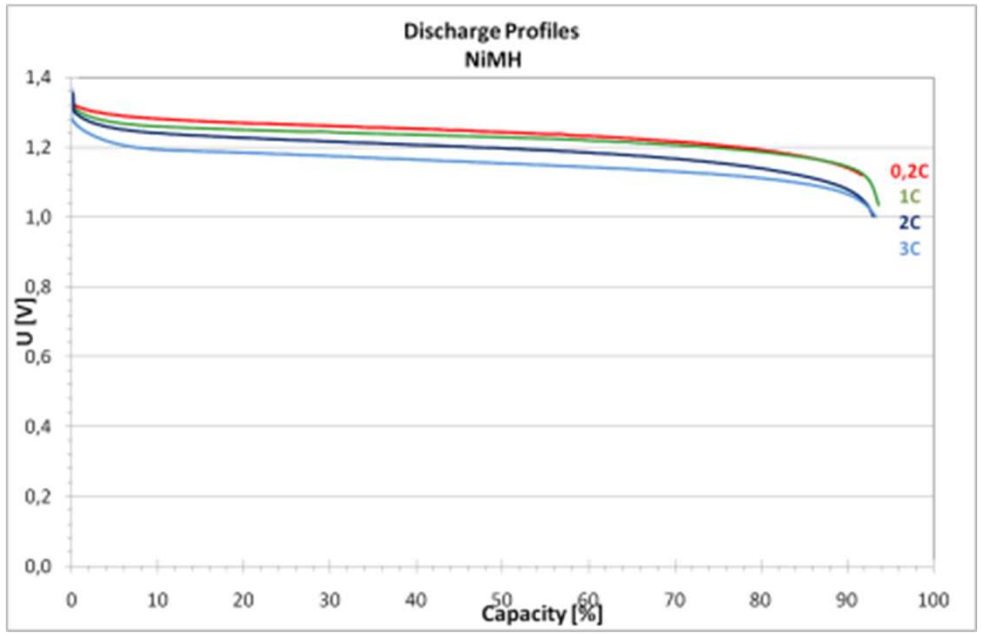
- Normal operating temperature range
- Restrained operating temperature range
- Highly restrained operating temperature range
- Not operating = downtime

* : for Battery End of life and Power

Discharge profile of battery technologies







Li-Ion:

- Continous discharge curve
- Capacity available even at high currents

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HOPPECKE ABT in Zwickau

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The HOPPECKE Advanced Battery Technology GmbH in Zwickau **develops and produces innovative electrochemical energy storage devices and system solutions.**

A continuous matching of synergies between development projects and product requirements for the respective business models is carried out.

HOPPECKE ABT in Zwickau

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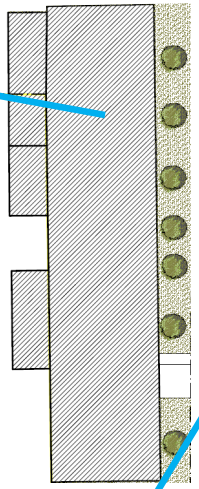
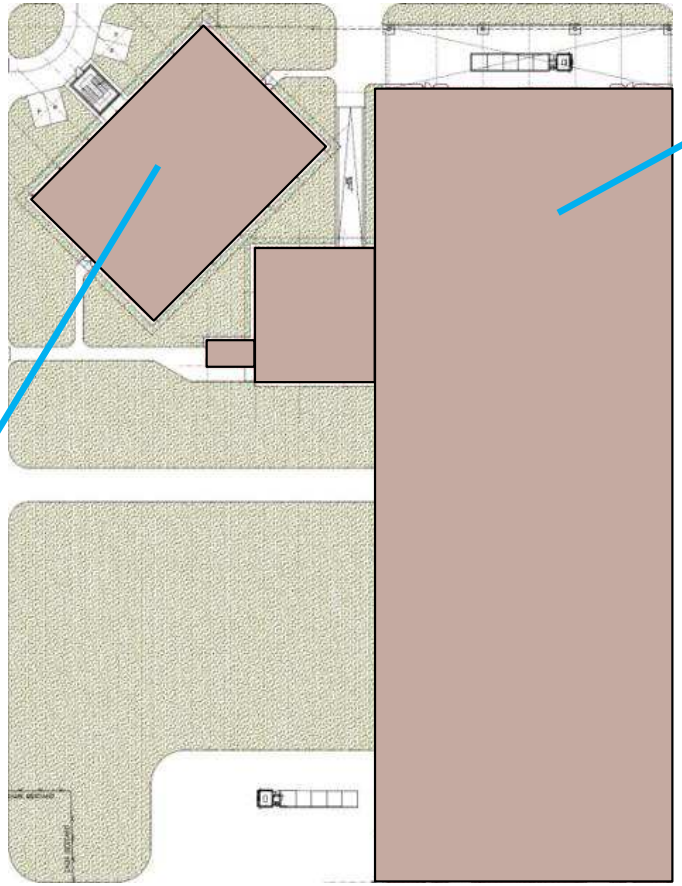
HOPPECKE Technologies

- Chargers
- AquaGen recom-bination plugs



New R&D center

in operation,
1.500 m²



New Production Site (LiOn & NiMH)

in operation, 5.000 m²

- Production of Li-Ion & NiMH batteries
- Assembly of complex energy storage systems with Lead-Acid, NiCd, NiMH and Li-Ion batteries

HOPPECKE R&D Activities

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	HOPPECKE Batteries, Brilon	HOPPECKE Battery Systems, Brilon	HOPPECKE Advanced Battery Technology, Zwickau
Technology	Lead-Acid	NiCd	Lithium-Ion / NiMH
Areas of expertise	▪ Motive & Stationary ▪ Flooded & Sealed ▪ Product, Process & Systems Development ▪ Applications Engineering	▪ Battery Systems for Railway Applications, Electric Busses & Automated Guided Vehicles ▪ Application Engineering for Special Energy Supply	▪ Cell Benchmarking ▪ Material Analysis ▪ Electronics ▪ Battery Management System (BMS) ▪ Development &Testing of Battery Systems ▪ Prototypes & Field Testing ▪ Process & Production Development ▪ Motive, Stationary and Special Applications

Shapes of large Lithium-Ion cells

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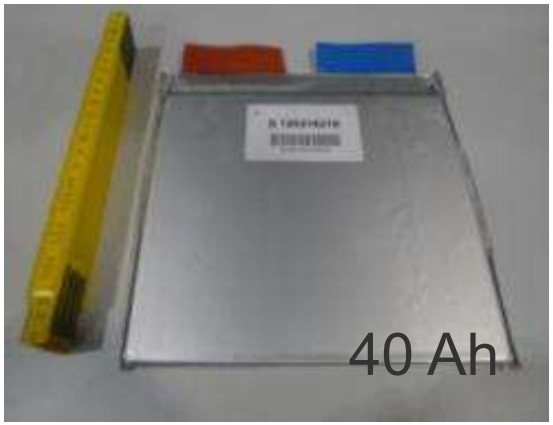
cylindrical

„coffee-bag“



prismatic

- Mass production established for consumer cells
- Large cells only from prototype or small series production

- Extensive benchmarking of approx. 20 international cell manufacturers
- Identification of cells for various industrial applications

Benchmarking

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Bundesministerium
für Verkehr, Bau
und Stadtentwicklung

Investigation of following criteria:

- nominal capacity
- current-carrying capacity
- temperature behavior under various loads
- cycling stability / lifetime under various load profiles
- self discharge
- etc…

Cycle life of large Lithium-Ion cells (LFP >10Ah)

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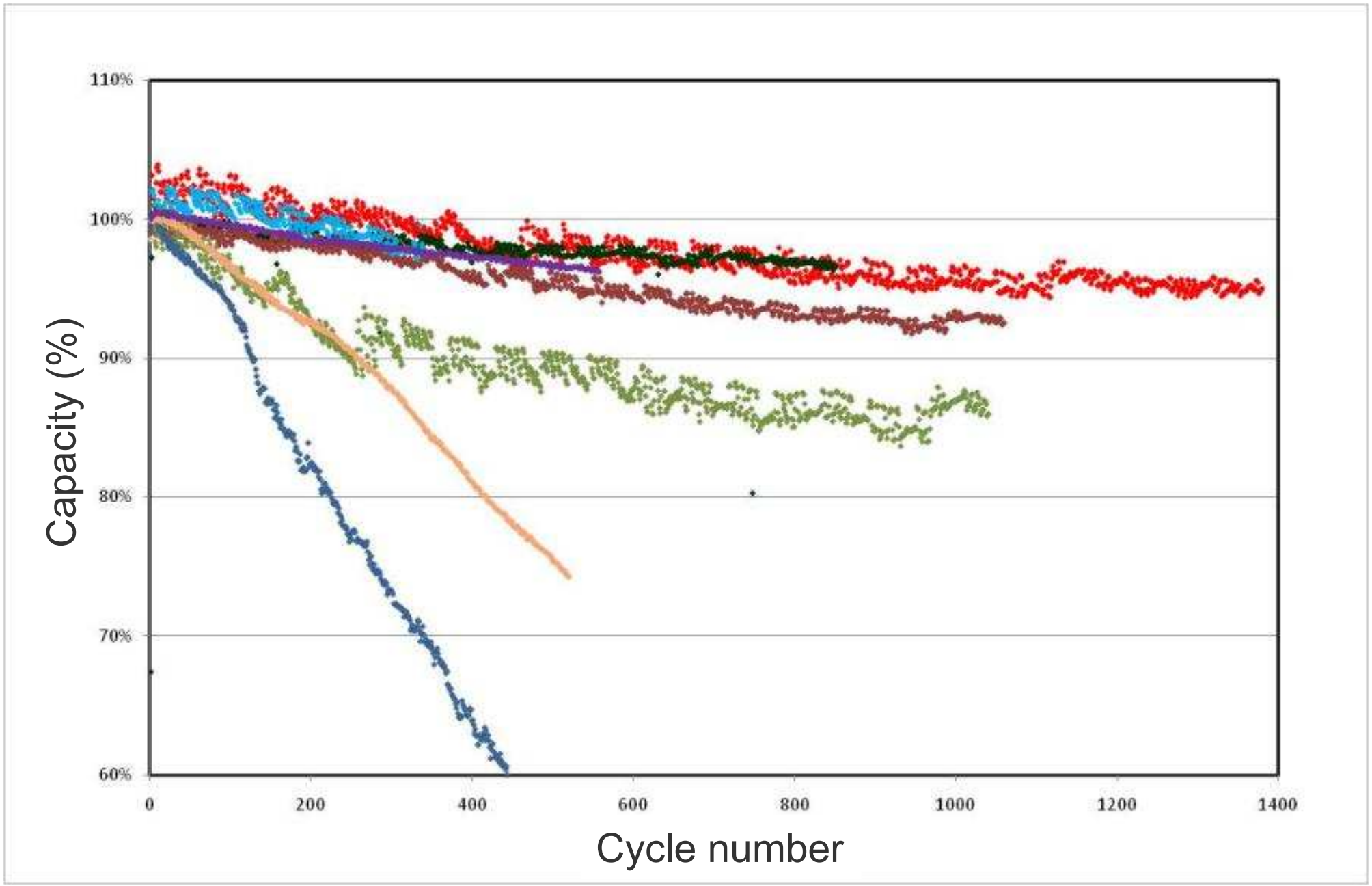

Cycle life of large Lithium-Ion cells (NMC >10Ah)

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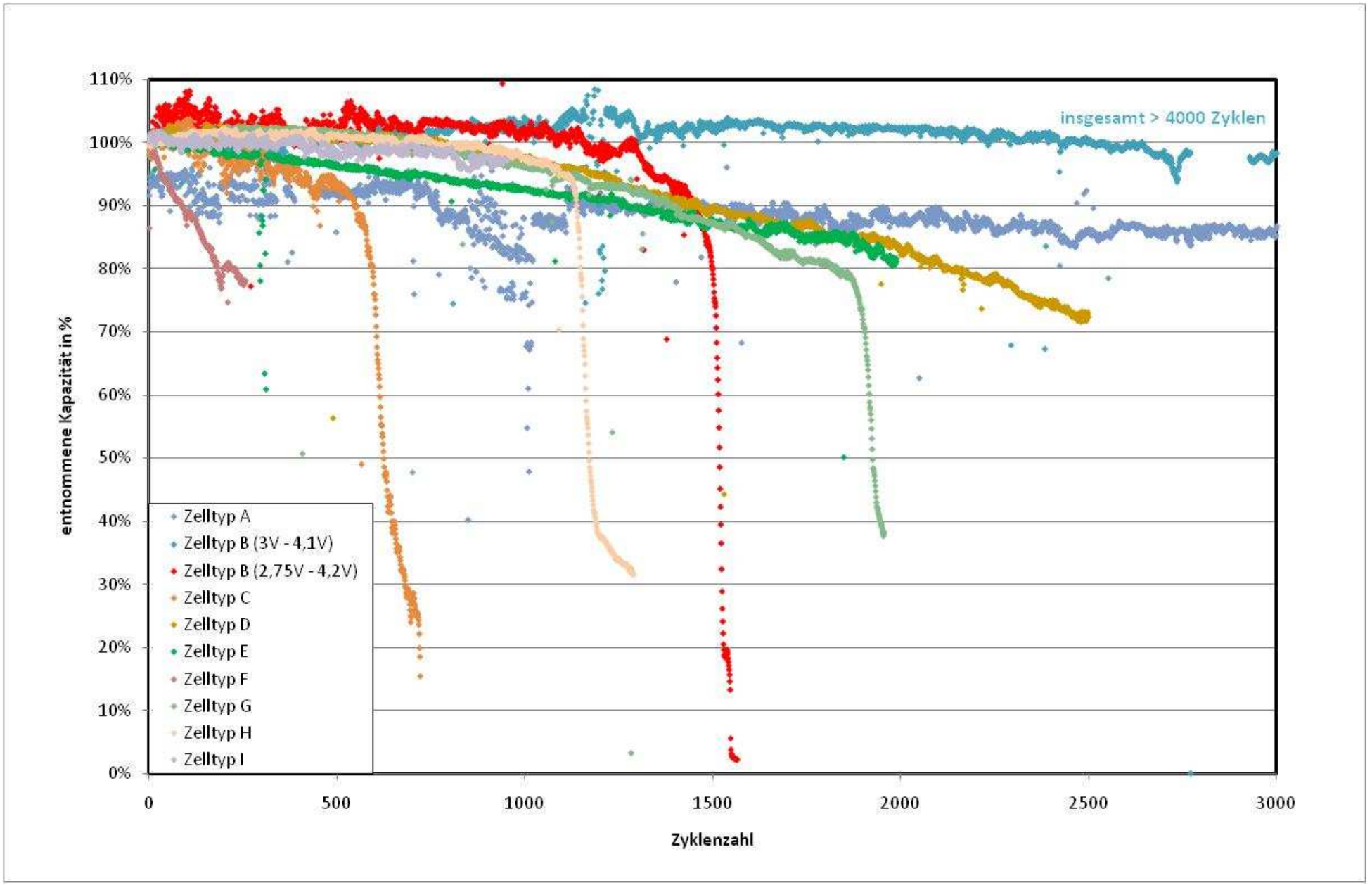
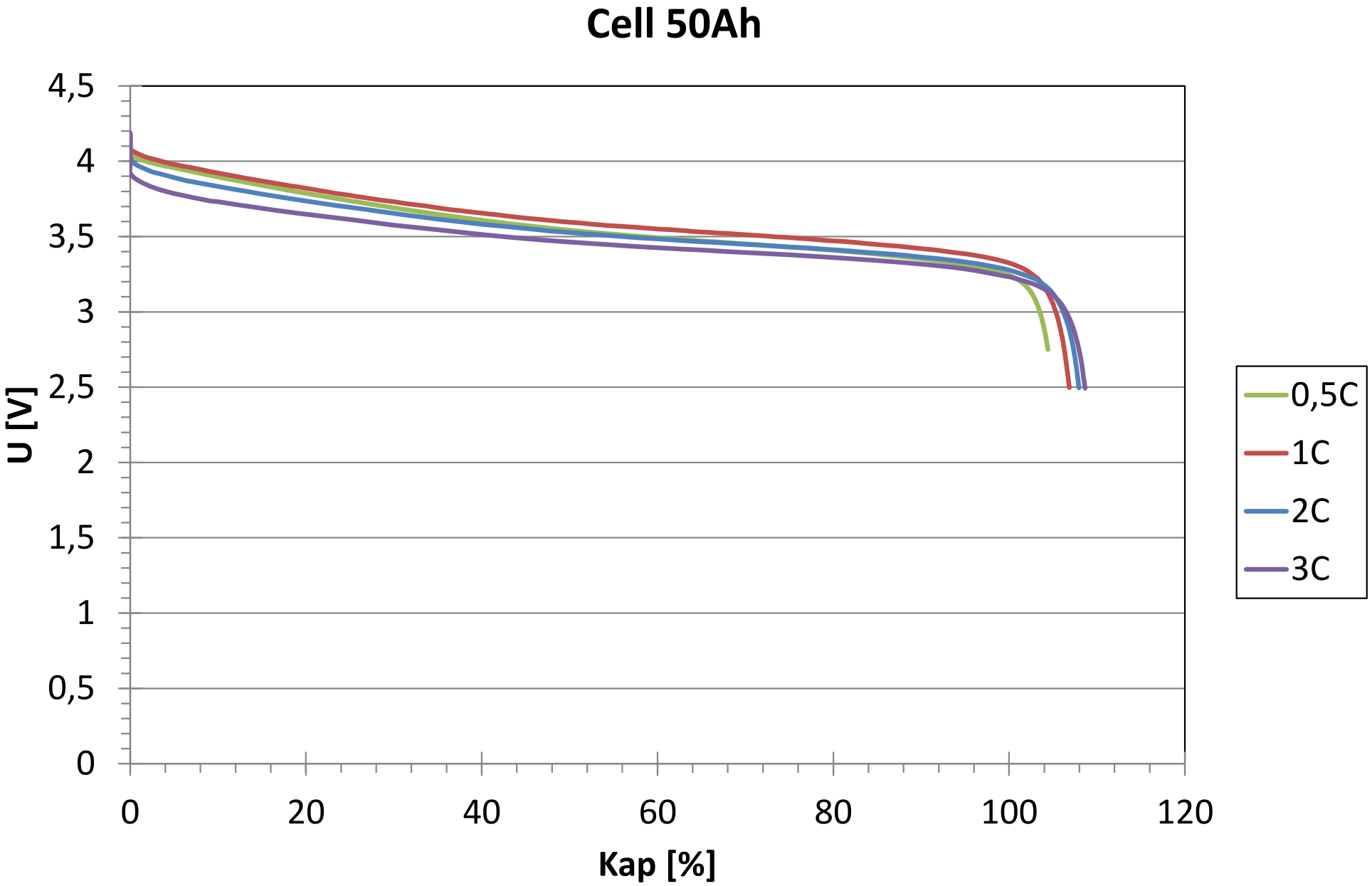
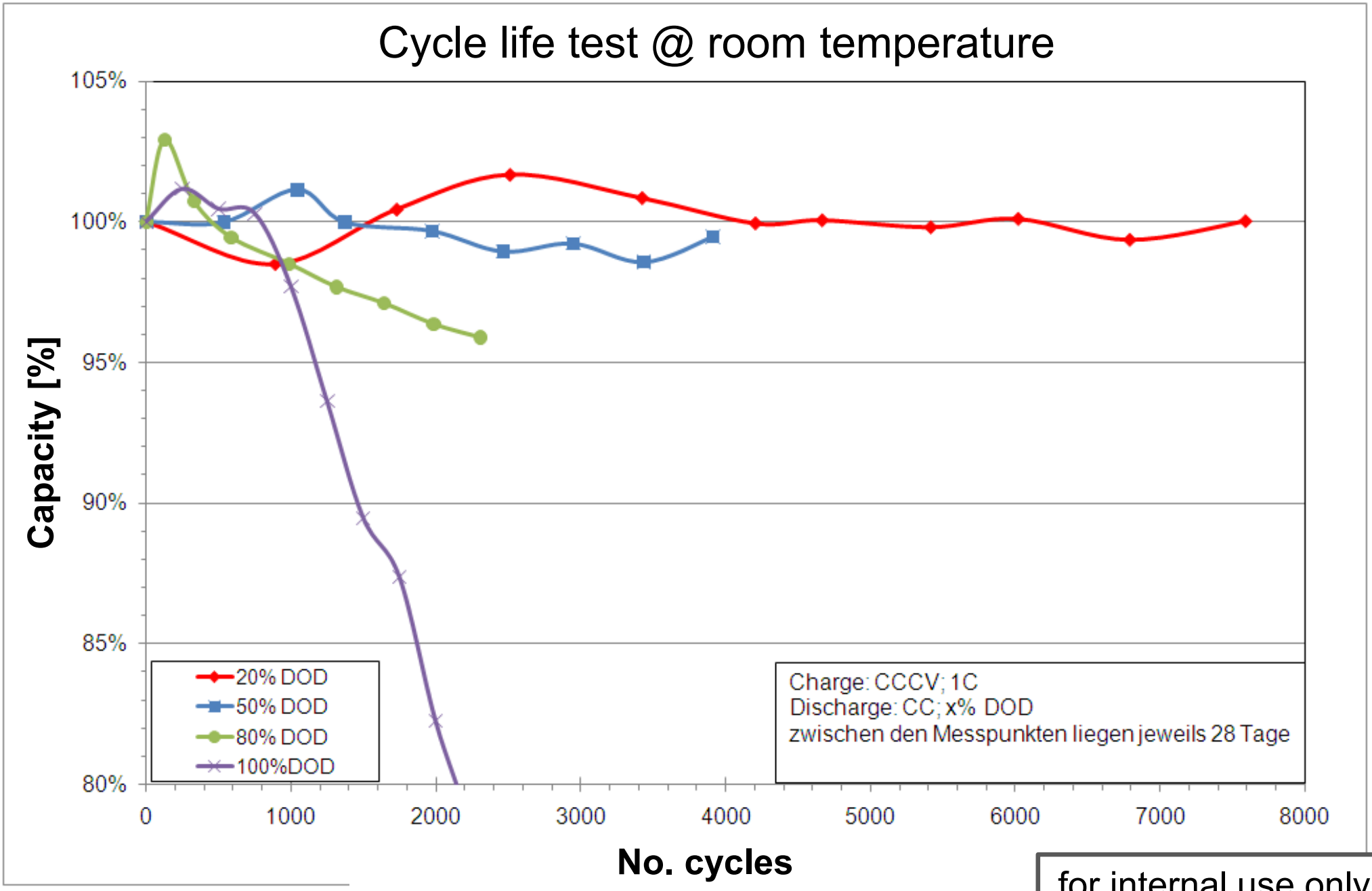


Discharge profile @ room temperature



Aging during cycling (no. cycles vs. DoD)



for internal use only!!

HOPPECKE Lithium-Ion Battery Modules

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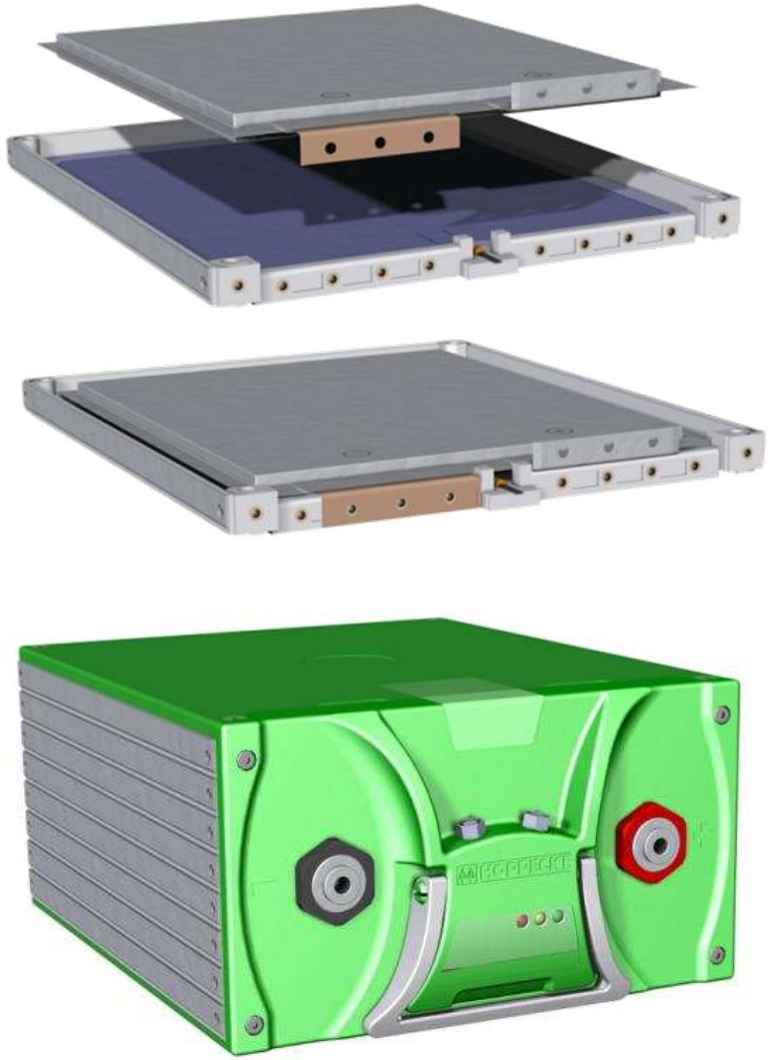
- 24 V & 36 V
- 40 & 50 Ah
- HighEnergy (50Ah) with high energy content or HighPower (40Ah) for high currents
- **Parallel and serial connection possible → Battery systems for various industrial applications**
- Integrated Battery Management System → Modules inherently safe
- Cooling or heating possible
- Communication with customer systems via HOPPECKE CAN standard
- Certification according to CE and UN38.3 in autumn 2012
- **Systems up to 60 V are available**

- **Battery modules for high voltage systems are in development** → prototypes can be requested from 2013

HOPPECKE Li-Ion Module Conception



Construction of Li-Ion Module:

- „Coffee-bag“ cells with a capacity of 50 or 40 Ah
- Cell frame for heat-dissipation and mounting of the cell
- Cell stack of 7 cells (25,9V/50Ah/1.3kWh HE or 25,9V/40Ah/1kWh HP)
  or 10 cells (37V/50Ah/1.8kWh HE or 37V/40Ah/1.5kWh HP) per module
- BMS electronics on own cell frame

Functions of the battery management:

- Module-based system architecture (operation of module as a single-component and possibility of connecting modules to large-scale battery systems)
- Inherently safe operation (range monitoring: voltage, current, temperature), guaranteed by shut-down of module by semiconductors
- Determination of SoC/SoH
- Balancing of cells and modules
- Data-logging function
- Communication interface

HOPPECKE LiOn Module

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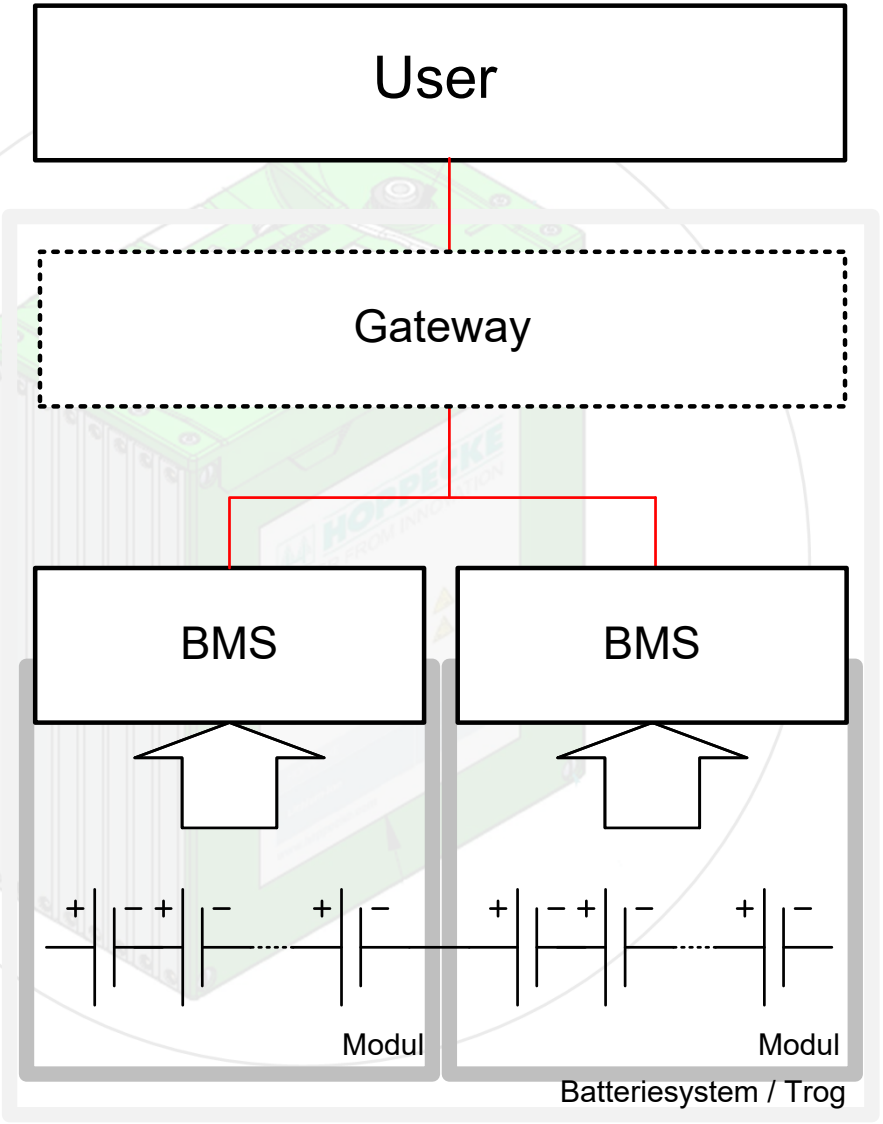
LiOn Module	24 V			36 V		
	High Energy	High Energy	High Power	High Energy	High Energy	High Power
nominal voltage [V]	25,9		25,9	37		37
nominal capacity [Ah]	40	50	40	40	50	40
nominal energy [kWh]	1,0	1,3	1,0	1,5	1,9	1,5
charge cut-off voltage [V]	29,0		29,0	41,4		41,4
discharge cut-off voltage [V]	22,4		22,4	32,0		32,0
constant discharge current [A]	100		240	100		240
peak discharge current (<10s) [A]	200		400	200		400
constant charge current [A]	50		80	50		80
peak charge current (<10s) [A]	80		160	80		160
charge/discharge cycles (100% DoD)	2500	1500	1500	2500	1500	1500
discharge temperature	-10 to 50 °C		-10 to 50 °C	-10 to 50 °C		-10 to 50 °C
charge temperature	0 to 40 °C		0 to 40 °C	0 to 40 °C		0 to 40 °C
storage temperature	-20 to 50 °C		-20 to 50 °C	-20 to 50 °C		-20 to 50 °C
weight [kg]	10,0	11,0	10,0	13,5	15,0	13,5
gravimetric energy density [Wh/kg]	104	118	104	110	123	110
dimensions L x W x H [mm]	228 x 128 x 289			228 x 170 x 289		

Focus on „coffee-bag“ cells with a capacity of 50 Ah
--> Other technologies (LFP, LTO), capacities (<50Ah) and other cell designs (prismatic) are in test for qualification at ABT in Zwickau

Battery Management & System Architecture

Customer specific protocol /
HOPPECKE CAN bus protocol



Master-Master Principle

System functions by group of
intelligent and communicating
Li-ion battery modules

BMS = Battery Management System

System Components

3 modules connected in parallel with a CAN2X gateway module

Operational safety of HO LiOn module

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Redundancy

- Measuring cell voltages by independent circuit
- Redundant measurement of operational data for crossing warning or error thresholds
- Independent measurement of module voltage and comparison with cell voltages

BMS safety functions

- Protection against overcurrents: long-term and short-term thresholds for charging and discharging currents; defined tolerance of high peak currents
- Short-circuit protection
- Overvoltage protection
- Temperature control

Melting fuse

- 160A fuse against thermal overcurrents and short-circuit current

CAN2X gateway module

HOPPECKE CAN protocol: adaption for customer is possible, but we would like to use our standard

Output connector and comm. protocol configurable

System Components

Diagnostic tool: Battery system analysis

- **Diagnostic tool to parameterize modules and system, read our warning / error codes and current system and modules status information**

Diagnostic tool: Module analysis

- **Diagnostic tool to parameterize modules and system, read our warning / error codes and current system and modules status information**

Chargers for LiOn - Technology

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- Optimal charging methods extend lifetime of battery significantly
- In addition to traditional charging methods **fast charging** methods (t < 1h) are established
- Requirements
  - Critical operation conditions must be avoided
  - Full charging in shortest time
  - Balancing of cells and modules for conditioning of unequal states
  - Minimizing of aging mechanism
- Standard **charging method „IUa“** with a max charging voltage of 4,1 - 4,2V
- In general: the lower the DoD, the higher the cycle lifetime
- Intermediate charging are possible and desired

LiOn 36V modules

High Voltage LiOn Module

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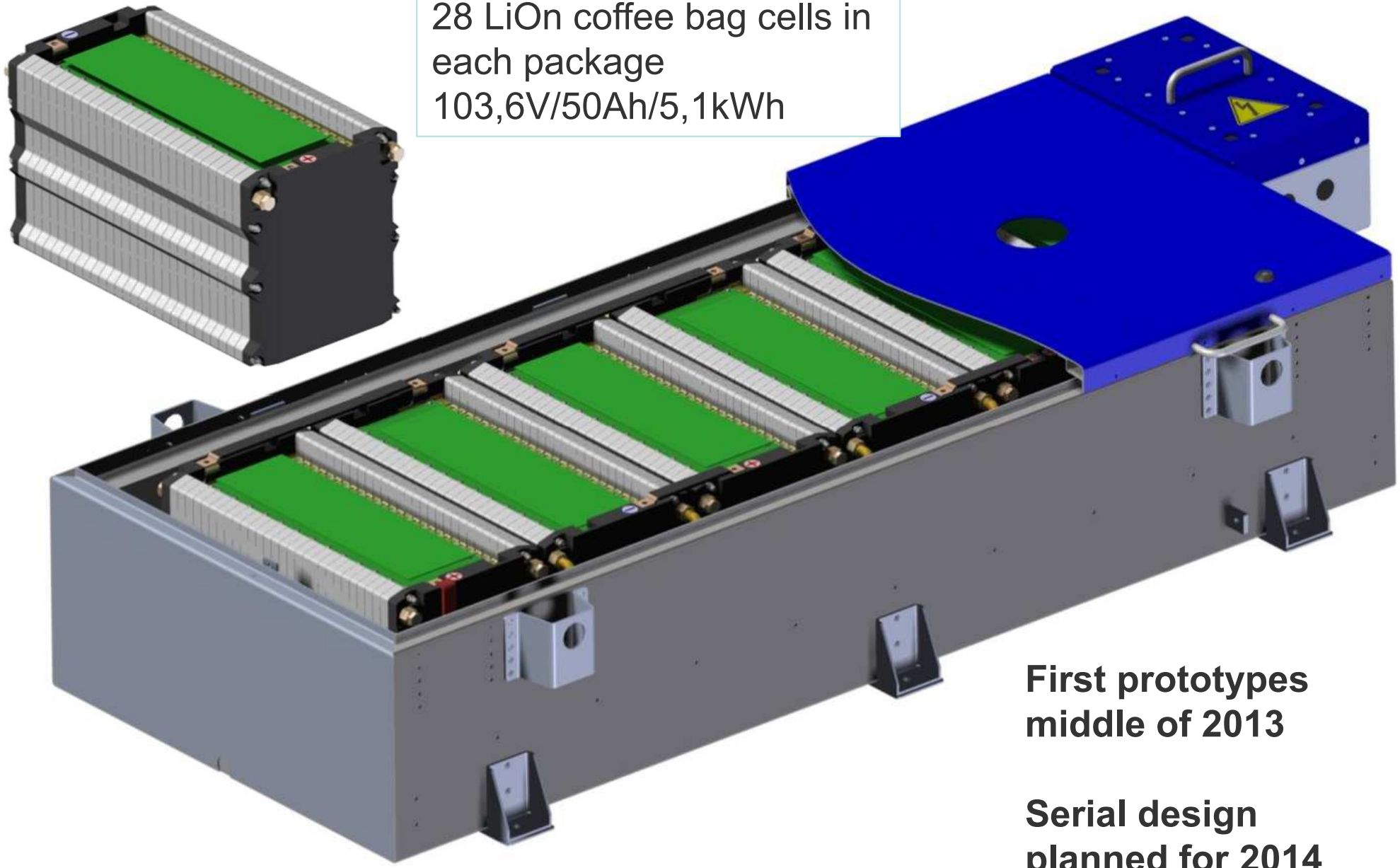
28 LiOn coffee bag cells in each package
103,6V/50Ah/5,1kWh



First prototypes middle of 2013

Serial design planned for 2014

HOPPECKE Li-Ion Roadmap

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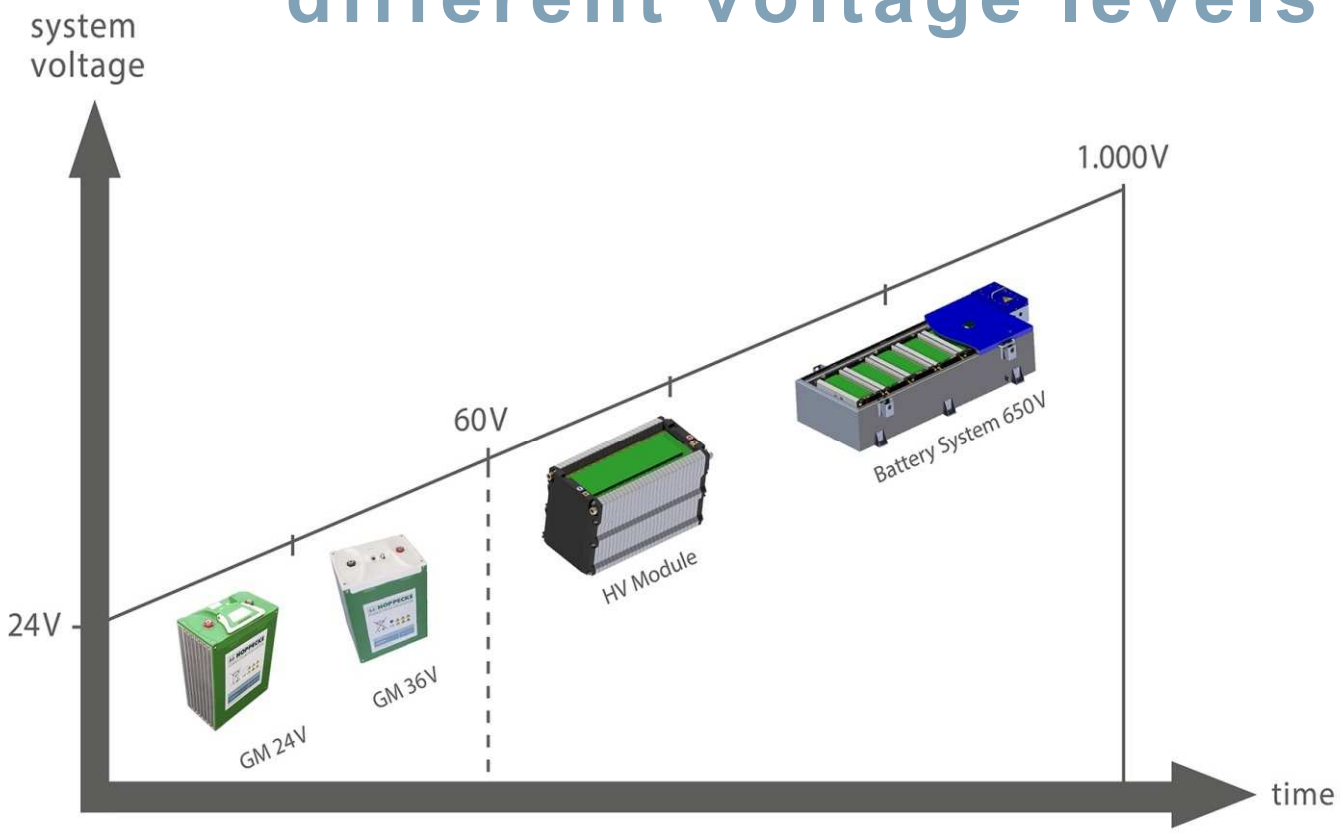
product launch for different voltage levels



Prototypes since 2010 **Series** from autumn 2012	**Prototypes** from middle of 2013 **Series start-up** at the end of 2014
Available as **High Energy** and **High Power version**	

Module production

Battery modules 3p + CAN2X

LiOn module production

Customer Benefits of HOPPECKE LiOn

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- **High energy density** and **high power density**
- **Very compact dimensions → savings in space** for the existing capacity or **much longer operating times** with available installation space
- **Low weight**
- **Nominal capacity** is available **even at high discharge currents**
- **High life expectancy**: Up to 2.500 full cycles at 100% capacity withdrawal and 4.000 cycles at 80% capacity withdrawal → **no replacement for many years**
- **Cycling behaviour**: Opportunity charging and partial discharges are possible
- **Quick charge ability:** A full charge is possible in a short time
- Completely **closed & free of gassing**
- Completely **maintenance free**
- **No equalising charges required**
- **Extremely low self-discharge**
- Very efficient charging due to **Wh efficiency rate >90%**
- **Can be recycled safely**
- **Maximum safety** thanks to **integrated battery management system**
- **Balancing** of cells & modules
- **Communication with user systems:** state of charge information transmitted
- **Modular:** May be adapted **for many applications** and is **flexible for interconnection** to form large battery systems!

Customer Benefits of HOPPECKE LiOn

HOPPECKE
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- **High energy density** and **high power density**
- **Very compact dimensions → savings in space** for the existing capacity or **much longer operating times** with available installation space
- **Low weight**
- **No**
- **Hi** les at
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- Co
- **No**
- **Ex**
- Very
- **Can be recycled safely**
- **Maximum safety** thanks to **integrated battery management system**
- **Balancing** of cells & modules
- **Communication with user systems:** state of charge information transmitted
- **Modular:** May be adapted **for many applications** and is **flexible for interconnection** to form large battery systems!

Summary: Li-Ion is excellent for the following applications:

- **Cyclical use with opportunity charging and partial discharging**
- Where **weight, space, avoidance of gasing and reduction of maintenance are crucial**
- Where **quick charge** is needed and **high disharge currents** may flow
- Where **much energy** is **put through**
- Where **only short breaks interrupt** a **permanent use**

Applications

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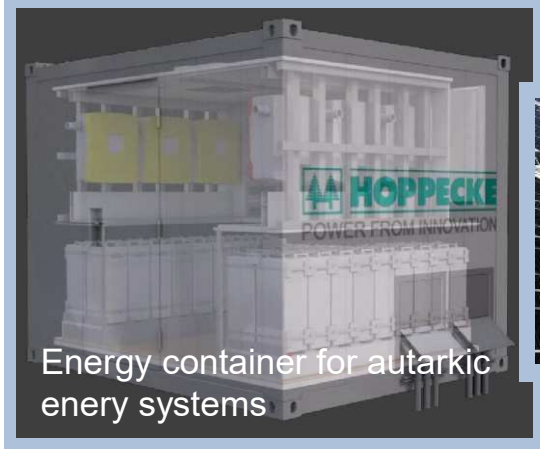
Electric & hybrid utility vehicles

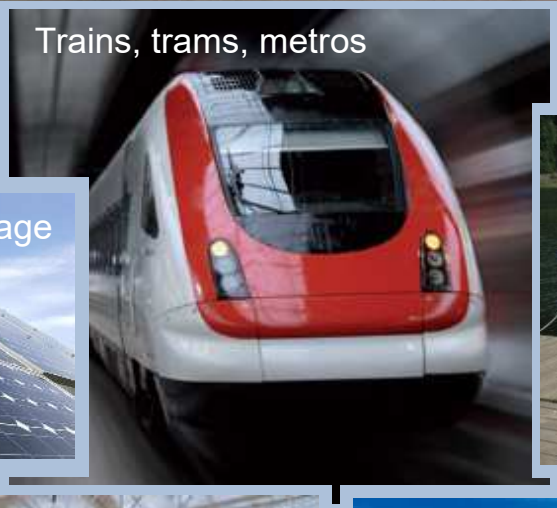

Electric & hybrid utility vehicles


Electric & hybrid busses

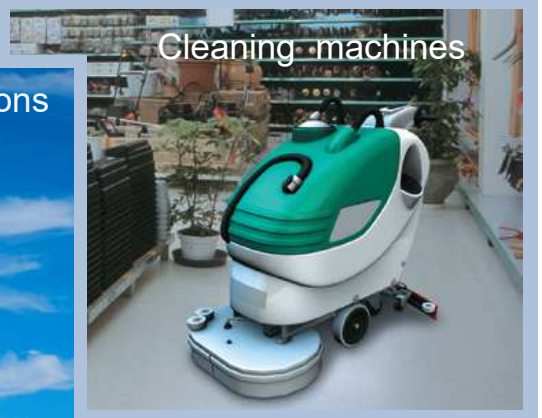


Energy container for autarkic enery systems


Solar energy storage


Trains, trams, metros

Electric & hybrid boats


Cleaning machines


Automated guided vehicles


Industrial trucks


Stationary applications

HOPPECKE Li-Ion: Applications

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Traction



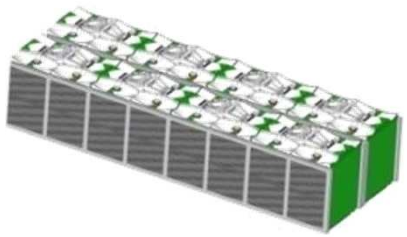


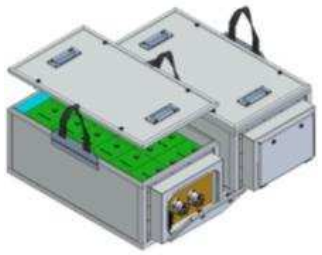


Li-Ion module

Stationary


Bus, Rolling Stock





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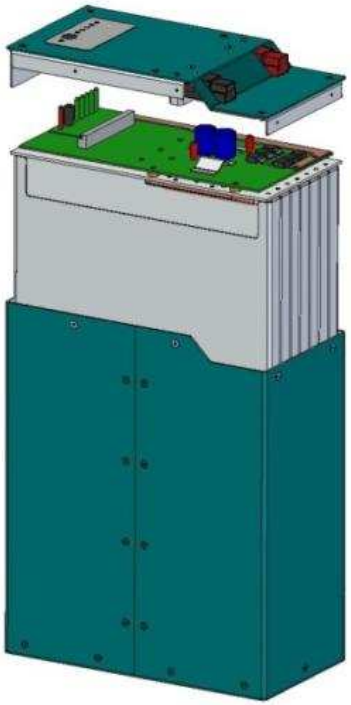
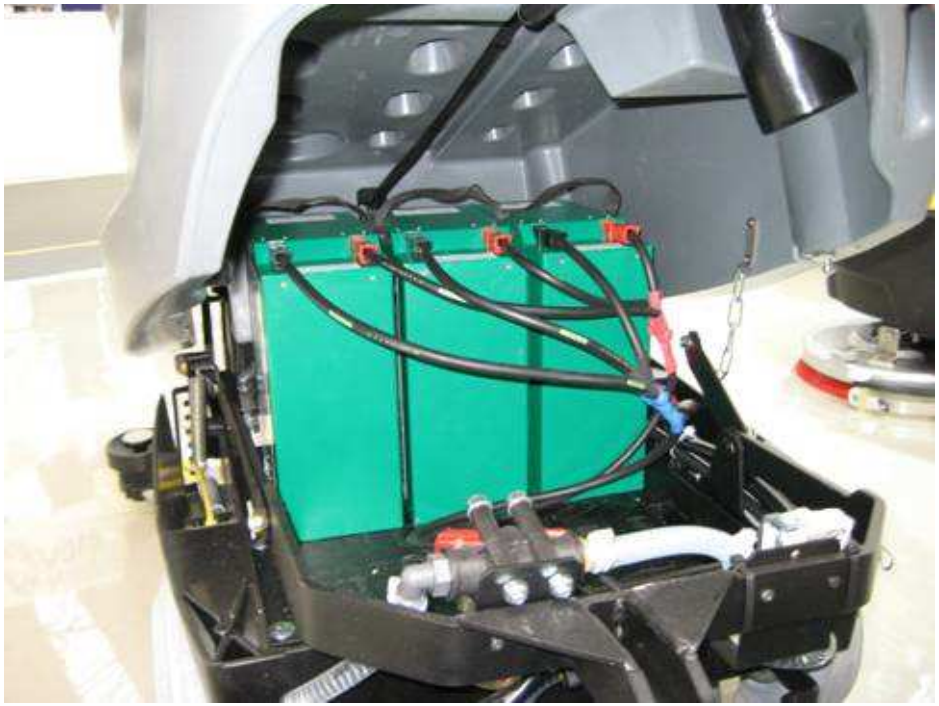
Light traction

24V/150Ah Parallel connection to increase capacity
Advantages: little weight and small volume, longer operating time, higher life cycle, Intermediate charging possible to afford higher flexibility





Projects MP: Material Handling

24V/150Ah

Projects MP: Material Handling

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- **Reduction of nominal capacity**
- **fast charging with 1C-2C**
- **Cooling realized**

8 modules (1s8p)
1C charging
IP65

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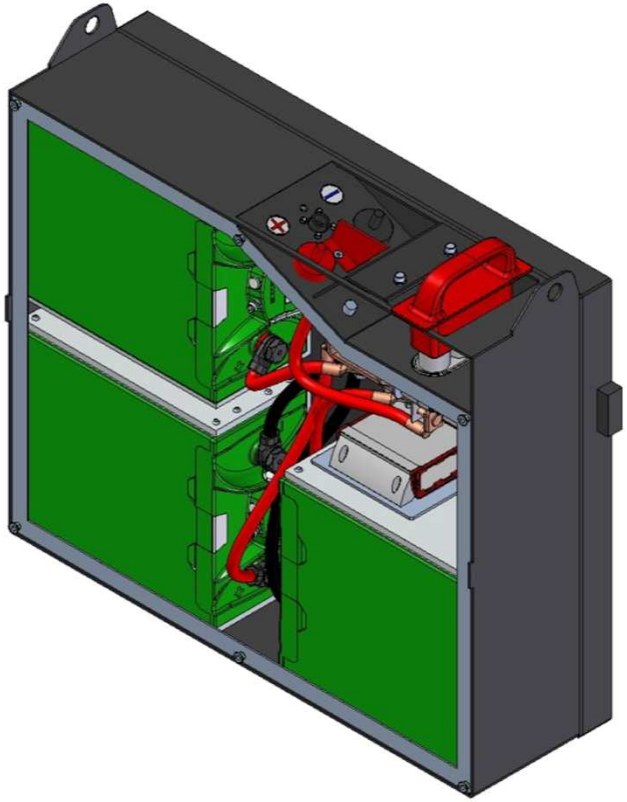
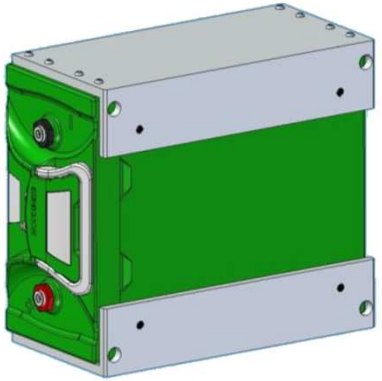
order truck with HOPPECKE LiOn battery (24V 400 Ah) in field test:

MH 24V 120Ah High Power





- high power cells 40Ah
- 3 modules in parallel (25,9V 120 Ah)
- Disharge current 3C (300A)
- Fast charging with 2C (240A) -> 30 minutes full charge
- IP65 - splash water proofed

BO-Mobil Van Bochum University of Applied Sciences

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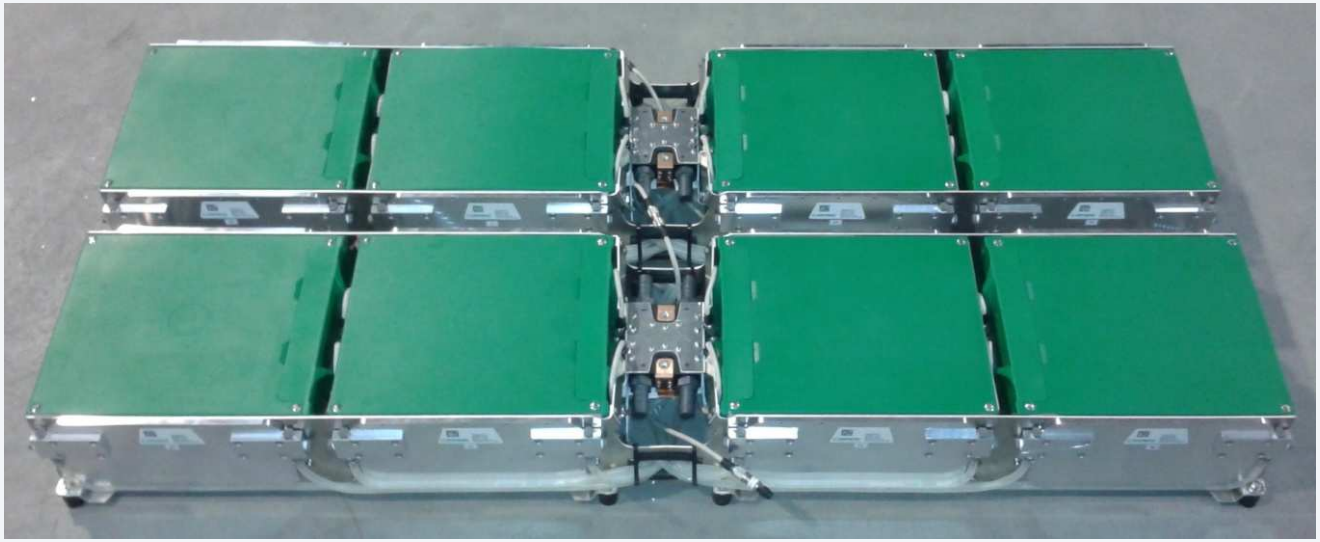
- **Application**
  Electric van for urban areas
- **Module configuration**
  2s10p
- **Voltage / capacity**
  51.8 V / 500 Ah
- **Energy content**
  25.9 kWh
- **Realisation**
  01 / 2012
- **Goal of the project**
  - Development of an electric powered van in urban use
- **The Battery**
  - High Energy Battery integrated in the bottom of the car
  - Water cooling



Electric transporter

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- **Application**
  Communal transportation
- **Module configuration**
  3s3p
- **Voltage / capacity**
  88.8 V / 330 Ah
- **Energy content**
  26.6 kWh
- **Realisation**
  06 / 2011
- **Funding**
  German electromobility region “Rhein-Ruhr”
- **Range**
  140 km (Pb: 80 km)
- **Weight**
  250kg (Pb: 330 kg)

Power tool waggon

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System consisting of 1 LiOn module and an onboard charger integrated in one compartment

Projects Stationary LiOn Batteries

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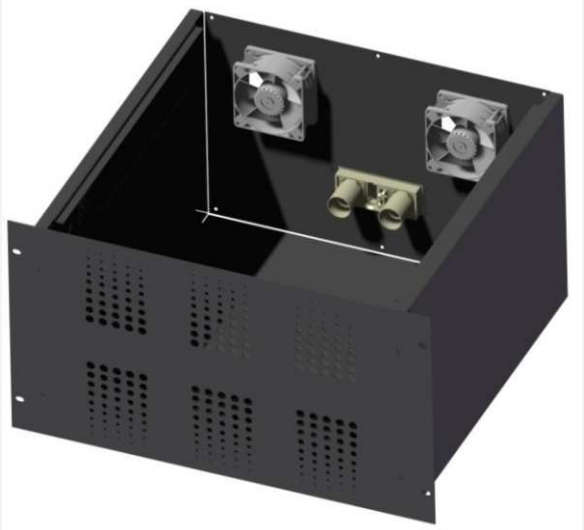
- **Application**
  Grid stabilization
- **Module configuration**
  1s6p
- **Voltage / capacity**
  25.9 V / 300 Ah
- **Energy content**
  7.8 kWh
- **Rectifier**
  24 V -> 400 V; 5kW
- **Realisation**
  06 / 2011



HyLis – Lithium-Pb Hybrid Battery System

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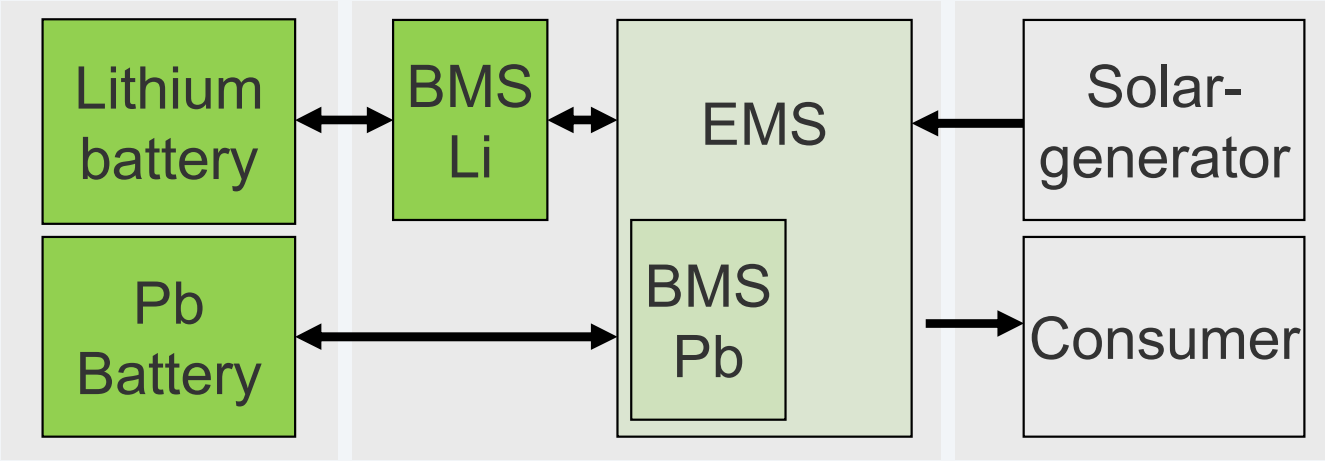
- **Application**
  Stationary off-grid storage of solar energy combining the benefits of lead-acid and li-ion batteries
- **Module configuration**
  1s2p
- **Voltage / capacity**
  - 25.9 V / 100 Ah (Lithium)
  - 24 V / 400 Ah (Pb)
- **Project duration**
  03 / 2009 – 02 / 2012
- **Dimension**
  19“, 3 HU
- **Funding**
  BMBF (German Ministry of Education and Research)

System layout: (green colour indicates Hoppecke components)



Project partners: ZSW phocos Hochschule Ulm

Hannover Fair & Intersolar 2012

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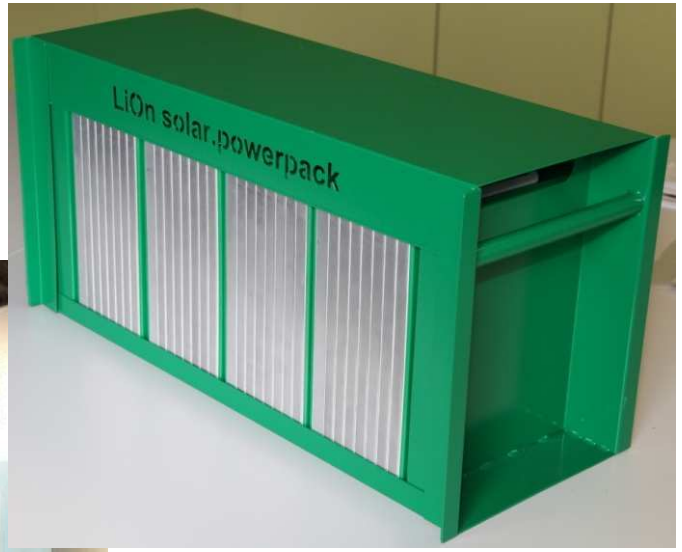
LiOn solar.powerpack



Projects SP: Tram - UPS

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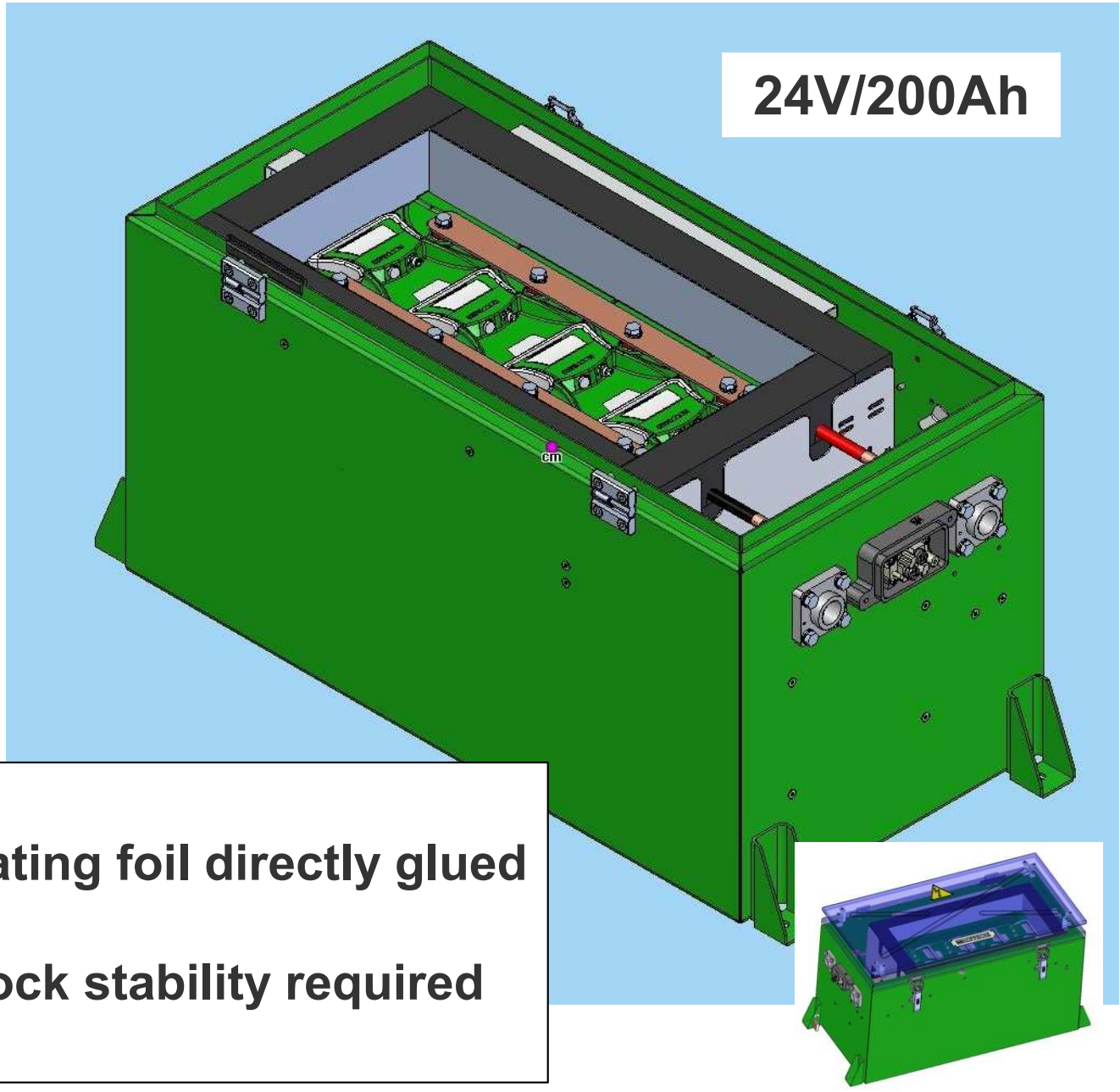

- UPS for tram
- cold temperature, heating foil directly glued on each LiOn cell
- high vibration and shock stability required
- Tests started

Content

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Workflow for requests

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Argumentation material:

- LiOn Flyer
- Standard LiOn Presentation
- LiOn Questionnaire

Workflow:

- **Specify requests with questionnaire**
- **Send requests to PM RP Mr. Bäcker/Hachmeyer or BD Mr. Haubrock/Linke**
- Information is provided by PM RP or BD
- **Battery designs and offers with pricing and date of delivery are prepared by PM RP / BD / ABT**
- Module and system engineering and construction will be done in Zwickau
- Final system tests and delivery will be done in Zwickau

Content

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Summary of HOPPECKE Li-Ion

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- **Summary: Li-Ion is excellent for the following applications:**
  - **Cyclical use with opportunity charging and partial discharging**
  - Where **weight, space, avoidance of gasing and reduction of maintenance are crucial**
  - Where **quick charge** is needed and **high disharge currents** may flow
  - Where **much energy** is **put through**
  - Where **only short breaks interrupt** a **permanent use**

- **HOPPECKE**: Module concept as basis for **Li-Ion battery systems:**
  - Extensive **benchmarking and knowlegde of Li-Ion cells**
  - Development and production of battery modules as base unit for systems
  - **Own battery management system**
  - **Field tests** are running
  - **Production capacity** installed
  - **Commercial projects can be requested**

Thank you. . .

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Thank you for your attention!

www.hoppecke.com

Production line and end-of-line test bench of lithium-ion battery modules

Open Points?

Questions?

Remarks?

Köszönöm a figyelmet!