Technische Universität Braunschweig

IBPC 2018

INTERNATIONAL BATTERY PRODUCTION CONFERENCE

14 to 16 November 2018

CONFERENCE BROCHURE

WELCOME

Dear participants of the IBPC,

Almost 200 nations have agreed to restrict the global temperature increase to a maximum of 2 °C. The transformation of the mobility and energy sectors towards minimum greenhouse gas emissions is of high importance to reach this goal. Key technologies and important part of the transformation are energy storage systems and especially electrochemical battery cells. However, various challenges within design and production have to be overcome.

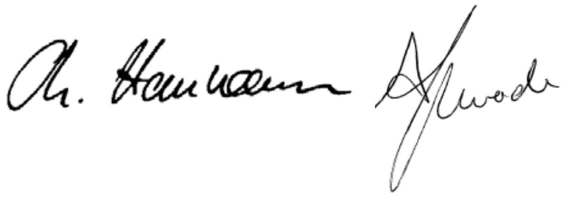
From a process and production engineering perspective, substantial cost reductions, quality improvements as well as higher safety levels are required. In addition, environmental impacts along the battery life cycle have to be taken into account to avoid problem shifting. While most conferences and congresses on battery technologies focus on materials science and engineering, the IBPC specifically addresses the production of batteries. The Battery LabFactory Braunschweig (BLB) brings together different engineering disciplines. With establishing the IBPC as a new conference, we want to provide an interdisciplinary platform to present and discuss technological advances in production processes, machines and equipment as well as related technical building services. In addition, engineering methods and tools to support the planning and design of processes, process chains, and even entire factories including battery life cycle are addressed.

The main goal of the IBPC is to connect experts from industry- cell and battery manufacturers, equipment and material suppliers as well as factory planners- and academia. We are very happy to welcome internationally renowned keynote speakers from different sections of the value chain. Moreover, we are especially thankful to have the VDMA Battery Production as our supporting partner in organizing this event. A special thank you goes to our sponsors PEC Group, Coperion, Netzsch and Custom Cells, without whom we could not have organized this event in this extent.

We will continue the conference to an annual conference series.

We wish you a very warm welcome, interesting talks and exciting discussions in the heart of the city of science, Braunschweig.

Prof. Christoph Herrmann & Prof. Arno Kwade



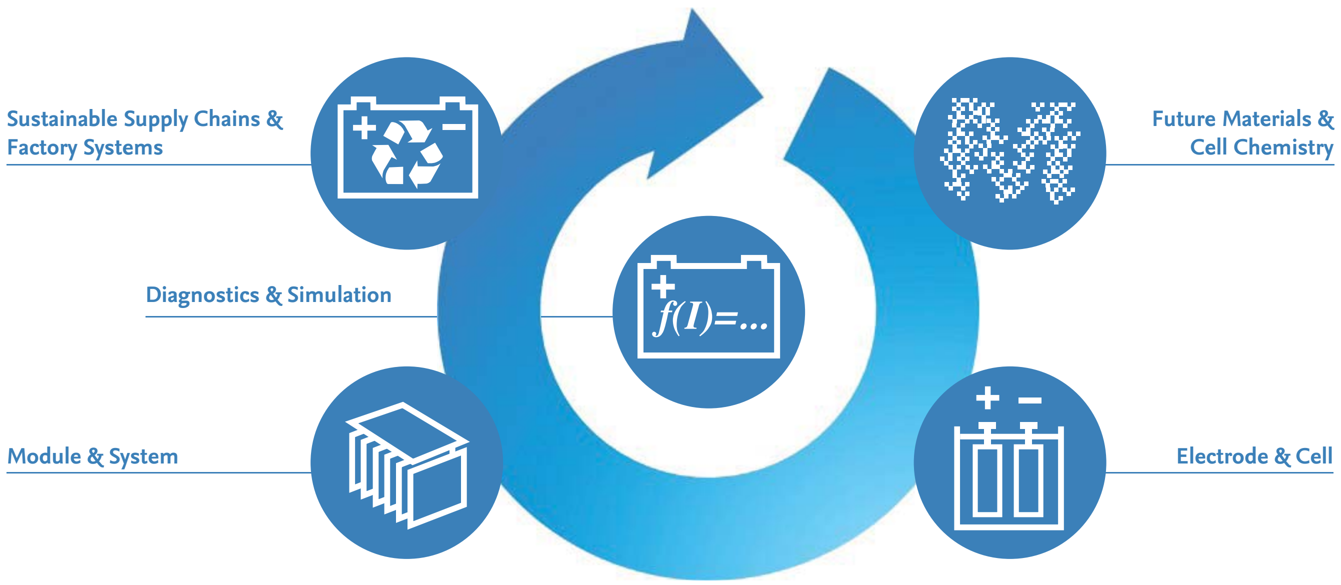
BATTERY LABFACTORY

The Battery LabFactory (BLB) stands for an open research infrastructure to investigate and develop electrochemical storage devices from laboratory to pilot plant scale. The research spectrum covers the entire value chain, from material, electrode and cell manufacturing, up to recycling.

The BLB holds the technical equipment to analyze large-size traction batteries as well as battery modules and packs. This infrastructure allows us to study fundamental and application-oriented research questions. The focus is on flexible production and process technology to increase the energy density, quality and safety of traction batteries considering electrical, electrochemical, ecological, constructive and economic aspects. For this purpose, the engineering and science expertise of 8 institutes of the TU Braunschweig, the Physikalisch-Technische Bundesanstalt Braunschweig (PTB), and institutes of the TU Clausthal and LU Hannover come together in this joined LabFactory. Integrated and connected with the research competences of the Niedersächsiches Forschungszentrum Fahrzeugtechnik (NFF), the Open Hybrid LabFactory (OHLF), the Niedersächsisches Forschungszentrum für Luftfahrt (NFL), and the tubs.city (Center for Informatics and Information Technology) the Battery LabFactory offers a German-wide unique transdisciplinary research and development platform to experience and design the battery of the future.

BLB BATTERY LABFACTORY BRAUNSCHWEIG

RESEARCH TEAMS



CONTENT

PARTNER

Coperion is the international market and technology leader in compounding systems, feeding technology, bulk materials handling systems and services. Coperion designs, develops, manufactures and maintains systems, machines and components for the plastics, chemicals, pharmaceuticals, food and minerals industries. Within its four divisions – Compounding & Extrusion, Equipment & Systems, Materials Handling and Service – Coperion has 2,500 employees and nearly 30 sales and service companies worldwide.

www.coperion.com

The NETZSCH Business Unit Grinding & Dispersing offers an extensive machine program for process engineering, providing solutions for wet and dry grinding, mixing, dispersing and deaeration. Long-term experience, consistent development work, daily contact with our customers and developments with more than 100 patents ensure our technical competence and further attest to our quality-consciousness. The bundling of process-engineering expertise and the extensive machine program, ranging from laboratory to production machines to complete production lines, is unique worldwide.

www.netzsch-grinding.com

The aim of the competence cluster for battery cell production (ProZell) is to research and improve the production process of battery cells and its influence on cell properties and product development costs. In the current 12 projects of the ProZell Cluster, scientists from 22 German research institutions are working together, building a network of science and industry in close cooperation with the BMBF and the KLiB. Together they establish the basis for a powerful and cost-effective battery cell "Made in Germany".

www.prozell-cluster.de

Customcells, Europe´s most versatile manufacturer in the lithium-Ion cell Industry. We offer tailormade cells in small and large volumes for customers' special needs. We are manufacturing the most recent electrode technologies in Germany, offer fast research products and Lithium-Ion cells.

Lithium-Ion cells, Prototyping, Consultancy, customized cells in small & in large volumes

Actual and future cell designs for mass market and niche market applications

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PEC delivers building blocks for development and manufacturing of large format cells, modules and battery packs for automotive, aerospace and defense applications. PEC's offerings include R&D test equipment and automated cell finishing lines automating all process steps after electrolyte filling (soaking, formation, grading, degassing, ageing, stand loss, sorting…).

www.peccorp.com

The VDMA Battery Production department is the partner for all questions relating to machine and plant construction in the field of battery production. The member companies of the department supply machines, plants, machine components, tools and services for the entire process chain of battery production: From raw material preparation, electrode production and cell assembly to module and packaging production. The current focus of VDMA battery production is on Li-ion technology. We research technology and market information, organize customer events and road shows, hold our own events, such as the annual conference, which has established itself as an important industry meeting place, and are in dialogue with research and science on current topics and on joint industrial research.

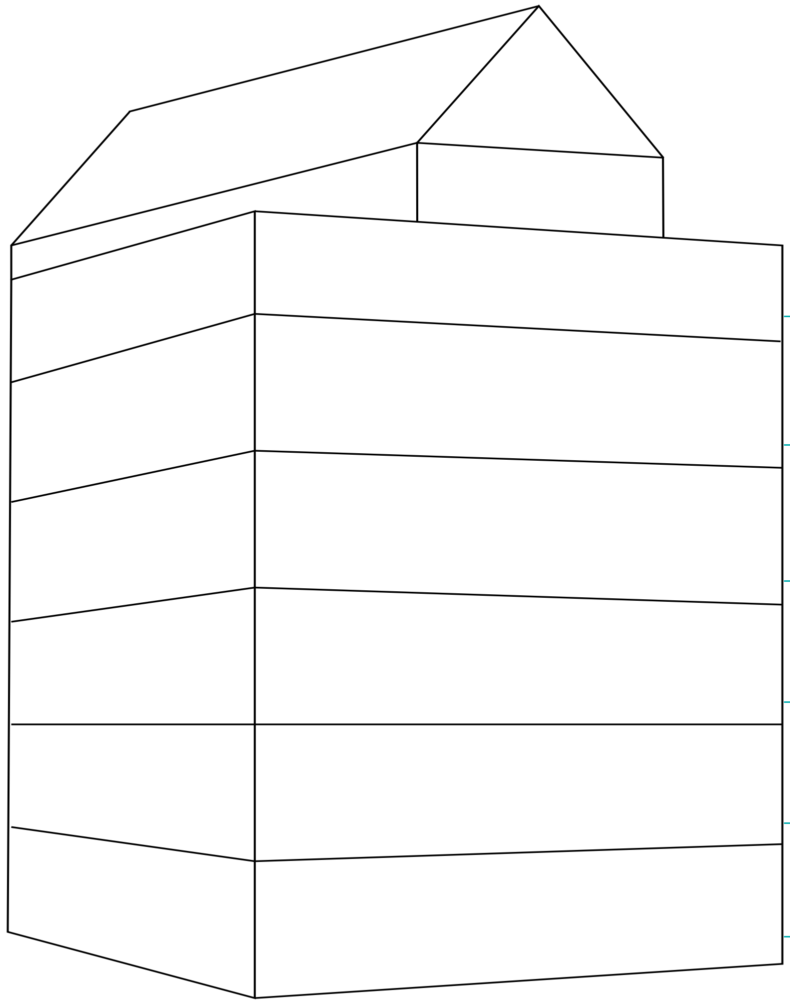
http://battprod.vdma.org

LOCATION PLAN

Venue

The scientific conference will be held from Nov. 15th to Nov. 16th at:

Haus der Wissenschaft I Pockelsstraße 11 I 38106 Braunschweig I Germany I www.hausderwissenschaft.org



5th floor I Room: Vision, Pilot line exhibition

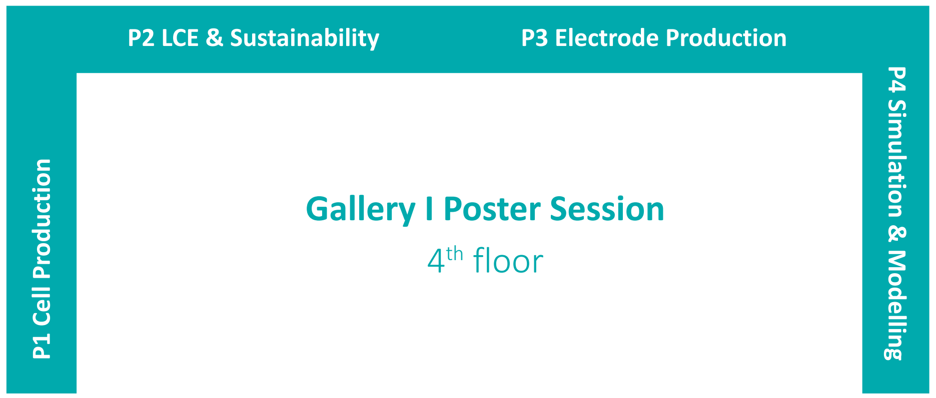
4th floor I Gallery, Access to poster exhibition

3rd floor I Room: Aula, Main Conference Hall

2nd floor

1st floor I Foyer with Catering

ground floor I Registration, Wardrobe



Conference Rooms
Room Aula on 3rd floor
Room Vision on 5th floor

PROGRAM

Conference Day 1 I November 15th 2018

8:30 I Arrival of attendees

9:00 I Welcome by the conference chairs

9:20 I Keynote by Patrick Bernard, SAFT
Strategies for defining the production parameters for high numbers of different cell designs

9:50 I Keynote by Torge Thönnessen, Custom Cells
Actual and future cell designs for mass market and niche market applications

10:20 I Keynote by Arno Kwade, BLB
Perspective on battery cell production research in Germany – the ProZell cluster

10:50 I Break

11:20 I **Parallel sessions**

Cell Production (I)

Room Aula I Chair: Prof. K. Dilger

BatteryCells & Troika Production Process – made in Thuringia,
T. Schäfer, Envites

Efficient Electrolyte Filling for Cost-Effective Lithium-Ion Cell Production,
F. Günter, IWB TU München

3 Strategies that Improve Quality in Battery Manufacturing,
B. Weber, Mettler Toledo

PHEV1 – Cell assembly: Quality assurance as key to high quality cells,
S. Rößler, ZSW Ulm

Simulation & Modelling

Room Vision I Chair: Dr. T.-P Heins

Fast self-discharge measurement for early detection of faulty cells in the formation process,
F. Kienberger, Keysigh

Virtual materials design for the 3D microstructure of lithium-ion battery electrodes,
D. Westhoff, Uni Ulm

Microstructure-Resolved Impedance Simulations for the Characterization of Li-Ion Battery Electrodes,
T. Danner, DLR

Development of microscopic tools for the quality assessment of Li-ion batteries,
A. Kopp, HS Aalen

12:50 I Lunch break

13:40 I Poster session

14:30 I **Parallel sessions**

Electrode Production (I)

Room Aula I Chair: Dr.-Ing. W. Haselrieder

Influence of the specific energy during mixing and dispersion on suspension and electrode properties of lithium-ion batteries,
J. Mayer, BLB Braunschweig

Continuous processing of LIB electrode slurries,
C. Nied, Buhler

Key factors in the production process of electrodes for LIB,
A. Hoffmann, ZSW Ulm

Formation & Testing

Room Vision I Chair: Prof. M. Kurrat

A frequency based test time optimization of measured load data for testing HV Battery Systems,
A. Karthikeyan, Fraunhofer LBF

Factory of the Future-proof EV battery and power-train testing,
A. Sokoll, Bosch Rexroth

Formation and aging of lithium-ion cells – probably the longest awakening of a cell,
C. Offermanns, PEM RWTH Aachen

15:30 I Break

16:00 I **Parallel sessions**

Electrode Production (II)

Room Aula I Chair: Prof. A. Kwade

Analysis and optimization of an extrusion-based coating process for high-energy li-ion cathodes,
S. Reuber, Fraunhofer IKTS

Single-step and scalable production method for stable pure-Si anodes,
A. Didden, LeydenJar Technologies

Atmospheric plasma pre-treatment for optimised surface wetting in electrode production,
H. Holeczek, Fraunhofer IPA

Cell Designs & Markets

Room Vision I Chair: Prof. T. Vietor

State of the art and future cell technologies for the European battery value chain,
M. Woland, P3

Large-Scale Production of Lithium Ion Cells and Modules in Germany 2018,
G. Neumann, Liacon

Electromobility – which cell formats prevails?,
K. Möller, Fraunhofer ZV

17:10 I **Parallel sessions**

Electrode Production (III)

Room Aula I Chair: Dr.-Ing. W. Haselrieder

Modeling of the calendering process and its effects on adhesive strengths of cathodes
D. Schreiner, IWB TU München

Process modeling of the electrode calendering for lithium-ion batteries,
C. Meyer, BLB TU Braunschweig

Separators & Safety

Room Vision I Chair: Prof. T. Vietor

LIB Separators – the inactive but not insignificant part of the cell,
G. Hörpel, GBH Energy

Challenge Battery Safety – Solutions by Multifunctional Battery Housings "B:HOUSE",
J. Kerspe, Vakuum-Isolierung

17:50 I End of day one

19:00 I Evening Dinner at Gewandhaus Braunschweig (Altstadtmarkt 1 I 38100 Braunschweig)

PROGRAM

Conference Day 2 I November 16th 2018

8:20 I Arrival of attendees

8:30 I Keynote by Peter Schulz, Manz
Machines and systems for the manufacturing of large battery cells and battery modules

9:00 I Keynote by Holger Manz, Volkswagen
Future Trends for Battery Systems – the OEM perspective

9:30 I Break

10:00 I **Parallel sessions**

Module and Pack Design

Room Aula I Chair: Prof. T. Vietor

Battery module for cylindrical cells with integrated direct cooling using coolant,
M. Eisele, KIT

A Novel Hybrid Thermal Management for Lithium-ion Battery Packs,
M. Mehrabi Kermani

Cell Performance

Room Vision I Chair: Prof. A. Kwade

Key Cell Design Parameter for the Performance of Lithium Ion Batteries,
P. Niehoff, MEET Münster

Investigation of 20 Ah cell format and packaging: Performance, Cycle life and Safety,
Y. Reynier, CEA

10:50 I **Parallel sessions**

Module and Pack Production

Room Aula I Chair: Prof. K. Dröder

Production of state-of-the art batteries for electric mobility,
T. Mertens, BMW

Laser processing for cost effective assembly of small series, customized battery packs,
J. Adriaensen, Absolem

Efficient contacting of battery cells into modules and packs for power tools and electric vehicles,
S. Hollatz, Fraunhofer ILT

Bond-technology solutions for battery pack production and electromobility,
H.G. von Ribbeck, F&K Devoltec

Industrie 4.0 & Factory Design

Room Vision I Chair: Prof. C. Herrmann

Cloud integration of electrode manufacturing via automated tracking and analysis of machine and quality data,
M. Schmauder, Fraunhofer IPA

The Benefits of Digitalization for Battery Manufacturing,
M. Deyda, Siemens

Smart Battery Factory design for todays and tomorrows requirements,
K. Eberhart, M+W

Decision Support System for quality assurance in the production of lithium-ion battery cells,
T. Kornas, BMW

12:10 I Lunch break

13:10 I Keynote by Anders Strømman, NTNU
Industrial ecology in battery production

13:40 I **Parallel sessions**

Life Cycle Engineering & Sustainability

Room Aula
Chair: Prof. C. Herrmann & Prof. A. Strømman

On the relevance of recyclability for the environmental impacts of secondary batteries,
J. Peters, Helmholtz Institute Ulm for Electrochemical Energy Storage

Energy Efficiency in Battery Cell Manufacturing – An Energy Value Stream Approach,
M. Thomitzek, BLB TU Braunschweig

Integrating Batteries in the Future Swiss Electricity Supply System: A consequential Environmental Assessment,
L. Vandepaer, Paul Scherrer Institut

Uncertain Environmental Footprint of Current and Future Battery Electric Vehicles,
B. Cox, Paul Scherrer Institut

Cell Production (II)

Room Vision
Chair: Prof. K. Dröder

Automation with vacuum handling solutions along the value chain of cell and battery production,
H. Kuolt, Schmalz

Challenges in conveying electrodes and new approaches to quality assurance,
B. Bold, KIT

Test methods in the production process of lithium-ion cells,
K.H. Pettinger, HAW Landshut

Highly integrated machine module for single sheet stacking,
H. Weinmann, KIT

15:00 I Break

15:30 I **Parallel sessions**

Innovative Cell Production Technologies

Room Aula I Chair: Prof. A. Kwade

Manufacturing technologies of ceramic-based all-solid-state batteries,
D. Fattakhova-Rohlfing, FZ Jülich

Challenges and bottlenecks in water processing of advanced Li-ion battery materials,
I. Urdampilleta, CIDETEC

Advanced battery electrode production for next-generation battery technologies,
B. Schumm, Fraunhofer IWS

Battery Safety

Room Vision I Chair: Prof. T. Vietor

Safety of lithium ion batteries – Between myth and reality,
K. Brade, Carissma

Fire protection in handling lithium-ion batteries,
S. Bruns, Stöbich Technology

Practical experience with triggering the thermal runaway of large Li-ion cells,
A. Golubkov, Virtual Vehicle

16:30 I End of conference and guided tour of Battery LabFactory Braunschweig

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confidence through partnership

WORLDWIDE MARKET
& TECHNOLOGY
# LEADER
IN COMPOUNDING
EXTRUSION, FEEDERS, MATERIALS
HANDLING AND SERVICE

ABOUT COPERION
Coperion is the international market and technology leader in compounding systems, feeding technology, bulk materials handling systems and services. Coperion designs, develops, manufactures and maintains systems, machines and components for the plastics, chemicals, pharmaceuticals, food and minerals industries. Within its four divisions – Compounding & Extrusion, Equipment & Systems, Materials Handling and Service – Coperion has 2,500 employees and nearly 30 sales and service companies worldwide.

CONTINUOUS EXTRUSION OF BATTERY MATERIALS
Coperion offers highly productive ZSK twin screw extruders for the continuous production of cathode and anode masses, as well as separator film. Raw materials such as active materials, binding agents, conductive carbon blacks and fluids are fed either separately or in the form of premixes into the process section of the extruders using highly accurate Coperion K-Tron feeding systems. Conveying, mixing, shearing and the homogenization essential for obtaining products of a consistently high and reproducible quality standard take place in processing zones that are optimally designed for the processes concerned.

Due to the often abrasive and sometimes toxic properties of the raw materials being processed, the parts of Coperion systems that come into contact with the product are made of materials offering particularly high resistance to wear. This makes it possible to avoid contamination of the end product from detached metal particles over the long term, even when processing ultra-hard silicon carbides. Dust-proof versions of the feed and refill systems for the raw materials are also available if required. In all these respects, Coperion draws on many years of experience as a supplier of extrusion systems for pharmaceutical applications. On top of that, ZSK plants for making battery masses are designed to conform to the stringent explosion-protection regulations.

UNIVERSAL HIGH-PERFORMANCE SYSTEM
With all the benefits of a development history spanning more than 60 years, today's ZSK twin screw extruder from Coperion is an universally applicable high-performance system for the processing of raw material mixtures, achieving throughput rates of between 200 g/h and 125 t/h with screw diameters of 18 mm to 420 mm. The modular process section of the extruder is made up of a series of barrels containing the co-rotating screws. This design principle ensures maximum adaptability of the system to suit the task concerned. The extruder, the feed system and the discharge technology from Coperion form a complete unit along with the associated process engineering support, both for start-up of the systems and during operation.

PEOPLE AND PLACES
Coperion is headquartered in Stuttgart, Germany, with manufacturing facilities located in Germany (Stuttgart and Niederbiegen); the United States (Sewell, New Jersey, Salina, Kansas and Wytheville, Virginia); India (Delhi); Switzerland and China (Nanjing and Shanghai); along with Engineering facilities in Germany (Stuttgart, Weingarten, Offenbach); USA (Houston, Texas); China (Shanghai); India (Delhi); Italy (Ferrara); and Singapore.

Contact Coperion GmbH I Theodorstrasse 10 I 70469 Stuttgart I Germany I info@coperion.com I www.coperion.com

POSTER SESSION

Cell Production

P1-01 Application of data-driven quality assessment for the cell stacking in Li-ion battery production
Fabian Konwitschny

P1-02 The Smart Battery Maker – a concept for automated flexible and agile production of cells
Tobias Storz

P1-03 Novel and green binder systems for silicon composite electrodes
Karina Ambrock

P1-04 Visualization of liquid electrolyte in large scaled Lithium-Ion Batteries by X-ray
Antje Schilling

P1-05 Filling and wetting of 18650-cells
Patricia Schneider

P1-06 Function validation of an alternative and format flexible pouch cell packaging
Ramona Singer

P1-07 Quality Analysis Methods in the End of Line Test of a Battery Cell Production
Uwe Westerhoff

LCE & Sustainability

P2-01 Social sustainability hotspots in the supply chain of lithium-ion batteries
Christian Thies

P2-02 Mapping Key Steps in Lithium-ion Battery Production to Evaluate their Contribution to the Life Cycle Environmental Impact of Electric Vehicles
Mudit Chordia, Anders Nordelöf

P2-03 Life cycle assessment of stationary battery systems with harmonized life cycle inventories considering different storage applications
Xiaojin Zhang

P2-04 Model based Life Cycle Engineering for Traction Batteries
Felipe Cerdas, Nicolas Bognar

P2-05 Data acquisition and data management for lithium-ion battery cell production optimization
Artem Turetskyy

P2-06 Complexity management of Li-ion Batteries to support the early stages of electric vehicle development
Sina Rahlfs

Electrode Production

P3-01 Investigation on mass transport in the intensive post-drying of components for lithium-ion batteries
Andreas Altvater

P3-02 Equipment for Dry and Wet Grinding of Active Battery Materials and the Production of Battery Slurrie
Dr. Stefan Mende

P3-03 Influence of mixing conditions on slurry characteristics
Desiree Grießl

P3-04 Electrode manufacturing of ultra-thick NCM 622 cathodes for high energy lithium-ion batteries
Emanuel Heider

P3-05 Ultra-thick electrodes based on aqueous processing
Lukas Ibing

P3-06 Bioepoxies as new binder adapted successfully for LIB cell production
Helene Jeske

P3-07 The Effect of Acidic Pretreatment of Binders in Silicon Composite Anode Pastes on the Electrochemical Performance in a Si/C/NMC Li-Ion Cell System
Elizaveta Keßler

P3-08 Influence of the mixing process on the electrode quality
Hai Yen Tran

P3-09 Lithium iron phosphate for Stationary Energy Storage Application
Anna Weichert

P3-10 High load NCM-622 cathodes based on a solvent-free coating process
Andreas Würsig

P3-11 Microstructural and electrochemical comparison of water- and NMP-based NMC622 cathodes
Xiaofei Yang

P3-12 Optimization and upscaling of the manufacturing process of a triple blend cathode
Stefan Zink

Simulation & Modelling

P4-01 Quality evaluation tool for automated defect detection in li-ion battery electrode using deep learning algorithms
Olatomiwa Badmos

P4-02 Laser application as a manufacturing technique to simultaneously improve energy and power densities of Li-ion batteries
Kim Hyeong-Jin

P4-03 Quality Control of Battery Electrodes using Thermography
Inga Landwehr

POSTER ABSTRACTS

Cell Production

Application of data-driven quality assessment for the cell stacking in Li-ion battery production

Fabian Konwitschny, Anna Kollenda, Joscha Schnell, Lukas Richter, Felix Theurer, Prof. Dr.-Ing. Gunther Reinhart
Institute for Machine Tools and Industrial Management (iwb), Technical University of Munich

Lithium-ion batteries are subject to high requirements in terms of performance, safety, lifetime, and cost. In order to meet these requirements, high quality of final products and a low rejection rate must be ensured during production, while at the same time maximizing the output of the processes. Therefore, consistent quality management along the entire process chain is key. In this poster, we present our approach regarding the acquisition, processing, and preparation of quality-relevant data in the production of Li-ion battery cells, and the algorithms identified for assessing quality parameters of the final cell. Additionally, the process of cell stack formation is used as an application case. In the first step, the possibilities for determining and defining specific quality parameters and appropriate procedures and technologies for data acquisition are examined, depending on the stacking method used and the error patterns typically occurring in the process. Computer-aided image processing enables process-integrated evaluation of quality parameters of the cell stack quality. A camera based vision recognition system delivers the offsets of separator and electrode sheets which are then used to automatically derive the stack quality directly within the stacking process. This approach enables in-line quality assessment in a reasonable cycle time. Furthermore, permissible values for an appropriate degree of compliance of the stack properties with the quality parameters are determined so that neither a high rejection rate nor an excessive deviation from the quality targets are the consequences.

The Smart Battery Maker – a concept for automated flexible and agile production of cells

M.Sc. Tobias Storz[a], M.Sc. Andreas Altvater[b], M.Sc. Janna Hofmann[a], Dr.-Ing. Philip Scharfer[b], Prof. Dr.-Ing. Jürgen Fleischer[a], Prof. Dr.-Ing. Wilhelm Schabel[b]
[a]Karlsruhe Institute of Technology – wbk Institute of Production Science; [b]Karlsruhe Institute of Technology – TVT-TFT Thermal Process Engineering - Thin Film Technology

Present day battery production happens almost exclusively in large production lines where each machine is responsible for one step in the process chain. This results in low cycle time and low production costs per unit, but also in a largely inflexible production. With an increasing number of different applications and electric vehicle models, requirements for the battery systems and each battery cell varies in size and materials used. To test and judge the performance of a novel battery cell type before going into production, research and performance tests on ready-to-use batteries are inevitable. Prototypes are usually assembled manually at high costs, with no possibility to scale up their production and with typically low reproducibility.
To handle this problem, a „Smart Battery Maker“ (SBM) pilot equipment, which produces battery cells with varying dimensions and materials, is being developed. The goals of the SBM are the proof of concept of fully automated prototype machinery that executes various production steps with a high reproducibility and the adaption of cell production steps to agile manufacturing. Different-sized pouch-cells are to be manufactured by the SBM equipment in small batches under industrial production conditions with minimal change of tools or equipment.
To achieve this goal, the partners, namely KIT (wbk, TVT-TFT, IAM-ESS) and Fraunhofer ICT, will agree on different electrode and separator materials as well as different cell formats to be processed. The processability and reproducibility of overall production processes with the considered materials and cell formats have to be checked and verified. A prototype coating equipment for agile electrode production will be designed and built, as well as a compact robot cell that handles the production steps of single-sheet stacking, contacting and pre-sealing. To prevent any unwanted interactions with water, a dry room atmosphere and microenvironments will be considered for cell assembly. Electrode and separator sheets will be delivered to the SBM robot cell by a novel material transportation system that guarantees a protective microenvironment throughout transportation. Potential safety risks will be identified and quantified to ensure lawful operation. Quality assurance regarding reproducibility, safety and overall battery cell quality will be implemented. This includes a Failure Mode and Effects Analysis of all considered processes. Furthermore, the battery cells produced by the SBM will be tested on electro-thermal stability and will be compared to commercially available Lithium-Ion battery cells (e.g. by EUCAR Hazard Levels).
By validating the SBM pilot equipment, the partners prepare the ground for a possible adoption of this agile concept by the battery cell industry. Production scale-up is easily manageable by using multiple robot cells, flexibility is given by the possibility to quickly adapt each equipment to different cell dimensions and materials.

Novel and green binder systems for silicon composite electrodes

Karina Ambrock, Dr. Alex Friesen, Dr. Falko Schappacher, Prof. Dr. Martin Winter
Westfälische Wilhelms Universität, MEET Battery Research Center

To encounter the growing population, the extent of industrialization and the CO2 emission problem; we need to find alternative sources of energy. Renewable energy sources like wind, sun, waterpower, etc. depends on daytime and weather and cannot produce the needed amount of current at any time. Rechargeable batteries offer one promising solution and can enable a constant supply of current at any given time. By converting electrical energy into chemical, not only a stationary storage, but also mobile storage of energy is possible as it becomes more important due to the increase of power consumption in electrical devices.[1–4]
Lithium ion battery systems outmatch other battery technologies in specific power and specific energy.[5,6] However, they still need improvement. Here, a green negative electrode with silicon and polysaccharide based binders is developed.
Silicon based composites are promising materials for the negative electrode of lithium-ion batteries. Silicon forms alloys with lithium and by uptaking 4.4 lithium atoms per silicone atom, it offers a high theoretical capacity.[7,8] The generous uptake of lithium leads to a volume expansion of up to 280% [9] at room temperature. This results in crack formation and pulverization of the electrode, which in turn causes capacity fading and loss of contact overall.
To tackle this challenge, new binder concepts that can buffer the volume change and mitigate the contact loss to ensuring a longer cycle stability are investigated. Precisely, polysaccharide with carboxylate and hydroxyl functional groups based binders are tested. These groups enable hydrogen bonds between the functional groups of the polysaccharide and the native hydroxyl groups on the silicon surface. Hydrogen bond are non-permanent and can, in contrast to covalent bonds, form newly bonds after one cycle.[10]

References
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Visualization of liquid electrolyte in large scaled Lithium-Ion Batteries by X-ray

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The electrolyte filling and wetting process of a Lithium-Ion Battery constitutes the interface between cell assembly and formation. The filling step offers a high potential to increase throughput and to reduce material and production costs. Despite this potential there are only few research activities in this field. Even the influence of filling parameters on electrochemical performance has not been studied sufficiently. However, for the filling procedure best practice solutions are available. But it is unknown which processes dominate the filling and wetting behavior and how to accelerate them. As studies have shown, the best results are achieved by filling the cell gradually in a vacuum chamber under low pressure conditions. Therefore, on the one hand, it is necessary to avoid gas inclusions between the sheets and inside the pore structure. On the other hand, a homogeneous distribution of electrolyte on the macroscopic and the microscopic scale is of great importance. Both phenomena need to be researched to avoid less wetted and as a result inactive areas, which influence the battery performance in a negative way. Consequently, an optical characterization needs to be done. Therefore, goal of this investigation was to visualize liquid electrolyte in large scaled Lithium-Ion Batteries during filling process by x-ray. Therefore, large scaled pouch cells had been prepared at the BatteryLab Factory in Braunschweig. In cooperation with Viscom AG an x-ray based inspection system was utilized to visualize the cells internals while filling it with liquid electrolyte. The presented poster shows the results of the x-ray measurements for the optical characterization of the liquid electrolyte in large scaled Lithium-Ion Batteries. The electrolyte distribution as well as gas inclusion as a result of the filling process could be identified. This study offers the first steps for quality control during the filling and wetting process of Lithium Ion Batteries.

Filling and wetting of 18650-cells

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The processing step of filling the liquid electrolyte into a lithium ion battery cell is one key step after cell assembling and before starting the formation. In combination with an effective cell wetting this step will determine the time until the cell finally can undergo its first formation cycle. Taking into account that there is a need for reducing manufacturing costs of lithium ion batteries this will also lead to a demand of shorter filling and wetting times.

Therefore, one has to understand first the mechanisms and effects during the filling and wetting of cells to finally make this process more efficient. Regarding wetting effects on materials level will help to get first impressions about relevant materials properties like contact angle, porosity or electrolyte uptake. Nevertheless, the filling and wetting of bigger cell formats like 18650-, PHEV- or Pouch-cells still remains a sophisticated process step along the manufacturing of a lithium ion batteries. This is mostly attributed to the complex mechanisms of soaking-up electrolyte and wetting porous materials with different material properties within a complete cell stack.

Within this study we investigated the filling process of cylindrical shaped cells in an 18650-cell format. In detail we systematically investigated different filling strategies as well as a set of different wetting times aiming for a faster processing. Regarding the material properties we were focused mainly on the separator properties and its influence towards the wetting time.

In line with these experiments we developed a new method for visualizing wetting processes on cell level via Lock-In thermography to evaluate the efficiency of the wetting.

Function validation of an alternative and format flexible pouch cell packaging

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Due to their outstanding technical properties, lithium-ion pouch cells are used as energy storage devices in electric vehicles. According to the current state of the art, these are manufactured primarily in rectangular footprints and electrically connected in cuboid battery modules to form a battery system. This has the disadvantage that the limited installation space in electric vehicles and portable devices cannot be used ideally, especially for vehicles manufactured according to the conversion design. A forward-looking research approach is therefore to produce the pouch cells in different geometries so that the installation space can be used in the tightest possible packaging.

A challenge at this point is the housing of the pouch cells, which consists of a thin aluminum composite foil. Deep-drawing, the state of the art process used to produce this packaging for pouch cells, is only partially suitable for the production of format-flexible packaging that fits close to the contour of the electrode stack. For this reason, the wbk Institute of Production Science has already developed an alternative packaging design (folded pouch packaging) that meets the requirements for format-flexible pouch cells. However, the functionality of the folded pouch packaging pouch packaging could not yet be finally confirmed on a real pouch cell. This will be presented within this poster.

In the first step, a geometric cell format is defined to validate the folded pouch packaging. A geometry is chosen that does not make the realization of the pouch packaging too complex. Due to the demand for gas tightness, complex folding templates for the folded pouch packaging may be necessary. The electrode stacks are stacked in a dry room atmosphere from common electrode and separator materials from individual sheets. The arresters are mounted on these sheets and, after integration of the electrode stack, nearly all sides of the packaging are closed. At least, one side of the packaging remains open so that electrolyte can be filled into the cell. Then the final sealing takes place, followed by the formation of the cell. During this process, gases are formed which must be removed from the gas pocket of the folded pouch packaging after formation.

This is followed by the aging process. The data generated in this way can be used to validate the functionality of the alternative pouch cell packaging.

Quality Analysis Methods in the End of Line Test of a Battery Cell Production

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In the End of Line Test, there are a number of measurement methods that can be used to determine the quality of a battery cell. One standard is the measurement of the open-circuit voltage with a subsequent short high-power test to determine the internal resistance. Checking the capacitance through a charge/discharge cycle takes a long time, which is why a capacitance test is often not performed. For the analysis of the cell quality further key parameters are suitable. These can be determined from different measurement and evaluation methods. The poster shows which key figures have a high information content and which requirements exist for data collection and evaluation.

LCE & Sustainability

Social sustainability hotspots in the supply chain of lithium-ion batteries

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Despite the considerable benefits that are associated with the use of lithium-ion batteries in electric vehicles and stationary energy storage systems, there are significant impacts related to their production. The current technology is based on several critical materials, such as lithium, cobalt, nickel, manganese, and graphite, which are associated with various environmental and social impacts in their supply chain. While the environmental impacts of lithium-ion batteries have been investigated in numerous studies, little attention has been given to the potential social impacts. Therefore, an assessment of the social sustainability hotspots of lithium-ion batteries is carried out. The assessment is based on a spatially differentiated resource flow model of the supply chain. Data on social risks with respect to child labor, corruption, occupational toxics and hazards, and poverty are extracted from the Social Hotspots Database in openLCA. The results of the social assessment are discussed along with environmental and economic considerations to generate recommendations for improving supply chain sustainability.

Mapping Key Steps in Lithium-ion Battery Production to Evaluate Their Contribution to the Life Cycle Environmental Impact of Electric Vehicles

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Current research with life cycle assessment (LCA) shows that Li-ion battery production constitutes a significant cause of environmental impact from electrified road vehicles, owing largely to energy demand for material processing and the production of battery cells. However, the manufacturing energy intensity is highly dependent on facility throughput. Thus, to provide relevant assessment of environmental impacts and a knowledge base for strategy work in the automotive sector, there is an increasing need to map battery production in terms of energy use, losses and emissions at the most granular level possible. This research will include a thorough literature review of current practices, both in LCA and technical literature, which will be further supplemented by primary data collection from a planned battery production facility in Sweden. This will help direct research towards mapping the key elements of battery production that are not as well represented in LCA studies thus far. The main outcome of this work will be an enhanced understanding of the key processes driving energy consumption and their relation, if any, to the overall factory throughput. Furthermore, an analysis based on the primary data from the battery production facility will enable a more accurate representation of aspects such as material quality requirements, components used in batteries, cell chemistries, inventory proxies and lastly a differentiation in the use of primary versus secondary materials in the lifecycle inventory.

Life cycle assessment of stationary battery systems with harmonized life cycle inventories considering different storage applications

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The penetration of renewable electricity has greatly increased in the past decade. Battery is one of the storage technologies to balance supply and demand and to facilitate the worlds's transition towards a sustainable energy system [1]. However, a comprehensive overview of batteries's life cycle environmental performance still remains a challenge, because battery technologies are of various kinds and there are different applications of batteries [2]. Applications are different in terms of required power and energy size as well as number of cycles per year. Due to these different requirements, the same battery technology could be sized and operated differently.

Numerous studies in the past investigated the life cycle environmental performance of batteries; however, most of them are focused on the application of batteries in electric vehicles, considering a limited number of lithium-ion (li-ion) battery technologies [3][4][5], while the stationary applications of batteries were less explored [6][7]. In addition, these studies are mostly conducted based on diverse sources of life cycle inventory data, without harmonizing the assumptions that are not necessarily different. Peters et al. have recently harmonized the inventory data for several types of li-ion batteries [8], but they are compared without considering the applications. Another study by Baumann et al. considers the applications of battery in the assessment [7], but didn't address the country of application. In addition, the functional unit used in Baumann et al. allows the estimate of environmental burdens not only related to battery storage, but also electricity used during charging.

This study therefore addresses these challenges, by considering six battery technologies for five storage applications in three representative application countries in Europe. On the basis of previous studies, the harmonization of inventory data is carried out to a greater extent. The functional unit is defined as storing 1 kWh of electricity, with which only battery system and electricity loss during charge and discharge are considered, thus limiting the life cycle environmental impacts related to battery storage only. We also extend the scope of the system, which is often limited to battery packs, to include the complete balance of systems, ensuring the operations required by the applications.

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Model based Life Cycle Engineering for Traction Batteries

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The environmental impact of an electric vehicle is defined by many factors throughout its life cycle. While a significant number of research studies towards evaluating and mitigating the effects of the transition to electric mobility have flourished, many of these approaches have emerged from large number of disciplines focusing on a specific question and most of the time disregarding a life cycle perspective of the vehicle. Aiming at integrating multiple models that allow to perform consistently a holistic analysis, we present in this research a Model-Based Life Cycle Engineering Framework for Electric Vehicles (MBLCE). The MBLCE couples different models for different life cycle stages. This allows a holistic evaluation of the life cycle impacts caused by the product system, within short computation and modeling time. An exemplary application of the framework is presented for the case of traction batteries. With its help, the key influencing parameters are identified. With the help of parameter variation studies, the impacts of the influencing factors are determined. The results can be used for various applications throughout the different life cycle stages of the battery.

Data acquisition and data management for lithium-ion battery cell production optimization

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The production chain of lithium-ion battery cells is a complicated process consisting of many different processes covering batch as well as single unit processes including converging and diverging material flows. Besides the influence of these processes, the product quality is affected by further criteria such as the amount and type of used material as well as ambient conditions. This complexity makes it harder to control and regulate economic and ecological target criteria (e.g. product quality, cost, energy demand). Therefore, it is necessary to develop a holistic system understanding as well as to identify and evaluate the interactions between the process steps within the production chain of battery cells and their effects on the relevant cell properties.
A suitable approach is to acquire production data, preprocess it and analyze towards desired goal criteria. However, due the complexity of lithium-ion battery cell production and possible process-product-interaction as well as the effects of ambient conditions upon the cell quality, data acquisition and management need a sophisticated approach. Therefore, the framework for the implementation of such system includes the identification of all relevant parameters of production processes and technical building services as well as environmental conditions, detailed value and energy streams during manufacturing and analytical features. The framework consists furthermore of data acquisition concept along the production line including technical building services, cell diagnostics and whether conditions. It includes automated and manual data acquisition as well as an interface for further investigation of the acquired data. The concept describes the merging of data from different sources, of different communication protocols and of different format towards its accessibility, convenient data management and visualization. The integration of further sensors and in-line analytical devices allows a visualization of product data and energy consumption live and its analysis and evaluation compared to given KPIs (key performance indicator). The gathered data is preprocessed and allocated to given production orders and can be furthermore analyzed towards desired goal criteria.

Complexity maagement of Li-ion Batteries to support the early stages of electric vehicle development

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The wide diversity and complexity of Li-ion Batteries is hampering the development of new battery electric vehicle (BEVs) concepts. The presented method supports the early design stages by describing the correlation between requirements, characteristics, properties, and product design for vehicle and battery system. Based on the findings of multiple analysis the product complexity can be reduced. Furthermore, this new development tool provides the user a deeper understanding of the influence of the battery electrode properties for the further car design, and allows an objective and cost efficient decision-making aid.

Electrode Production

Investigations on mass transport in the intensive post-drying of components for lithium-ion batteries

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Lithium-ion batteries have become ubiquitous in mobile and stationary applications. For the production of high-quality battery cells, the water and solvent loading must be reduced as far as possible in a drying step before the cell assembly. This is necessary because residual water during the operation of the battery can have a negative effects on cell performance or even lead to degeneration of the battery. This post-drying process is energy-intensive and represents a high cost factor in the production process. Methods frequently used are drying of anodes, cathodes and separators in a roll-to-roll process or in vacuum drying ovens. While in the continuous roll-to-roll process drying is realized by infrared radiation, water is removed from large material rolls at low pressures in the vacuum drying process.
In order to remove moisture cost-efficiently from the cell components, an exact and comprehensive knowledge of the mass transport processes is necessary for both methods.
In this study, the sorption behavior of different sample geometries was investigated by means of a magnetic suspension balance. For this purpose, samples in a sorption cell were exposed to different temperatures and humidity levels, and the solvent sorption was detected in the form of mass change. Sorption equilibria and diffusion coefficients were determined from the measurement data. In addition, first findings regarding the mass transport processes in electrode and separator windings were drawn from these experiments.

Equipment for Dry and Wet Grinding of Active Battery Materials and the Production of Battery Slurries

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We need batteries for mobile phones, tablets, computers, tools, toys, medical devices, cars, bicycles and many more. To increase the power, the capacity, the life cycle and to reduce the charging time, the weight and the size of batteries we have to improve the chemical composition, the particle size distribution and the homogeneity of battery slurries. NETZSCH Grinding & Dispersing is the world leading group of companies manufacturing equipment and machines for mixing, classification, dispersing, dry and wet grinding and others. The presentation gives an overview about dry and wet grinding technologies. Three different examples for grinding of active battery material will be discussed. Furthermore a survey of equipment for mixing, dispersing and homogenization of binders, additives and active materials for production of high viscose battery slurries. Finally the performance of three batteries produced with different production process will be compared.

Influence of mixing conditions on slurry characteristics

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The mixing process is an essential step in the electrode production. Apart from material selection and constitution, remarkable influence of the mixing procedure on the electrode properties have been detected. Through the energy application of a mixing device, materials are supposed to be homogenized and potentially desagglomerated. Different approaches exist in order to produce an electrode slurry.
The desagglomeration and fine dispersion of conductive additives is decisive in order to ensure adequate conductivity for the electrode coating, especially in the case of active materials with poor electrical conductivity.
In this work, an approach based on the desagglomeration of conductive carbon in a binder solution has been focused. Investi-

gations have been made concerning the grade of conductive carbon desagglomeration. Also the structure of the carbon in the binder solution has been taken into consideration. Various analytical methods were used for those findings.
The results show the influence of production parameters on the properties of the intermediate product. Based on those findings, scalability of different mixing devices is evaluated.

Electrode manufacturing of ultra-thick NCM 622 cathodes for high energy lithium-ion batteries

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Energy density is one of the key factors limiting the application of lithium ion batteries in portable devices and electric vehicles. This obstacle can be encountered by reducing the portion of passive material via increasing the mass loading of electrodes up to extreme values, yielding ultra-thick electrodes. Ultra-thick electrodes, however, suffer from drawbacks like a low rate capability[1-2], reduced adhesion and flexibility or crack formation[3].
The electrochemical and mechanical properties of an electrode are mainly attributed to mass loading, porosity and the distribution of passive materials in the binder-network[4]. In this contribution, the influence of the manufacturing process of the electrodes is added to the analysis.
At the example of ultra-thick electrodes with an areal capacity of 8 mAh/cm² based on NCM 622, prepared in pilot scale, it is shown how mixing, dispersing and drying steps in the manufacturing process strongly influence the properties of the porous electrodes.
This contribution especially demonstrates that the mixing procedure used for slurry preparation significantly alters the microstructure including the distribution of active and passive materials and the resulting mechanical properties like adhesion strength and flexibility. Furthermore, it has decisive influence on the electrochemical performance, which can especially be used to mitigate the kinetic limitations typical for ultra-thick electrodes.

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Ultra-thick electrodes based on aqueous processing

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The production of cost efficient and environmental friendly electrodes is one of the key parameters for optimization of Li ion batteries to be used in electric mobility or stationary storage applications. To overcome the remaining drawbacks new ways towards cheaper processing of Lithium ion battery electrodes and also higher energy densities are the main topics of nowadays research. One way to combine both requirements is the preparation of ultra-thick electrodes based on aqueous processing: High dry film thicknesses (high active material mass loadings) allow an increase in energy density, while the reduction of needed copper and aluminum current collectors reduces the costs.
However, compared to conventional processing, aqueous electrode formulation also goes along with some disadvantages like surface crack formation and basic pH values accelerating the active material degradation, especially in case of cathode materials like NCM.
Sodium-carboxymethylcellulose (CMC), which is mostly used in aqueous electrode processing, has a major impact on the electrode paste viscosity. The resulting high viscosity limits the total solid content in the electrode paste. Thus the increased amount of solvent evaporation contributes to crack formation during drying. To overcome these issues a mixture of the water soluble components polyacrylic acid (PAA), polyethyleneoxide (PEO) and CMC has been used as new binder system. This mixture combines high flexibility (PEO) with low viscosity (PAA) and sufficient adhesion (CMC) resulting in a superior water compatible binder system to manufacture ultra-thick cathode sheets. Using this binder composition it was possible to achieve high contents of active material (93 wt.%) and with active mass loadings up to 50 mg cm-2 mg the capacity was 120 mAh g-1 at 0.2C. Furthermore, the impact on effective energy density and estimated costs has been conducted with regard to different mass loadings.

Bioepoxies as new binder adapted successfully for LIB cell production

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Reactive biobased epoxy resins are investigated as alternative binders for application in LIB cells, which are gaining in importance and are well-established in the electric mobility field and as stationary energy storages. In conventional cathodes, LIB cell binders based on fluorinated polymers and copolymers, especially polyvinylidene fluoride (PVdF) are state of the art. From an ecological and economic point of view, the use of this fluorinated polymer is questionable, as its processing requires usage of organic solvents such as N-methylpyrollidin-2-one (NMP). NMP is classified as a harmful substance of very high concern, as seen also in the investigations of the United States Environmental Protection Agency. It is no longer approved for certain original equipment manufacturer (OEM) applications in other areas of industry, e.g. automotive engineering. NMP as a solvent requires expensive efforts for safety reasons and equipment. PVdF dispersion used for battery production is quite expensive (15-20 US$ per kg) and it is prone to cause delamination of the active material layer from the current collector during the charging and discharging process. Delamination between the current collector and the coated surface causes loss in capacity and battery lifetime.
In this work bioepoxies based on fatty acid modified bisphenol A (FA-DGEBA) cured with biobased diamine are investigated. The obtained resigns show good rheological properties during the preparation of slurry for Li-Ion electrode production, adapted to the coating process. With good curing behavior and thermal, chemical, mechanical and electrochemical properties adjusted to the battery specifications and industrial process. The renewable binder system is evaluated in comparison to PVdF, especially in the field of improved adhesive strength towards the current collector foil. Other advantages like enhanced binder flexibility can be adjusted. Especially pre-polymerization of a FA-DGEBA/diamine mixture shows promising characteristics in production steps like electrode and cell production and cell conditioning for a lithium-ion battery design process. First epoxy-based cells were successfully produced and tested after scale up. However, long-term tests and optimization steps are planned for the future.
Our results highlight an alternative cathode binder to PVdF based on processable bioepoxies as a sustainable, cost-efficient and safe ingredient for LIB cell production without use of toxic solvent. Our future developments are a more economic and environmentally friendly battery assembly process by a substitution of the toxic solvent (NMP) and the expensive and halogenated binder.

The Effect of Acidic Pretreatment of Binders in Silicon Composite Anode Pastes on the Electrochemical Performance in a Si/C/NMC Li-Ion Cell System

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The research on binders for Si based negative electrodes is of great interest as binders play an important role to overcome the challenges in the use of Si including its volume expansion over 280% while lithium uptake resulting in mechanical stress, breaking of the solid electrolyte interphase (SEI) and contact loss to the current collector and the surrounding particles.[1,2]
The aim of this work was the enhancement of the binding interactions between Si and the binder by acidic pretreatment of the binder mixture with deluted acid. Acidic pretreatment have already been done in terms of surface functionalization of Si nanoparticles to achieve better cycling performance or to generate an artificial SEI on the particles.[3,4]
The electrochemical performance was compared between the pretreatment with sulfuric and phosphoric acid between CMC and SBR/CMC based Si/C anodes in Si/C/NMC(111) Li-ion cells. Electrochemical characterization was carried out by using one formation cycle at 0.1C and following 100 cycles at 1.0C at RT. The pretreatment by phosphoric acid showed higher initial discharge capacity at 1.0C and higher capacity retention after 100 cycles at 1.0C compared to the pretreatment by sulfuric acid. The absence of SBR in the acid pretreated slurries showed a decrease in initial discharge capacity at 1.0C and capacity retention.

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Influence of the mixing process on the electrode quality

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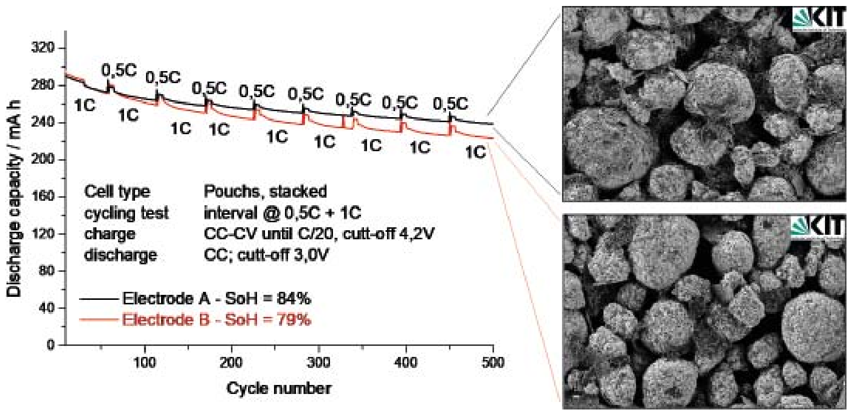
The electrode manufacturing for lithium-ion batteries has been evaluated. It has been shown that a proper tailoring of the mixing process can greatly improve the electrochemical performance of the electrode. The mixing effectiveness was examined by means of rheological measurements and electrochemical performance. Preliminary results demonstrate that electrodes with multi-stage mixing sequence provide a better carbon black distribution along the coating and the corresponding cyclability of the electrode is improved.



Lithium iron phosphate for Stationary Energy Storage Application

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For household applications, power can be produced by solar or cogeneration systems. However, the generated energy needs to be stored in a safe and long lasting storage system. A suitable active material fulfills the following requirements: safety and low cost. Therefore, lithium iron phosphate (LFP) is an appropriate choice. However, LFP has a low average potential, a low electronic conductivity, and nanometer particle size, which makes it hard to process, especially with the aim of high mass loadings, which, however, can decrease the cost.
Here we show that LFP electrodes can be significantly improved by the electrode recipes through variation of binder and conductive material. All investigated systems are water based, due to the lower production costs and better safety compared to N-methyl-2-pyrrolion systems. The performance is evaluated by electrochemical testing of LFP graphite cells.

High load NCM-622 cathodes based on a solvent-free coating process

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Due to the increasing requirements in terms of energy density and costs of lithium ion cells especially for electromotive applications, new coating concepts are needed. Li-ion battery electrodes normally are manufactured by coating solvent containing slurries on a metallic current collector. The most commonly used solvents are N-Methyl-2-pyrrolidone (NMP) as well as water, while the latter is normally used for anodes. The drying of the coated electrode slurry is an energy consuming process. It also requires a large available space because of the long drying sections needed for optimal process results. Furthermore, in the case of NMP, a special recovery system of the evaporated solvent is needed. With a dry coating process as it was developed by Fraunhofer ISIT, the use of solvents is no longer required. This allows significant cost reductions and can also lead to a better environmental sustainability of the manufacturing process. The BMBF funded project "Umweltfreundliche Hoch-Energie-NCM 622-Kathoden mit optimierter Speicherkapazität/High-Load-Kathoden" (HiLo) which is part of the competence cluster for production of battery cells "ProZell" addresses this issue. Solvent-free processing of electrodes by i.e. atomic laser deposition (ALD) is used for thin film batteries but solvent-free coating of thicker electrodes using dry-spraying techniques, is a relatively new topic although it is widely used in paint/lacquer industry. Nevertheless, the electrode thickness achieved so fare is still low if compared to nowadays available high energy electrodes with loadings of above 4 mAh/cm². This is basically due to limitations of adhesive properties determined by the applied high voltage electrostatic field. In this contribution, promising results of manufacturing high load electrodes based on a new solvent-free coating process developed by Fraunhofer ISIT will be presented and a comparison of electrochemical results as well as physical properties between the "classical" and the "new" route is drawn.

Microstructural and electrochemical comparison of water- and NMP-based NMC622 cathodes

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In current industry-oriented manufacturing processes for lithium ion battery electrodes, the non-aqueous solvent N-methyl pyrrolidone (NMP) is widely used to produce suitable electrode pastes. However, due to the high toxicity of NMP, aqueous electrode processing was established as an alternative [1] in case of anode production, which allows for a more environment friendly process.
The current study focuses on the comparison of water-and NMP-based cathode electrodes in terms of C-rate and cycling

performance. Furthermore, the effect of aqueous processing on the Li(Ni0.6Mn0.2Co0.2)O2 (NMC622) cathode material is analyzed by different methods, e.g. XRD, XPS, BET, ICP-OES.
For the cathode material NMC622, only a slight amount of lithium loss is observed once the material gets into contact with water. However, the water-based cathodes show a stronger capacity fade compared to NMP based cathodes. The reasoning behind this is presented in the current study.

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Optimization and upscaling of the manufacturing process of a triple blend cathode

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Electrode development is a key issue for improving the energy density of Lithium-Ion-Batteries. The development of new active materials, blending commonly used active materials, and optimization of the electrode compositions are the common ways to improve the electrode performance. Especially, blend electrodes represent an innovative approach to improve the electrode properties based on synergetic effects making use of the advantageous properties of active materials while overcoming their drawbacks. However, besides the composition of electrodes, the manufacturing process and the structure of the electrode have a major impact on the electrode's electrochemical performance.
In this contribution, the influence of the dispersion and the calendering process on the microstructure of the electrode is elucidated by means of SEM analysis. The impact of process parameters on capacity, rate capability and energy density is evaluated on the basis of laboratory and pilot scale experiments with a novel cathode blend consisting of the active materials NCM (523), LMFP and LMO. The different materials in this blend are affected differently by the applied conditions during dispersing. Especially, the size of the soft particles of LMFP is strongly influenced by the applied dispersion method, which was found to highly influence the overall electrochemical performance. We show how a customized dispersion process implements the optimum contribution of each active material of this blend to the overall electrode performance. The blend electrode manufactured by the customized process results in a significantly increased energy density at high C-rate compared to a state of the art NCM-cathode. Additionally, the influence of the compression on the porosity, energy density and further electrochemical performance was investigated for the NCM (523) / LMFP / LMO blend cathode electrode.
Finally, the scale-up of the optimized electrode manufacturing process from pilot scale to pre-industrial scale is demonstrated. The determined process parameters were transferred and successfully adapted to the equipment for industrial production. The produced blend cathode (30 cm * 450 m) was electrochemically tested in full cells and confirms high energy density at high C-rates like reported for the cathode produced in pilot scale.

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Simulation & Modelling

Quality evaluation tool for automated defect detection in li-ion battery electrode using deep learning algorithms

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Microscopy methods have long been successfully used for quality assurance and evaluating the influence of production parameters in various fields such as powder metallography, high performance ceramics and high strength steels. Similar technique can be applied to the high resolution inspection of sectioned li-ion batteries, thus facilitating the possibility of automated quantitative and qualitative microstructure analysis.
In this presentation we demonstrate how machine learning and its subfield deep learning can be used for the quality assessment of large prismatic li-ion batteries. It has been shown in various studies that the performance of a li-ion battery is intrinsically linked to the electrode microstructure. Consequently, quantitative measurements of key structural parameters will enable the optimization as well as motivate systematic numerical studies for the improvement of the battery performance. The aim here is to evaluate various cell components (cathodes, anodes, and separators) in high-resolution from optical microscope images to automatically detect various types of defects such as metal particle contamination, cracks, layer deformation and non-uniform coating present in the battery microstructure.
The problem of automated defect detection can be approached as a supervised or unsupervised machine learning problem depending on the available dataset for training the machine learning algorithm. It is also possible to approach the problem as a semi-supervised learning problem which would be somewhere in-between the two categories. In machine learning, supervised learning is by far the most common case. It involves learning a representation for mapping the input data to known target values given a set of training examples (often labelled by humans). In the case of defect detection in battery images, this would involve a person (battery expert) examining a large amount of images and labelling each one as either with defect or without defect. This of course can be a very expensive process since getting a substantial amount of images with defects, enough for training a deep leaning algorithm can be quite challenging. As a result, such a problem can be also addressed through unsupervised learning. Which entails finding useful transformations of the input data without the help of any labels to better understand the correlations present in the data. Both methods have been successfully explored for the detection of defects in micrographs of li-ion battery.

Laser application as a manufacturing technique to simultaneously improve energy and power densities of Li-ion battery

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Increasing energy and power densities is one of the important requirements in Lithium ion batteries. To enhance the battery performances, most researchers focus on improving material characteristics, for example, fabricating nanostructure-based active materials, changing chemical compositions of the electrode, coating with assistant elements, and introducing additives in electrolyte. However, these processes would increase the manufacturing cost, and cause the increasing complexity of process and unintended deterioration of the rest of the performances. Thus, the typical approach to increase the energy and power densities is to thicken the electrodes and/or lower their porosity in the industry. Nevertheless, there exist limitations in increasing both characteristics simultaneously because of trade-off between the energy density and power density from the LIB design. In this study, laser technology is applied as a solution to achieve the simultaneous enhancement of both performances. Thicker (thickness of 100 to 210 µm) and denser (porosity of 26%) electrodes than conventional electrodes used in the industry are prepared. Uniformly spaced micro-grooves are produced by femtosecond laser using a scanner on the electrode surface with little thermal effects. As a result, the rate capability of laser-structured thick and dense electrodes is better than that of unstructured thin and sparse electrodes at the same current rate or even at a higher current rate. Especially, the specific energy of the laser-structured thick and dense electrode shows a considerable increase despite mass loss by laser structuring, while retaining better rate capability. From cyclic voltammetry analysis, the improvement of lithium ion diffusivity and cell polarization by laser structuring are confirmed. These effects can compensate the deterioration of power and energy densities caused from a thick and dense electrode. If optimization for grooves by controlling laser-structuring parameters is accomplished, laser process is expected as a novel technique to enhance the critical performances such as energy and power densities in Lithium ion battery manufacturing.

Quality Control of Battery Electrodes using Thermography

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Present and prospective battery manufacturing technologies – like all manufacturing technologies in the context of Industry 4.0. – require a quick and easy to adapt quality control system. Such a system must be based on inline, real-time observations. Thermography is a feasible method for manufacturers to control the grammage of porous electrodes. Thermography can also detect the location of flaws of coated electrodes in real-time by observing electrode temperatures directly after thermal treatment and during the ensuing cooling process: Defects and inhomogeneous coatings act as thermal hotspots or cause extensive changes in temperature. These characteristics can be detected by thermal imaging systems, allowing a detailed detection of expected and unexpected process fluctuations of the coating quality. The data gained can then be analysed both optically and by regarding the variances of samples' cooling behaviour. After the subsequent determination of all quality characteristics, the whole electrode manufacturing process can be monitored and controlled based on the acquired information. The proposed approach includes an integrated and automated data analysis process as well as the tracking of information from the electrode to the final product, situating it clearly in the context of Industry 4.0. It makes zero-defect manufacturing feasible, whereby the overall production costs of a battery cell are drastically reduced. In other words, quality control using thermography leads to higher process stability, resulting in better quality, a lower rejection rate, and therefore significantly lower costs per kWh.

ProZell
Kompetenzcluster
zur Batteriezellproduktion

ProZell - Competence cluster for battery cell production - Influences of production steps and parameters on cell performance and quality

Challenges and goals

In the Competence Cluster for Battery Cell Production (ProZell), German research institutions work together to strengthen the national battery cell production. The aim of the research cluster is to build the scientific base for the establishment and sustainable further development of internationally leading battery cell production in Germany. The economic efficiency of cell production is highly relevant in this context. The focus and overriding goal of the competence cluster is therefore to increase cell performance, especially energy density, while simultaneously reducing the energy-related cell price (€/kWh).

Due to the complex and interdisciplinary value chain, a targeted and structured combination of national competencies in the field of battery cell production has been achieved. The identification of influencing variables that cause relevant changes in intermediate product properties as well as cell performance, quality and costs is the main focus of the cluster research. The joint development of understanding along the entire production process is goal-oriented and valuable for this purpose. The cross-linking of the specific knowledge, the special equipment and the competence of the various research institutions in joint projects is the central concept of the cluster. An accompanying project strengthens cooperation and networking within the entire cluster and ensures a structured bundling of knowledge in a results database. In addition, an advisory committee with representatives from industry and science, which accompanies the cluster projects throughout the entire project duration, ensures that the cluster is united with industry.

Contents and main areas of work

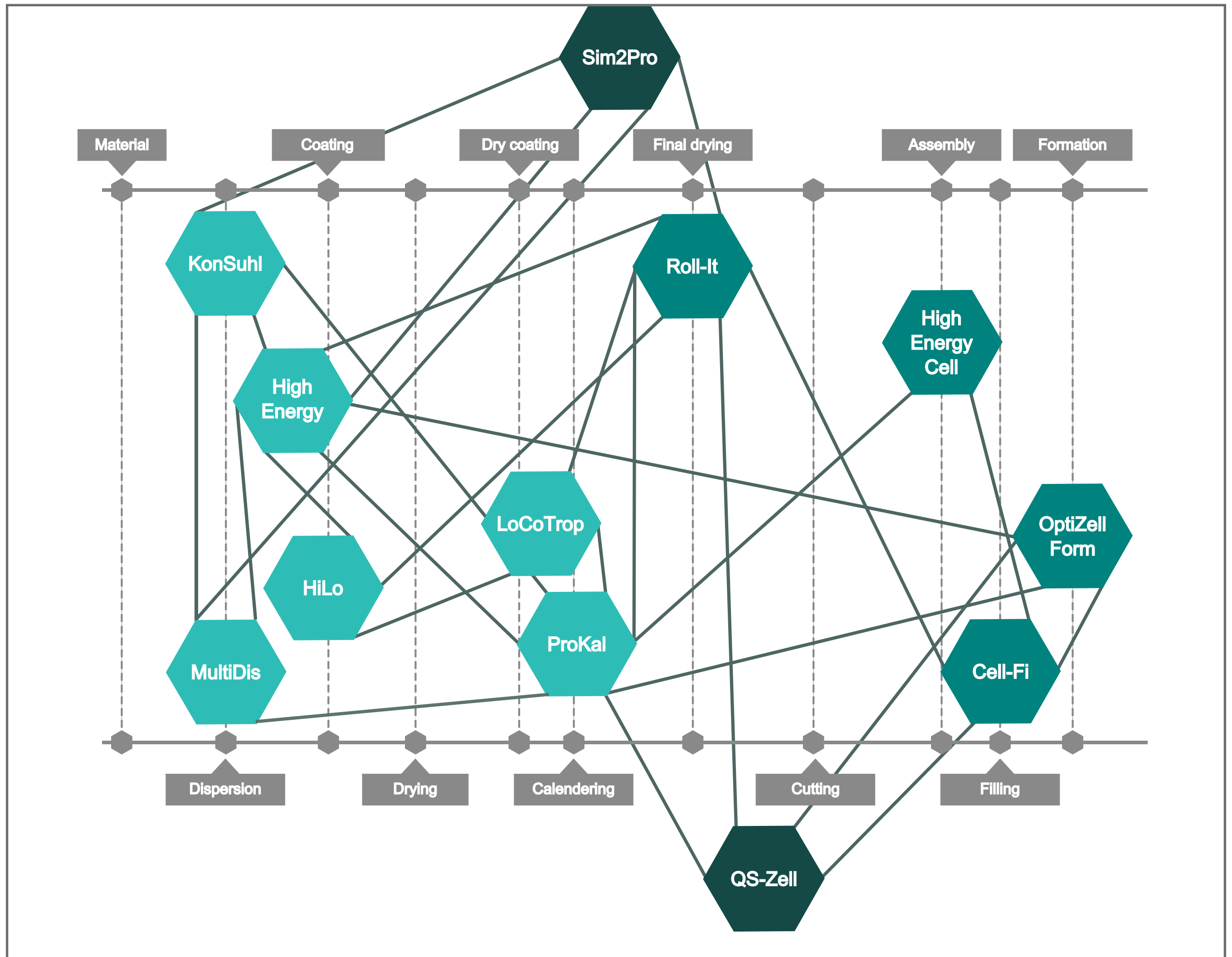
The continuous production of battery suspensions by extrusion, in addition to increasing the energy density through the targeted structuring of high-capacity electrodes and the use of silicon is a major focus in the field of electrode production. The simulative description of the dispersion process at various levels of detail and the use of innovative technologies for solvent-free electrode production is also promoted in the cluster in order to implement optimized process and production routes. In addition, interactions between process control and product properties are investigated in detail, especially for calendering and post-drying of electrodes.

Within cell production, special attention is paid to the optimization of filling and wetting processes, taking into account all essential cell components. The energetic optimization of cell formation is investigated together with the upstream process steps, so that both cause-effect relationships and causes of energy loss can be identified in the process. The investigations regarding cell stack formation focus above all on the special requirements of high-energy electrodes.

Cross-process projects in the cluster develop innovative quality assurance concepts to reduce fluctuations and reject rates and optimize the interlinked production processes with regard to an appropriate definition of production tolerances. A results database brings together the key findings of the project work in a transparent manner.

Funded collaborative projects in ProZell

ProZell Cell-Fi	ProZell EMKoZell	ProZell HighEnergy	ProZell HiLo	ProZell KonSuhl	ProZell LoCoTroP
ProZell MultiDis	ProZell OptiZellForm	ProZell ProKal	ProZell QS-Zell	ProZell Roll-It	ProZell Sim2Pro



Research along the process chain of batterie cell production

Application, use of results and contribution to energy storage

The properties of electric vehicles and systems for the electrochemical storage of energy as well as their respective customer benefits correlate directly with the properties of the battery cells used. A better understanding of influencing variables along the entire process chain, including the production environment, is therefore essential. The establishment of an economical and sustainable battery cell production is the central milestone on the way to establishing Germany as a leading market and provider of electro-mobility. The fundamental challenge for competitive battery cell production is to increase cell performance while simultaneously reducing the energy-related cell price (in € per kWh).

The knowledge gained in the competence cluster should form the essential basis for the development of economically producible battery cells, i.e. battery cells with a significantly improved performance-cost ratio. The results provide a scientific basis for achieving and continuously expanding the sustainable, international technology and cost leadership of all German industries involved in the value chain of cell production.

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PRESENTATION ABSTRACTS

Cell Production (I)

BatteryCells & Troika Production Process - made in Thuringia

Tim Schaefer, Manager BatteryCell & Systems, Envites Energy
Envites Energy GmbH

Envites Energy BatteryCell production and development. The IP of Troika Production process and efficient production of BatteryCells. Polymer II and new solid state cells. Know-how in electrode.
For more than 5 years we have been working in international cooperation on the topic of state of the art cell production and have developed concepts as well as good references on the market (Envites Energy). Based on 25 years of experiences in the field of large format Li-Ion Battery cells.
One background is the advanced development of new type of battery cells, we describe in our separator/electrode assembly as well further.
Insofar as our project relies on innovative stacking winding or s-folding. A further development that enables the efficient production of long-axis cells. Here we will take on a pioneering role in Germany.
For instance: Under view of processing of the high press density electrodes we do claim the following selected detailed innovations:

- ✓ High quality punching &
- ✓ Good electrolyte soaking.
- ✓ Our electrode backing condition is very important factor for reducing time at formation process and improvement of cycle performance.
- ✓ Advanced dry or ceramic separator – better safety and life time.
- ✓ Non flammable electrolyte composition for nail penetration test-abuse,
- ✓ Pre charge step: for melting of metal contamination.
- ✓ Pre formation: applied Low current condition to clear Black spot & Li-plate issues, make thin SEI layer of anode electrode, should be apply the factor of dv / dt and dq / dt for safety.
- ✓ Deagassing & main formation, OCV drop at rest 10min (ΔV1) after 3.870V (Safety check).

With our process we reduce CO2 emissions and are highly efficient, especially in terms of yield. The yield of quality cells with low scatter is very important. And this has a direct and decisive influence on the carbon footprint.
If one considers as an example that in the Troika process the formation is structured and the energy is preferably not burned or recovered with loss, technically complex, then this shows a comparative savings potential of estimated 33%.
Troika Production process is a patent family for the EU.

Efficient Electrolyte Filling for Cost-Effective Lithium-Ion Cell Production

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In the production process chain of lithium-ion batteries, the filling of the cell and its components with electrolyte liquid at the end of the cell assembly is the necessary step to ensure ion conductivity within the cell[1]. Therefore, the filling, consisting of dosing and wetting steps, is eminent for the final product quality and costs. In view of the great uncertainties regarding the functionality and costs of all-solid-state batteries[2], the optimization of the major cost drivers in the conventional production of lithium-ion batteries is essential.
In this presentation, the interactions in connection with the filling process will be addressed. Main objective of the process design is to reduce the wetting duration between filling and formation, and thereby the production costs with constant product quality of the cell[3]. On the input material side, the requirements for the process are taken into account by the electrode design and the cell format. The electrode porosity as well as, whether it is a wrap, a roll or a cell stack in a flexible pouch foil or a rigid housing, has an immense influence on the process. Furthermore, possible control variables, like pressure, temperature and dosing volume, which define the necessary plant capabilities are considered. As is the influence of those control variables on the product quality of the cell and on the processing rate. In addition, the methods electrochemical impedance spectroscopy and neutron radiography to measure the wetting state of the cell will be presented and compared.

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3 Strategies that Improve Quality in Battery Manufacturing

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Experts are forecasting the number of lithium-ion batteries in electric driven vehicles to multiply. To keep up with these quantities, machine builders must design highly automated manufacturing lines capable of fulfilling market demand. Highest quality standards in the battery production seek for the expertise in high-precision weighing. In the presentation we want to introduce 3 Strategies that improve quality in battery manufacturing.
1. Avoid expensive waste and accidents
Expensive raw materials are used to formulate the electrode slurry. These materials represent up to 60% of overall production costs. Weighing is used because it is the most accurate method of meeting high process tolerances for repeatable formulation. To avoid expensive waste, which could lead to millions of dollars lost per 0.1 percent overfilling within one year, high-accuracy weighing technology is the right choice.
2. Improved quality improves the company image
After the electrodes are stacked, the fine-filling procedure is performed to finish the battery cells. In addition, weighing is the solution for electrolyte filling. Even if it is possible to control the electrolyte flow, the accuracy of high-precision weighing devices can ensure 100% quality control. This quality control is critical because device recalls caused by exploding batteries have a drastic cost impact and will forever damage a brand's image.
3. Perfect finish for highest quality
To increase power density, battery cells are packed into one module. For this reason, the cells need to be combined manually with an electric welding machine. Double-welded wires and missing parts could cause a fire and destroy the module. This can be prevented by using a high-resolution scale for a completeness check. This before-and-after weighing process even eliminates detection issues linked to shiny surfaces and even detects hidden components. Relying on this technology will help give your high-quality batteries a perfect finish.

PHEV1 - Cell assembly: Quality assurance as key to high quality cells

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Since established in 2014, the Research Production Line (FPL) at ZSW Ulm provides close-to-production conditions for LIBS in PHEV-1 format in order to support the transfer of laboratory-research results to mass-production. High standards are set regarding quality, automatization as well as reproducibility and continuously optimized during the large amount of conducted orders for cell production on the FPL over the last years.

With special emphasis on the cell assembly process, failure mechanisms such as misaligned electrodes or current collector welding defects are clear bottlenecks that need to be avoided to guarantee a high-quality and cost-effective production chain and to meet the high safety standards. In this regard, a comprehensive understanding of each processing step under real conditions is indispensable. Hence, each process with its special requirements is closely monitored and evaluated.

Subsequent to the assembly process, the cells are subjected to preformation. This step is comparatively time-consuming, and hence has a huge impact on the costs per cell. Without any compromise in battery's performance and safety, ZSW-scientists work towards quality assurance methods and process improvements to ensure a cost-effective, faultless cell assembly of large format PHEV1 cells.

Simulation & Modelling

Fast self-discharge measurement for early detection of faulty cells in the formation process

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Keysight Technologies

In Lithium-ion battery manufacturing it is essential to detect bad cells as early as possible to minimize production costs and safety risks.
Traditionally, the open circuit voltage (OCV) is measured during the formation process at the beginning and at the end of a two-week interval. In case of significant OCV drop high self-discharge (SD) is indicated and the cell is removed from production. Recently, Keysight Technologies introduced the BT2152A SD analyzer which is based on a potentiostatic method that provides direct measurement of the SD current and significant reduction in measurement time. Instead of two weeks, the measurement takes only 30 minutes. In this SD method,
a precisely matched constant voltage is applied to the cell, and the resulting exponentially decaying current is acquired over time, while a parameterized model is used to calculate the final SD current. We use electrical circuit analysis and a complementary SPICE simulation
model to demonstrate the advantages and the validity of this method. Measurements of 'good' and 'bad' 18650 Lithium cells are shown within a range of 1-100 µA SD current, and measurements are compared with the circuit simulation. The different SD currents reflect thereby the various internal cell defects ranging from small to large (1 kΩ- 1 MΩ) leakage resistances that can be interpreted both from an
electrochemical and a manufacturing perspective.

Virtual materials design for the 3D microstructure of lithium-ion battery electrodes

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As the microstructure of battery electrodes strongly influences the performance of the cells, designing electrodes with optimized microstructural properties is an important goal. However, exploring a large amount of possible design concepts in the laboratory involves huge efforts. Therefore, model-based simulations have become an important tool to support such studies. This allows for a preselection of promising morphologies on the computer, which reduces the amount of experimental efforts in the laboratory. Parametric stochastic 3D microstructure models have proven to be a valuable tool to capture the complex microstructure of battery electrodes [1]. In this talk, an approach to systematically analyze a broad range of possible morphologies and design concepts based on such a model is introduced. In particular, a flexible stochastic microstructure model is introduced, and its calibration to tomographic image data of different types of electrodes is shown [2]. A subsequent validation using various morphological image characteristics indicates a high accuracy, which shows that the model realistically captures the microstructure of a broad spectrum of different electrodes. After model calibration, the model parameters can be systematically varied to generate virtual electrode microstructures, which differ in predefined morphological parameters. This includes, e.g., the volume fraction of the active material and the distribution of particle sizes. Moreover, it is shown how further design concepts can be investigated using the stochastic model. To give an example, virtual two-layer electrodes are generated, where a different particle size distribution and volume fraction of the particle phase are used for the bottom layer compared to the top layer. Finally, it is shown how spatially resolved electrochemical simulations [3, 4] can be applied to investigate the performance of the virtual microstructures.

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Microstructure-Resolved Impedance Simulations for the Characterization of Li-Ion Battery Electrodes

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The production of Li-Ion battery electrodes is a highly interconnected process and many parameters determine the functionality of the final battery cell. Therefore, characterization techniques are very important to monitor the quality of the electrodes and to analyze deviations in electrode performance. The impedance of the porous electrode is a characteristic performance indicator, relatively easy to measure, and the corresponding spectra provide a comprehensive overview of characteristic timescales of different processes. For a detailed analysis impedance spectra are commonly evaluated integrally with the help of equivalent circuit models. However, often the performance of the electrode is affected by local structural inhomogeneities due to compression in the calendering process or an unfavorable binder and/or carbon black distribution. For instance, it was found that harsh drying conditions cause binder migration to the electrode surface and consequently reduce the rate capability[1]. In this contribution we interpret impedance spectra of Li-ion battery positive electrodes with the help of 3D microstructure-resolved simulations[2]. This allows us to study in detail the effect of local structural inhomogeneities on the electrode impedance and, thus, performance.

NMC electrodes with different thickness and density were prepared and characterized electrochemically by galvanostatic cycling and electrochemical impedance spectroscopy. Impedance spectra were recorded on symmetrical cells[3] which are especially advantageous for the characterization of electrode transport properties. Reconstructions of the electrodes were created with the help of synchrotron tomography and a 3D stochastic structure generator[4]. The resulting microstructures are then input to microstructure-resolved electrochemical simulations. With the help of our simulations we are able to extract the contribution of the carbon black and binder network to the overall pore transport resistance by comparing our simulations to the experimental data. Additionally, we use different models for the spatial distribution of binder and carbon black to mimic different drying conditions and investigate the effect on the electrode impedance and cell performance.

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Development of microscopic tools for the quality assessment of Li-ion batteries for mobile and stationary applications

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The increasing demand for batteries for mobile and stationary energy storage applications require further research to increase the energy density and the lifetime of battery cells. The functionality, performance characteristics and quality of the cell are directly linked to the microstructural properties of the battery. The microstructure itself is influenced by various production steps, especially the calandering process and the active materials. Therefore it is mandatory to understand the evolution of the electrode morphology being generated during battery production. Beside classical electrochemical characterization methods microscopic methods provide detailed spatially resolved information on the internal structure. Microscopic methods are state of the art for microstructural analysis and quality inspection of materials as steel or functional ceramics. These methods need a more intensive and further development for application on complete cross sections of Li-ion batteries. Due to the different materials used in a battery with different hardness and brittleness, the preparation of artefact-free cross sections is very challenging. Large scale images of the cross sections are recorded and allow the automated detection of defects and deviations of the microstructure i.e. foreign particles, inhomogeneous particle size distributions and layer thickness deviations. These defects are directly linked to the quality of battery cells. Furthermore, foreign particles may damage the separator and cause an internal electrical shortcut and are safety-relevant for the successful use of Li-ion batteries. Different machine learning algorithms are used to process the large amount of image data and quantify different key parameters of the microstructure. For the investigations we use mainly light microscopy images. If higher resolutions are necessary SEM and FIB/SEM techniques are used. For an overview of whole battery cells and the detection of large geometric deviations in the battery cell, setup of non-destructive computer tomography (CT) methods are used. The methods can be used for the development of new production processes and the determination of the influence of single production steps on the microstructure. Additionally the methods are also suitable for the evaluation of different battery suppliers and quality assessment of Li-ion batteries. It is shown, that the combination of different imaging methods can help to assess the quality of different Li-ion batteries. These methods provide very valuable additional information. They help to improve the knowledge about the influence of the production on the microstructure and on the quality of the Li-ion batteries.

Electrode Production (I)

Influence of the specific energy during mixing and dispersion on suspension and electrode properties of lithium-ion batteries

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Energy storage is a key technology for alternative drive systems, like electric and hybrid electric vehicles. Lithium-ion batteries (LIB) are widely used for this purpose due to their high energy density and their developmental state. The increasing usage of electrified transportation leads to ever-increasing demands on LIBs in terms of fast charging ability and power density.
The fragmentation of carbon black (CB) aggregates and CB agglomerates, respectively, has high impact on the resulting mechanical integrity as well as conductivity of electrodes and furthermore the electrochemical performance of LIB's. To achieve optimized power densities and to reduce the process time to reach defined particle sizes and distributions, a systematic investigation of process and formulation parameters of the dispersion is mandatory. Additionally, an in-depth understanding of the carbon black disintegration and breaking process leads to knowledge about an optimal CB size distribution, which further results in a reduced amount of CB. Consequently, this knowledge leads to an optimized cathode, which increases the energy and power density of LIB's.
The presentation shows the correlation between the specific energy or time of the dispersion process in a planetary mixer and the resulting properties of the cathodic suspensions (e.g. viscosity) and electrodes (e.g. adhesion force, conductivity, electrochemical performance), with focus on the CB particle sizes. The basic slurry formulation has industrial relevance and contains > 95% active material and < 2% CB.

Continuous processing of LIB electrode slurries

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Up to now, mainly batch kneading processes are used for the production of lithium ion battery slurries. As the demand for lithium ion batteries is expected to increase drastically within near future, batch processes fall behind continuous mixing processes which allow for significantly lower investment and operational costs at higher production rates. Continuous processes operated in steady-state also show less variation in product quality than batch processes. Bühler has developed a continuous mixing process based on a co-rotating twin-screw mixer that meets the requirements for consistent slurry quality even at highest throughputs. With respect to the inherent differences between batch and continuous mixing essential characteristics of Bühler's mixing process are highlighted and discussed. With particular emphasis on process optimization, various examples are shown how slurry properties such as the rheological behavior can be tailored by means of adjusting process parameters. Furthermore, the milestones in the development of Bühler's continuous mixing technology as well as examples of the implementation in the battery industry will be presented.

Key factors in the production process of electrodes for LIB

Dr. Alice Hoffmann, Dr. Giulio Gabrielli, Dr. Nicola Jobst, Dr. Andreas Klein, Stefan Zink, Emanuel Heider, Christian Dreer, Dr. Peter Axmann, Dr. Margret Wohlfahrt-Mehrens
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Implementation of a production site for Lithium-ion batteries in Germany is assessed to be a crucial factor to promote a sustainable transition towards electromobility. Extensive research is done to explore possibilities to improve the performance and cost of state of the art LIB in order to enable competitive products. In most studies, preparation of electrodes is either done in a lab scale environment which differs greatly from the equipment and techniques applied in industrial production, or the process parameters are not described in detail. These studies consider the applied materials, formulations and macroscopic electrodes properties like mass loading and density, but neglect the procedure of preparation. However, for a given formulation, the processes of dispersing, coating and drying have a decisive influence on the properties and performance of the resulting electrodes and cells.
This contribution gives an overview about influencing factors that have to be considered in the production process of electrodes. Occuring challenges and corresponding counter measures are explained at the example of electrodes produced in pilot scale and pre-industrial scale and aimed to improve energy density or reduce cost compared to state of the art electrodes. The examples shown include waterbased anodes, blend cathodes consisting of different materials and ultrathick electrodes. The impact of the dispersions properties and of process parameters on the processability and on the properties of the electrodes is illucidated by different analytical methods like SEM and electrochemical investigations in half cells and full cells.

Acknowledgement
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Formation & Testing

A frequency based test time optimization of measured load data for testing High Voltage Battery Systems on Multi-Axis Shaker Table

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The development and popularization of new electric vehicles is largely dependent on development of efficient battery systems with higher capacity, offering longer driving range and lifetimes. This development calls for evaluation of these battery systems for durability and ageing. Conventionally, durability testing of batteries is carried out in the laboratory either based on pre-defined testing standards or by replicating measurement data representing mostly accelerations from proving grounds representing real test drives on test benches. These testing activities are often expensive in terms of testing time and costs. There is ample opportunity to reduce testing time by processing and optimizing the test signals. Several such methods already exist which reduce testing time by optimizing signal length. These methods quite often are based out of the time domain and there exists few methods based out of the frequency domain as well. In this work, one such method based on the frequency domain is described which is aimed to accelerate a testing by optimizing the test signal using the power spectral density (PSD). Accordingly, the test signal is pre-processed using filters, which is subsequently processed based on a 'Reference PSD' which serves as the criterion. The effectiveness of the optimized signal is compared against the original signal in terms of pseudo damage and RMS content. Using frequency domain instead of time domain enables deciding and withholding frequencies of interest and removing sections which have their frequency content lower than threshold in this frequency range. Also, this enables the accounting of resonance frequencies and signal peaks which appear in measured signals. The 'Reference PSD' used as the criterion is either computed based on the input signal or generated based on user defined parameters. This process can lead to shortening of a signal of up to one fifth the original time length with also retaining the frequency relationships.

Factory of the Future-proof EV battery and power-train testing

Andreas Sokoll
Bosch Rexroth AG

Growing production volumes for hybrid and plug-in vehicles and the need for higher quality and safety standards in EV battery production require faster, more efficient testing solutions and seamless, cloud connected test data collection. During this presentation, attendees will learn about a real-world example of a fully automated and connected battery testing system enabling faster engineering, higher productivity and more transparent, open standard test data communication in the Factory of the Future. The presented solution is based on proven Rexroth automation technology utilizing our modular, efficient IndraDrive Testing Drive and DC-DC System ranging 50W-4MW with the OpenCore LabVIEW and IoT interface.

Formation and aging of lithium-ion cells – probably the longest awakening of a cell

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The lithium ion cell is the most expensive component of a battery system. The clear objective of research is thus to reduce battery cell production costs. An analysis of the costs of battery cell production reveals clear cost drivers, which are essential to enable potentials for cost reduction. In particular, the formation and aging process represents a high potential for a cost reduction with the enormous time expenditure. The industry requires up to 3 days for formation and up to 3 weeks for aging. Aging is primarily a pure quality assurance process, however, in this phase impurities in the cell are also reduced by high temperature aging.

Due to the high relevance of these processes, the project OptiZellForm examined these processes in more detail. In detail, the environmental conditions such as pressure and temperature as well as the electrical and chemical conditions during formation and maturation were investigated. The focus of this contribution is the investigation of the environmental conditions pressure and temperature as well as the electrical analysis.

The investigations are based on a test setup which makes it possible to control the pressure and the temperature effect on the cells. The pressure cylinder applies a flat force to the cell. In addition to the pressure, a temperature chamber is used to set the ambient temperature of the cell. In this way, both ambient conditions can be set exactly. The aim of the investigation is to identify time saving potentials by applying a pressure and adjusting the ambient temperature.

In order to investigate the behavior of the cell and the energy losses during formation more closely, temperature sensors were embedded in the pressure device. With the help of these, the temperature development at the cell contacts and on the surface of the cell can be recorded. The aim is to identify energy losses due to temperature development in the cell and thus draw conclusions about the causes of energy losses.

On the other hand, the c-rates and formation procedures were varied to investigate their effect. The basis of the investigation is a CC-phase, a CV-phase and again a CC-phase at the end. Within this test cycle, the C-rates were varied.

The current results from formation and ageing show a clear time saving potential with the application of the pressure to the cell, as well as the high c-rates. For a more precise statement on the long-term stability of the cells, further investigations with the help of cyclisation tests are necessary.

Electrode Production (II)

Analysis and optimization of an extrusion-based coating process for high-energy li-ion cathodes

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Li-ion batteries are used for a wide variety of applications, ranging from small devices like cellphones to cars. One approach to increase the cells energy density is to minimize inactive parts of the electrode by enhancing the electrode thickness. However the state of the art tape casting process is limited in terms of coating thickness and drying procedure, which requires alternative coating processes. An attractive and more efficient process for electrode production with high solid fractions is the thin film extrusion process.

Firstly, the mixing of electrode pastes in a twin screw extruder was analyzed for different cathode recipes. Thereby cathode pastes with solid fractions between 85- 90wt% could be processed to high energy electrodes via slot die coating. It will be shown, that screw speed and shear rate have a predominant effect on paste homogenization and particle crushing. During the coating process different nozzles have been considered. It turned out that the slot die is the most promising, as it allows direct coating on the current collector by omitting an additional lamination process step. Lastly, the follow-up processes drying and calendaring were examined. The experimental results confirmed that the extrusion-based coating process with high solid and low solvent contents offers a big potential to both increase coating speed and reduce energy consumption. This is due to the fact that electrode pastes compared to conventional slurries have much lower solvents content, which eventually shortens the drying process.

The development is supported by simulations to systematically design electrodes towards highest practical energy density and rate capability, measured in test cells. By combining simulation and experiment the number of necessary experiments could be significantly reduced, as will be shown in der presentation. The experiments were accompanied by measurements of manufactured electrodes to identify process-structure-relations. Main methods are electrochemical rate and cycling tests, to evaluate the performance in the final cell. Additionally, to investigate the coating process rheological measurements, REM-imaging and tortuosity measurements of electrodes and pastes are used. The best cathodes in terms of energy density achieved a mass load of 47 mg/cm², a coating thickness of 159 µm at 38% porosity using NCM622 (93wt%). The effect of conductive additives to optimize the rate capability of the cathodes will be discussed in the presentation.

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Single-step and scalable production method for stable pure-Si anodes

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We have developed a MW-PECVD process to deposit porous a-Si directly onto a Cu current collector. MW-PECVD is a widely used technology for mass production of semiconductor and PV materials and can be modified for the use in large scale production of battery electrodes. We have re-engineered the MW-PECVD single step process in such a way that it can be adopted in existing Li-ion cell mass production process at a cost competitive way.

Our Si anodes have a thickness up to 15 micron and a porosity of 30-50% depending on the process conditions, such as T, p, and gas composition, and consist of regular copper substrates and a porous silicon layer. The Si anodes were tested in 26 cm² pouch cells with NMC cathodes and have a Coulombic efficiency of 99.9% at a charge/discharge rate of C/3. By increasing the Si thickness, and improving cell layout, we aim to reach a full-cell energy density of 1200 Wh/l or 450 Wh/kg in the charged state.

We are planning to start producing pure silicon anode rolls in our upcoming base plant, located in Eindhoven, the Netherlands, to a) supply silicon anode sheets for testing programs and first prototype products, based on current OEM dialogues, to b) demonstrate the semi commercial production of silicon anodes, and c) to demonstrate the fit with existing battery production processes without the need for substantial capex investment.

Atmospheric plasma pre-treatment for optimised surface wetting in electrode production

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Atmospheric plasma discharges can be used to easily improve the wettability of surfaces. Good wettability in turn is a key surface property to obtain an ideal contact at boundary surfaces and a quick spreading of liquids, as is necessary in the electrolyte filling step.

The surface energy of metal foils can be considerably enhanced by applying an atmospheric plasma surface treatment. This has been shown with several different substrates such as copper, aluminium and nickel. Using this effect the homogeneous coating of surfaces can be improved, which opens the way to reduce adhesive additives in the slurry formulations for electrodes. In addition, a positive effect on the contact resistance between foil and active material has been found.

Besides using metallic current foils, research is going on at Fraunhofer IPA to use conductive papers as substrate for electrodes in energy storage cells. These have a lower density than metal foils and could greatly improve the carbon dioxide balance for future electrodes and enable more sustainable and better-to-recycle electrodes. This research is publicly funded and focusses on the usability of such paper-based electrodes in energy storage cells. Further it analyses the possibilities of a scale-up of manufacturing processes for such electrodes and the prerequisites for future mass production.

A very important property of the carbon-containing, electrically conductive paper in the coating process is here also its wettability and the penetration of the water-based slurry during coating. Both can be improved by a plasma pre-treatment which resulted in the reduction of the contact angle by over 60 percent. Also the adhesion was increased. By these improvements in turn also the electrochemical performance could be enhanced.

Different combinations of active materials and substrates for electrodes have been manufactured with and without plasma surface treatment. They have been compared for their wetting behaviour, their contact resistance and their electrochemical performance. These measurements showed various advantages of atmospheric plasma treatment.

Cell Designs & Markets

State-of-the-art and Future Battery Cell Technologies for the European Battery Value Chain

Markus Woland, Paul Wolff, Robert Stanek

P3 Group

An increasing electrification leads to a growing demand for batteries. Due to a wide diversity in the fields of application and differing requirements on customer side, the cell technologies are being developed. Especially the mobility industry requires high standards on both production and customer side. To meet those requirements, new cell technologies are emerging to the markets and pose new challenges for European mechanical and plant engineering manufacturers.

P3 is a Technology Consulting Company that focusses on the complete value chain of the electric powertrain. In more than 500 different industry projects around eMobility at OEMs as well as Tier1, Tier2 and Tier3 suppliers, P3 has built up expertise of the battery value chain from raw material up to complete battery systems.

In this context the equipment manufacturing of the state-of-the-art battery cells as well as the impact of future cell technologies on the European mechanical and plant engineering manufacturer are examined in the presentation based on both cost and technology aspects.

Market Development

The industry focus within the current automotive value chain has changed, as the battery system in fully battery electric vehicles (BEV) is the most challenging and expensive part in this new powertrain setup. Thus, cell and battery pack manufacturers are becoming increasingly valuable for OEMs and their suppliers. To meet the requirements of the rising battery cell demand, a wide variety of cell manufacturer invest in new plants all over the world.

Experience in state-of-the-art Li-Ion battery cell production in the past years has enabled Asian suppliers to become the market leaders in the cell production equipment industry. Due to this strong competition, European mechanical and plant engineering manufacturers face new challenges.

State-of-the-art

The state-of-the-art Li-Ion battery production process for automotive applications is marked by large production volumes. With the increasingly accelerated demand for BEVs, this production volume is also rising every day. Requirements regarding energy density, safety and cycle life for the batteries require highest quality standards and the appropriate equipment. Over the last years automation and up-scaling has led to a significant efficiency gain within the value chain.

As the production process comprises numerous steps from the electrode manufacturing and cell assembly to the formatting and aging, a wide variety of production equipment exists to cover all aspects. A correspondingly large number of cost reduction drivers are available.

Challenges

One important aspect of the rising interest in cell and battery manufacturing is that the production technology must keep up with the new innovations in the cell design. As the current Li-Ion cell design NMC will most likely change in the future e.g. to All-Solid-State, Lithium-Sulfur or Lithium-Air, the production equipment needs to be adaptable to upcoming production process changes. This has a major impact on how mechanical and plant engineering manufacturers should design and build their equipment. Most of the next-generation technologies are not yet ready for a large-scale production, so that equipment manufacturers should consider those trends already today.

This presentation provides the comparison of costs and technology aspects for European manufacturing of Li-Ion cells and battery systems. Furthermore, there will be an outlook to the next generation battery technologies and challenges in adoption to current production setups, plants and environments. In conclusion, potentials and options for production equipment suppliers will be shown and discussed with regard to global trends and strategies of leading cell and battery manufacturers.

Large-Scale Production of Lithium Ion Cells and Modules in Germany 2018

Dr. Gerold Neumann, Gunnar Grohmann
Liacon GmbH

Liacon is currently finalizing the set-up of a volume production facility of Lithium ion cells with pouch type housing and modules close to Dresden. The production equipment covers four fully automated cell production lines for two different cell dimensions. For one cell type a module assembly line also fully automated is additionally installed. Parts of these lines have in the past already been utilized for production of cells and modules for automotive applications. Therefore a re-certification along with the IATF 16949 standard after starting of operation is planned.
All lines may be run with different products. The production depth of Liacon starts from electrode production over cell assembly to module set-up including BMS and software. One major activity of Liacon in the past has been stationary and high power applications. This activity will be covered primarily by an LFP/LTO cell chemistry. For high energy density demands like e.g. in mobile applications an NMC/C technology will also be produced. In total an annual production capability of up to 150 … 200 MWh will be available making Liacon become a major cell manufacturer in Germany. First products are expected to leave the production in the first quarter 2019.

Electromobility – which cell formats prevails?

Dr. Kai-Christian Möller[a], Dr. Tim Hettesheimer[b], Dr. Axel Thielmann[b], Dr. Christoph Neef[b], Dr. Mareike Wolter[c], Dr. Vincent Lorentz[d], Markus Gepp[d], Martin Wenger[d], Dr. Torben Prill[e], Dr. Jochen Zausch[e], Peter Kitzler[f], Joachim Montnacher[f], Martin Miller[g], Dr. Markus Hagen[g], Patrik Fanz[g], Prof. Dr. Jens Tübke[g]
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The market for lithium-ion batteries (LIB) is growing dynamically with the sale of electric vehicles. With more than 3 million electric vehicles sold worldwide by the end of 2017 (battery electric- BEV and plug-in hybrid- PHEV), over 80 GWh of cell capacity have been installed in electric cars. In 2017 alone, more than 30 GWh were demanded for the automotive segment, which corresponds to the global LIB demand of five years ago. In the next ten years, demand will grow to several hundred GWh maybe even up to the TWh range, and accordingly, global cell production capacities will be built up to this scale.
While roadmaps of cell manufacturers and automobile manufacturers have consolidated for the further development of the cell chemistry used for high-energy LIB cells, so far no dominant cell format has prevailed. Samsung, for example, produces its cells in prismatic form, while LG mainly fabricates them in pouch cell format. Panasonic, on the other hand, manufactures its cells in a cylindrical 18650 format and will soon be producing in the "Gigafactory" cells in the 21700 format. In view of the emerging economies of scale, future R & D investments, strategic decisions and business models of suppliers of the automotive industry and other systems integrators are closely related to the standardization and establishment of cell formats.
However, selecting a cell format involves several aspects relevant to OEM, such as the achievable energy density, the geometric dimensions and cell integration in modules, the heat development of cells and the need for thermal management, the safety of cells, modules and the overall system, as well as the costs of cell and module production. A statement about the potential of development of different cell formats is therefore difficult to make due to the associated complexity. It requires a systemic view of all aspects and criteria from the cell to the module level and finally the individual vehicle concept.

Electrode Production (III)

Modeling of the calendering process and its effects on adhesive strengths of cathodes

David Schreiner, Nicolas Billot, Till Günther, Prof. Dr.-Ing. Gunther Reinhart
Technical University of Munich, Institute for Machine Tools and Industrial Management (iwb)

Driven by the increasing demand of electric mobility, new materials and chemicals for lithium-ion cells are developed. One of the main challenges in transferring batteries from laboratory to industrial use is the upscaling of the production process. The production of lithium-ion cells consists of a series of interlinked process steps and is divided in two major sections: electrode manufacturing and cell assembly. Calendering, as the last step of electrode manufacturing, is a crucial production process, influencing mechanical and electrochemical properties of the battery-cells. In the research project ProKal the modeling of the calendering process for high-energy electrodes is investigated. Besides the characterization of electrode properties such as adhesion strength, the behavior of the calendering machine during compression is analyzed.
This poster will introduce an approach for predicting the behavior of dependencies between calendering and the factors material, composition, thickness, and machine. First, the characterization of the calendering process is carried out through experiments. Based on that, the characterized properties are modelled. First results show improvements in understanding the different effects from calendering on electrodes and outline the machine behavior of the rollers during the compaction process. With these results a deeper understanding of the calendering process and its impact on electrodes could be achieved and forms a base for further experiments and investigations. The accompanying measurements of adhesive strengths for different degrees of compacted NMC 622 cathodes verify the predicted behavior and provide guidelines to optimize the process ability of the electrode. Further investigations need to be done concerning the effect of different compression rates and roller temperatures as well as on a more precise modeling of the calendering process.

Process modeling of the electrode calendering for lithium-ion batteries

Chris Meyer, Dr.-Ing. Wolfgang Haselrieder, Prof. Dr.-Ing. Arno Kwade
Technische Universität Braunschweig, Institute for Particle Technology (iPAT)

Calendering is the very important, well established compaction step for electrodes of lithium-ion batteries. The compaction determines the porosity of the electrode coating, which is decisive for the cell performance, especially the energy density. Thus, the ability to comprehensively control the compaction process is of significant importance.
This contribution presents a process-structure-model for the one-step calendering of battery electrodes based on the compaction model of Heckel. Two parameters characterize the compaction behavior: the compressibility as a scale for the achievable minimum porosity and the compaction resistance as a scale for the necessary effort.
The impact and interaction of different process and product parameters are investigated. The achievable minimum porosity rises with content of large carbon black agglomerates and small particles of active material. The minimum as well as the compaction resistance decrease with increasing roll temperatures using the thermoplastic binder PVDF. On the other hand, the resistance rises with higher mass loadings and distribution degrees of carbon black because of growing interparticular friction.

Separators & Safety

LIB Separators - the inactive but not insignificant part of the cell

Benjamin Hörpel, Dr. Gerhard Hörpel
GBH Energy - Gesellschaft für Batterie Know-how mbH

In an overview, Lithium ion battery cell separators will be presented as inactive materials beyond the active materials anode and cathode.
The development of cells follows 5 golden rules: safety (1), performance (2), life (3), cost (4), environmental (5), as Bob Galyen, CTO CATL, pointed out recently[1)]. Separators usually contribute significantly to all of the 5 objectives in achieving better cells. On the other hand, separators as inactives need to be minimized, in particular in targeting energy densities beyond 300 Wh/kg. Here the lower limit for separators reaches already 12 µm for xEV applications (large formate cells), while in small cells for consumer electronics (wet) separators go down to 5-6 µm. Thickness and the porosity of separators rules the electrolyte uptake and thus contributes to the energy density of the whole cell. In order to maintain safety as objective #1 in cells for xEV application a 3-4 µm ceramic coating is applied, mostly on separators, sometimes on anode surface. The ceramic coating is considered as a must-be in xEV cells.
Different types of separators will be discussed, both membrane and non-woven based nature. Production processes will be compared with respect to production steps and cost including inorganic coatings which will be compared to coextruded technologies. Furthermore, the specific separator consumption comes down from almost 40 m2/kWh for high power LIB to 5 m^2/kWh for future high energy density LIB, which may be recognized as a significant cost cutting contribution.
The overview comprises the main players with their state-of-the-art technology, their developmental products and their view on the role of separators in solid state battery technology.
Finally, a landscape of markets and market developments will be shared.
1) Robert Galyen, CTO CATL, SAE Forum, Brussels September 18, 2018

Challenge Battery Safety - Solutions by Multifunctional Battery Housings "B:HOUSE"

Dr.-Ing. Jobst Kerspe
TEB Dr. Kerspe

When designing and building up battery housings for EVs, many guidelines and regulations have to be considered: regulations – e.g. UNECE R100/2; functional requirements – e.g. thermal management of the battery; consideration of installation conditions – e.g. available space, options for load transmission into the car body; and last not least requests by the owner/ driver of the car – e.g. a failure free car under different climatic conditions with full range.
At the same time, available space and weight of each module are rare resources – that means lightweight and multifunctionality are stringent demands. With the B:HOUSE®-konzept in GVI®-technology, new and high efficient solutions are possible: effective passive and active thermal management; vibration proof and crash tight fixation of the battery cells and modules; fire protection in both directions; EMC-safety; environment protection; lightweight construction.
In addition, all this is focused in one single unit – the B:HOUSE®
Basic physical properties of the GVI®-technology will be presented. Characteristics of the B:HOUSE-concept will be shown by means of test results and executive examples.
Outline:
A) Definition the guidelines, regulations and functionality of the battery
B) The B:HOUSE®-Conzept for design and manufacturing of „Multifunctional Battery-Housings“
C) Samples of application and test results
D) Outlook

Module & Pack Design

Battery module for cylindrical cells with integrated direct cooling using coolant

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To meet customer requirements, battery systems of future EVs or PHEV have to be fast chargeable and have to work under different thermal conditions. Therefore, an adequate temperature control of the battery cells is necessary to guarantee a homogeneous temperature distribution inside the battery system as well as to limit temperatures. Using cylindrical battery cells, cooling is a challenge, due to the geometry of the cells. Conventional air cooling systems work without complex thermal contacting of each battery cell, but are limited in heat dissipation.
We developed a direct cooling for cylindrical battery cells using liquid coolant. The objective was, to integrate the cooling system into a 48 V battery module, to enable a flexible arrangement and connection of the modules in mobility applications like EVs or PHEVs. Space efficiency, cost-saving design were also objectives in the development.
The validation of the cooling design was done by CFD simulations and physical tests. Finally, we proved the cooling performance by fast charge and fast discharge tests with 3C current rate and evaluated the temperature rise of the battery cells inside the module.
All design and validation activities lead to a 48 V battery module consisting of 96 battery cells of the format 18650. Two half shells of polymer fix the cells and define the space of cooling. The coolant flows around the cells to enable a homogeneous heat dissipation. Charging and discharging the high energy cells with 3C current rate, lead to a maximum temperature spread of 2.3 K between the cells and a maximum temperature of 26 °C. This indicates a homogeneous and powerful cooling design. With regards to the cooling system, the goal of a fast chargeable module was achieved.
To prove the flexibility of the module concept, adaption on other cell formats like 21700 should be investigated. Another question is, which concept adaptations would be necessary for series production and which production requirements would have to be met?

A Novel Hybrid Thermal Management for Lithium-ion Battery Packs

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This paper presents the result of an experimental investigation into the potential failures of the existing thermal management systems (TMSs), active and passive, for high-powered lithium-ion battery (LIB) packs for electric vehicles. These systems have been designed to eliminate overheating problems of LIBs during charging and discharging; however, their efficiency regarding the energy consumption level and their reliability is still questionable. To approach these issues, we introduce a unique practical TMS design under the umbrella term of hybrid thermal management in a real driving situation and hot weather condition. The active TMS was conducted with forced air convection through a pinned heatsink, and the passive TMS was running using phase change materials (PCMs). The hybrid TMS made from PCM embedded in a copper foam composite with the porosity of 90% combined with forced-air convection to simultaneously enhance the conductivity of PCM and directly connect the battery surface to the pinned heatsink. Thin-film heaters of constant heat flux were used to emulate the heat generation of LIBs' cells at different discharge rate. In the first stage, we employed all three TMSs in standard weather condition of 20 °C. Although in the active TMS, the average temperature of the cell surface reached a steady state under safety temperature of 60 °C, the surface temperature non-uniformity was a chief problem. Consequently, the heat accumulation in PCMs caused by low thermal conductivity resulted in the failure of passive TMS. Our experiment reveals that while the airspeed (vehicle speed) was an only 3.2 km/h (2.0 mph), the hybrid TMS could entirely keep the cell surface temperature under 60 °C. We also performed a dynamic mode to challenge our TMSs in a real driving state including high and standard discharge rate and a stop mode in which there was no air convection. The results showed that just hybrid TMS could reach a steady state under 60 °C while the active TMS could keep temperature only for four cycles. Furthermore, our test proved that the proposed hybrid TMS maintains outstanding reliability and efficiency in the hot weather condition of 40 °C.

Cell Performance

Key Cell Design Parameters regarding the Performance of Lithium Ion Batteries

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The performance of a lithium ion battery is critically dependent on its design parameters. In recent years the energy density of electric vehicle cells increased from 130 Wh/kg up to 270 Wh/kg. However, most of this improvement was not achieved by new technology but by changes in cell design which trade-off performance vs. energy density.
Quantifying the performance trade-off for a specific design parameter reveals critical spots for new innovations and allows a cell design based on the product requirement. Furthermore, tolerances for specific production processes can be estimated.
In this conclusive study we present the effects of single design parameters on the performance of 5 Ah multi-layer pouch cells. Highlighted parameters are material selection, coating recipe, mass loading, porosity and electrode balancing.

Investigation of 20 Ah class cell format and packaging: Performance, Cycle life and Safety

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Li-ion and Na-ion large cells have been developed in the framework of the H2020 projects SPICY and NAIADES (Silicon and polyanionic chemistries and architectures of Li-ion cell for high energy battery and Na-Ion bAttery Demonstration for Electric Storage). SPICY was focusing on polyanionic phosphates for the cathode material with PHEV cell designs and an energy density from 100 to 165 Wh/kg whereas NAIADES cells integrate sodium based materials with lower energy density but higher power capabilities. 4 cell architectures and packaging were investigated in ageing or in abusive tests with the support of understanding and modelling activities. Soft and hard packaging were compared, but also prismatic vs cylindrical design. All other parameters (formation condition, active materials, electrodes, electrolyte) were kept the same in order to have a fair comparison.

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Module and Pack Production

Production of state-of-the art batteries for electric mobility.

Dipl.-Ing. Thomas Mertens

BMW Group, Technology Development Prototyping Battery Cell

The continuous development of innovative production technologies is a prerequisite for being able to permanently produce state-of-the-art batteries as a company. From the early product development stage, technology development provides advanced and industrializable processes for the adaptive production system. This ensures flexibility and responsiveness to further market development with focus on time, cost and quality for the future production system. Moreover, maturity stage management and validation are essential for ensuring the technology transfer. The presentation describes the general approach of BMW to develop new production technologies and to transfer them into series production of battery modules and packs.

Laser processing for cost effective assembly of small series, customized battery packs.

Ing. Jurgen Adriaensen

Absolem Prolab

Absolem Prolab is an experienced innovation partner specialized in battery pack assembly using laser technology. Our focus is to guide the customer (e.g. manufacturers of battery packs) from concept development over prototype realization and small series production up to mass manufacturing on the production floor of the customer.
Based on our learnings from former projects we detected 3 main challenges customers are facing. Absolem uses a structured way of working to tackle these challenges and bring products to the market in a cost-effective way throughout the product lifecycle.
The first big challenge for “small” series battery packs is the fact that the sourcing and choice of the components is different for every application. There is no “standard” solution. This renders a very large variation in material combinations, different geometries and side criteria.
The second challenge is that the component value that is put into the pack is very high and the rework options are limited and expensive. To avoid any risk, the developers stick to the known technology (nuts and bolts). This way of working is blocking the way to a cost-effective and reliable assembly in the next phases of the product life cycle.
The third challenge is the investment cost needed for specific production equipment. This is most often very high. Nevertheless, the customer and the manufacturer want to have the final manufacturing technology from the first product that is delivered to the market. Otherwise the product needs to be re-designed and re-validated which takes a lot of time and money.
As an answer to these challenges Absolem has developed:
1) A structured way to successfully assemble batteries with the highest reliability with the lowest TCO possible for every phase in the life cycle of the product.
2) The best measurement tools to investigate materials, packs, components on all critical parameters.
3) Different pilot production setups to assemble battery packs. On these setups we prove the capabilities and do the manufacturing of small series of packs.
For small series battery packs most of the components used are not designed for laser processing.
Therefore, different innovative laser strategies were developed in our lab. In the presentation we will point out these challenges and the solutions we have implemented in the field.
Thanks to the very large installed base of equipment and the experience of the people of Absolem the customer will get the optimal solution and support for the assembly of battery packs.

Efficient contacting of battery cells to produce modules and packs for power tools and electric vehicles

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Smartphones, laptops, toothbrushes or toys: In our everyday lives, battery power is already a matter of course. The more powerful these devices become, the higher our demands on batteries or accumulators get. For the electrification of traffic and for the use of high-performance power tools, batteries are combined to form modules or packs in order to meet the high demands placed on battery technology.
Laser welding is predestined as a connection technology for robust, efficient and reproducible contacting of batteries. Key technologies are highly brilliant fiber laser sources that enable smaller spot sizes and high-quality deep penetration welding. A locally focused energy input reduces the thermal load on the connectors and cells. Laser micro welding offers the flexibility to

interconnect different types of battery cells such as cylindrical, prismatic or pouch cells. Spatial power modulation- a linear feed rate with superimposed circular motion- enables an increase of the connection area, which leads to a more efficient laser process and thus increases the current carrying capacity. The dynamics of the melt are reduced in a modulated welding process, which can reduce instabilities and process failures. By varying the oscillation frequency and amplitude, the geometry of the weld seam changes from a conventional V-shape to an almost rectangular shape. This allows the connection cross section to be increased, minimizing the contact resistance. The presented work contains the results of connecting different types of battery cells through laser micro welding.

Bond-technology solutions for battery pack production and electromobility

Dr. Hans-Georg von Ribbeck
F & K DELVOTEC Bondtechnik GmbH

Process and process trends for Module and pack production: In power electronics, ever larger currents have to be handled, which also poses new challenges for assembly and connection technologies. Another field of application has opened up with the development of electric vehicles. Here, storage batteries are required which, depending on their design, consist of numerous individual Li-ion battery cells. Different connection techniques are used for the electrical wiring between the cells, whereby wire bonding with thick aluminum wires is particularly suitable for the currently market-leading small Li battery cells of type 18650 or 21700. In this process, a wire with a diameter of up to 500 µm is welded directly onto the anode or cathode of a battery cell using an ultrasonic friction welding process. It then runs to the second contact point on the package, another battery terminal or a bus bar.
Classical ultrasonic wire bonding though, reaches its limits at high currents. The newly developed LASERBONDING in oscillation welding mode provides a remedy. It is suitable for considerably larger wire cross-sections and at the same time has the advantages of wire bonding in terms of excellent flexibility and automation. With Laserbonding, not to be confused with laser welding, we present highly reliable and process-safe high-current contact technology which allows for automation and tolerance compensation as a challenge in the joining process while applying low stress on the joining partners. Laserbonding is a further development of laser micro welding as a joining technology and its potentials. Concrete and newly available methods are Laserbonder and Laser TAB (Tape-Automated Bonding). Further we present Laserbonding as a process option for contacting aluminum and copper for battery and power electronics delivering solutions for current application topics as:

- Large connection cross-sections for battery technology for high reliability and high performance,
- reliable joining processes with low surface quality requirements,
- optimal utilization of the available bond pad/joint area for minimized contact resistances due to multiple contacts at the same location and
- new materials and surfaces.

Industrie 4.0 & Factory Design

Cloud integration of electrode manufacturing via automated tracking and analysis of machine and quality data

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Electrode manufacturing is one of the most critical processes within the energy storage production chain, as the electrodes coating quality determines the later performance of the energy storage system in large part. The process step of electrode coating is influenced by many parameters, like the process parameters during coating itself but also by the earlier process steps like the mixing of the electrode slurry and the quality of the raw materials.
Within the research project DigiBattPro the automated and cloud-based collection of the data of all process parameters was developed. Based on these datasets algorithms can evaluate complex correlations across different process steps. Therefore, at Fraunhofer IPA, the whole electrode manufacturing process was digitalized and documented within a joined database. Starting with the raw materials, parameters like the particle size or the specific surface area were recorded. In the following process step, the electrode slurry will be mixed out of these raw materials. During the mixing process of the electrode slurry, the energy input is recorded, realized by the cloud integration of the laboratory-mixing unit. Next the electrode slurry is coated onto the current collector foil and dried using a roll-to-roll pilot plant. During this process, machine parameters like web speed, web tension and drying parameters are monitored. The machine is integrated into the cloud via an OPC-UA interface and a smart connector that stores the parameters in a database in the cloud. Furthermore, the quality of the dried electrode is recorded inline using a 3D height sensor and a visual camera. The sensors detect resp. measure quality features of the coating, such as its thickness, pinholes in the surface, and the steepness of the border. Single sections of the electrode foil are marked uniquely with an Ink Jet Printing Head, allowing them to be identified in following process steps via the printed Data Matrix code.
With the usage of the Experiment Managing System developed at Fraunhofer IPA all experiments can be fully digitally planned, managed, documented and reviewed. Adding machine and quality data to the results helps evaluating the experiments. Algorithms have been developed that evaluate the datasets collected in the executed experiments. Coating machine parameters, quality features and properties of the used slurry are combined using machine learning methods in order to build a quality prediction model of the process.
The approach of digitalizing the electrode manufacturing is one first step towards a more flexible production of energy storage systems, which can adapt faster to new materials or cell sizes. A profound database of continuously tracked process parameters allows it to keep manufacturing quality stable and reduce set-up times for new materials. It is also the base to develop better process simulation models to predict favorable process parameters for completely new cell chemistries and cell designs.

Smart Battery Factory design for todays and tomorrows requirements

Dr. Klaus Eberhardt
Exyte Management GmbH (former M+W Group GmbH)

The predicted growth in the Battery industry with an estimated production capacity of 500GWh in 2025 requires approximately 50 new large scale Battery Factories in the years to come.
Currently it looks like that, due to the expected market volume in China, the majority of these Factories will be located in China. However, there will be a considerable number of Factories spread around the world, in vicinity to the car manufacturers. The question is how large these factories will be and what are the challenges in designing and constructing such factories. The design has to fulfil various requirements, which are partially competing against each other: Cost effective-clean-green and fast. The impact from each of these topics on the Factory design will be discussed. In addition Safety aspects as well as criteria for the permitting will be reviewed. The environmental permitting appears to be an important factor since huge volumes of hazardous, flammable and toxic materials have to be stored.
Further focus on the factory design discussion will be on optimized logistics, sustainability and flexibility to implement future technology upgrades, such as Solid state and/or dry coating. Value Engineering aspects and energy saving potentials (Dryroom…) will be highlighted as further cost reduction potentials.
Finally the optimum building concept and overall building area will be discussed and the resulting manufacturing capacities will be estimated.

Decision Support System for quality assurance in the production of lithium-ion battery cells

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Today, there is a high level of uncertainty about cause-effect relationship between material properties and manufacturing processes in the production of lithium-ion battery (LIB) cells. Each step in a process chain can be characterized by a set of input parameters as well as intermediate properties, which may serve as an input for subsequent processes. Several hundred inputs and intermediate features determine the quality of LIB. In order to shorten the ramp-up time for battery cell production plants, the influences on the quality need to be discovered.
An approach to develop a Decision Support System for quality assurance in the production of LIB will be presented.
The system aims to assist the domain specific experts at their research and development by combining expert systems, key performance indicators and data mining.
Practical examples from the prototype production line at BMW show how the Decision Support System can assists quality assurance in the production of Li-Ion cells.

Life Cycle Engineering & Sustainability

On the relevance of recyclability for the environmental impacts of secondary batteries

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The end-of-life phase of secondary batteries is highly relevant for their (life cycle-) environmental performance. However, studies on the environmental impacts of battery production often disregard the end-of-life stage, why significantly less works can be found that model and quantify the impacts and potential benefits of battery recycling. Apart from that, data on recycling processes are scarce and available only generically (not considering specific battery types) while the recoverable metals and thus the recycling efficiency depends strongly on the actual battery chemistry. Based on a review of existing studies on the environmental impacts of battery recycling, we model the currently existing recycling processes in detail and apply these to different battery types. In contrast to existing end-of-life studies that either focus on a single battery chemistry or assess a generic mix of waste batteries, this provides a more differentiated picture of the environmental impacts and benefits of recycling processes, considering the specific composition of each battery. Two conceptually very different technologies are assessed for this purpose, a lithium-ion battery (LIB) and a vanadium-redox-flow battery (VRFB) for stationary energy storage services (renewable support). Secondly, also the effect of different cathode chemistries is evaluated by comparing three different chemistries of comparable LIB cells, an LFP, and NMC and a NCA type. The results show that a high recyclability can improve the environmental performance of batteries over their life cycle significantly. For the stationary battery systems, the good recyclability of the VRFB can overcome the disadvantage of its lower efficiency and lower energy density, making it the better performing battery system for the chosen application. When looking at different LIB chemistries, a low recyclability of the LFP- type battery can be pointed out, where only a very small fraction of the materials is actually recovered. This reduces the environmental benefit of the recycling processes and increases the lifetime impacts relative to other LIB chemistries like NMC. Here, a re-processing and direct re-use of recovered active materials could increase the share of recycled materials and thus the benefit of battery recycling significantly. This underlines the need for a design for recyclability of batteries for minimising environmental impacts of battery systems and the corresponding loss of valuable resources.

Energy Efficiency in Battery Cell Manufacturing – An Energy Value Stream Approach

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Electric vehicles promise a mitigation of environmental impacts of the transportation sector by avoiding the production of tailpipe emissions. However, this technological shift in the transportation brings new environmental challenges. Especially, the production of the battery system potentially contributes to around 50% of the total cradle-to-gate environmental impacts of the production of an electric vehicle. In this regard, the energy required for the manufacturing of battery cells has been identified as one of the largest environmental and economic hotspots and thus requires further knowledge. The present work provides an analysis of the energy demand during the production of battery cells in the Battery LabFactory Braunschweig and identifies main energy consumers along the process chain. Different sets of process parameters have been investigated allowing to identify reduction potentials for selected processes.

Integrating Batteries in the Future Swiss Electricity Supply System A Consequential Environmental Assessment

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Stationary batteries are projected to play a role in the electricity system of Switzerland after 2030. By enabling the integration of surplus production from intermittent renewables, energy storage units displace electricity production from different sources and potentially create environmental benefits. Nevertheless, batteries can also cause substantial environmental impacts during their manufacturing process and through the extraction of raw materials. A prospective consequential life cycle assessment (LCA) of lithium metal polymer and lithium-ion stationary batteries is undertaken to quantify potential environmental benefits and drawbacks. Projections are integrated into the LCA model: Energy scenarios are used to obtain marginal electricity supply mixes, and projections about the battery performances and the recycling process are sourced from the literature. The roles of key parameters and methodological choices in the results are systematically investigated. The results demonstrate that the displacement of marginal electricity sources determines the environmental implications of using batteries. In the reference scenario representing current policy, the displaced electricity mix is dominated by natural gas combined cycle units. In this scenario, the use of batteries generates environmental benefits in 12 of the 16 impact categories assessed. Nevertheless, there is a significant reduction in achievable environmental benefits when batteries are integrated into the power supply system in a low-carbon scenario because the marginal electricity production, displaced using batteries, already has a reduced environmental impact. The direct impacts of batteries mainly originate from upstream manufacturing processes, which consume electricity and mining activities related to the extraction of materials such as copper and bauxite.

Uncertain Environmental Footprint of Current and Future Battery Electric Vehicles

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In this presentation we compare the environmental burdens of current and future passenger cars with different powertrain configurations, placing special focus on battery electric vehicles. The main novel component of this work is that we deeply integrate future electricity scenarios into the ecoinvent LCA database. We thus capture the effects of the "energy turnaround"

not only on the charging of future electric vehicles but also throughout the entire supply chain, most notably to produce future vehicles and batteries. The second novel aspect of this contribution is that we define all vehicle performance parameters using probability distributions and generate results using Monte Carlo analysis. This allows us to examine results using global sensitivity analysis techniques to determine the input parameters that contribute most to overall result variability.
We find that of all powertrain types, results for battery electric vehicles are most sensitive to changes in future electricity scenario, not only due to the electricity used to charge the vehicle, but also the electricity used in upstream processes, especially battery production which has large electricity consumption. For future "green" electricity scenarios the upstream burdens of producing battery electric vehicles are substantially decreased, leading to comparatively better performance relative to conventional vehicles. This indicates that inclusion of future electricity scenarios into background processes in the LCA database is necessary to accurately compare different future passenger car powertrain types. Uncertainty analysis shows that the environmental burdens of passenger cars are most sensitive to variability regarding vehicle mass and lifetime. Battery electric vehicle performance results are also quite sensitive to vehicle battery size and the carbon intensity of the electricity source used for battery charging.

Cell Production (II)

Automation with vacuum handling solutions along the value chain of cell and battery production

Dr. Harald Kuolt
J. Schmalz GmbH, Glatten

During this presentation it will be shown how vacuum handling technology can improve the value chain of cell and battery production.
In General, handling is not a value-adding process. But automated handling is necessary to cut costs during production.
The focus of this presentation is on handling of the sensitive, damageable cathode-, anode- and separator-parts. These must not be damaged or contaminated during the handling process and have to be placed very quickly and reliably with high precision on their target position to reduce cycle time. This is also important for all other production steps along the value chain as long as the battery is not yet completely built and placed in their casing. As long as it is necessary to handle pouch cells, for example, there is a risk that the characteristics of the cell could be influenced due to handling operations.
In the past months it was investigated, how (wrong) handling can harm the characteristics of batteries and their components und how handling components can be developed and designed, that there will be no risk of harming these parts by handling applications. This is important, because deforming or contamination of these battery components can lead to a performance drop of batteries and can furthermore be dangerous for the end-user of such batteries.
These results were actually used to design vacuum gripping components to handle parts and completely built Li-Ion-batteries, solid-state-batteries, redox-flow-batteries, fuel cells and other technologies. During this presentation, some solutions will be presented.

Challenges in conveying electrodes and new approaches to quality assurance

Benjamin Bold, M.Sc.; Hannes W. Weinmann, M.Sc.; Prof. Dr.-Ing. Jürgen Fleischer
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Electric mobility is gaining importance in Germany but high battery costs are still an obstacle. The production of battery cells amounts to a considerable share to the total costs and therefore efficiency must be further increased.
Within the battery cell production the electrode is processed continuously as an electrode web until stack formation. In the individual process steps the material is guided via deflection rollers, including various compensation systems, which are designed to eliminate unevenness in the web tension and to align the position of the web edge.
Such systems are mostly adapted from the paper or film processing industry. However, compared to paper or foil the electrode consists of a composite material consisting of active material and current collector. As a result, the electrode forms a system of complex properties since it consists of two materials with different mechanical properties.
The presentation thus gives an overview over available market solutions and sets out why an adaptation is not possible without further ado. It also presents the challenges that occur within the material transport of electrodes. These include the wrap angle, roller diameter and web tension applied. With regard to the material parameters, the distortion of the electrode and the formation of folds are described. Up to now, the electrode behavior has been evaluated qualitatively as there are no measurement methods available.
New approaches for optical methods are presented that enable a quantification of the electrode distortion within the electrode web. Three variants are described which show first promising results. By means of image processing and applied colored points their displacement is detected and thus how the electrode deforms in the process. Furthermore, another similar method is presented which works with a sprayed-on pattern and a software from the GOM GmbH for evaluation. Since these methods do not allow for an in-line quality evaluation a further variant is being considered in which the deformation of a laser pattern projected onto an electrode is assessed. Finally, a description of the material flexibility with respect to the measurement methods is given, as this will play an important role in the future.

Test methods in the production process of lithium-ion cells

Prof. Dr. Karl-Heinz Pettinger
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Lithium-ion cell production processes always have high vertical integration rates in spite of production technology developments. Crucial to the overall yield in the process is product control within the individual production stages, which have a multiplicative effect on the overall yield. In the talk will be presented and discussed test methods for control of the coating, the cell assembly, the electrical and electrochemical parameters, as well as the ripening storage and long-term quality control:

- incoming inspection
- tests during coating
- cell assembly tests
  - manufacture of the electrode body
  - checking the cell body for short circuits
  - control of the thickness of the cell body
  - positioning of the electrodes
- tests for electrolyte dosing
- formation, quality control
- final inspection after ripening
- restitution sample monitoring

The electrochemical functionality of the entire system and the interaction of anodes, cathodes, separators, electrolytes and housings cannot be tested until formation has been performed. Physical methods are used to estimate a best guess to the quality up to this point.
Formation isn´t more than a production step, it is the first quality control of the operating cell. The formation data can be used to obtain information on data sheet parameters, the spread of the process, its overall quality and slowly creeping process deviations or material deviations. Countermeasures can be initiated in good time to maintain overall quality by monitoring the data obtained during forming.
Final inspections prior to delivery and sample retention monitoring document essential data records for communication in customer contact.
The presentation (report) gives an overview of the measuring methods and explains the significance of the measurement data obtained for securing and increasing production yields.

Highly integrated machine module for single sheet stacking

Hannes W. Weinmann, M.Sc.; Prof. Dr.-Ing. Jürgen Fleischer
Karlsruhe Institute of Technology (KIT), Institute of Production Science (wbk)

The number of electrified vehicles and portable electronic devices announced by manufacturers is rising continuously. This inevitably leads to an increase in demand for battery cells, whereby the pouch cell is particularly well suited for some applications since it offers for example the advantage of higher format flexibility, due to the cell assembly from individual sheets, and the possibility to process thick-film electrodes.
The breakthrough of the pouch cell format is currently counteracted by the comparatively high production costs which are largely attributable to the time consuming process steps of separation and assembly. The general challenges in the production for pouch cells lie in the fast and damage-free separation and positioning of the individual sheets (anode, cathode, separator) relative to each other. Thick-film electrodes and increasingly thin separators place additional demands on the production process. Thick-film and heavily calendered electrodes for example exhibit higher rigidity, resulting in new challenges for material guidance, handling and separation.
According to the state of the art, electrodes and separators are often cut using lasers. This procedure favors the formation of particles which are difficult to remove from clean and dry rooms. After assembly, the individual sheets are oftentimes temporarily stored in magazines, whereby tolerances in the magazines lead to degrees of freedom and finally to a loss of the previously defined orientation and position. The contact between the magazine guide and the single sheet can also cause damage to the material, especially on the edges, just like those additional process steps for realignment and positioning of the single sheets on the cell stack.
The aim of the presentation is to present a systematic derivation of a new and efficient process for forming single sheet stacks considering process related requirements. In particular, feeding and alignment of the material web as well as the separation and positioning of the individual sheets on the cell stack will be addressed. The new process is to be implemented in a highly integrated machine module that incorporates the functions of separating, conveying and depositing for electrodes or separators and thus enables a significantly reduced number of process steps. Furthermore, magazines and subsequent alignment of the electrode or separator sheets prior to cell stacking can be dispensed with. The new module should also be explicitly suitable for processing thick-film electrodes and allow a variation of the individual sheet size in one dimension. The higher format flexibility and efficiency achieved by the new process should help to further strengthen the application fields of pouch cells and at the same time reduce production costs.

Innovative Cell Production Technologies

Challenges and bottlenecks in water processing of advanced Li-ion battery materials

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Water processing of electrodes will reduce the cost in the production of advanced lithium ion batteries and will lower the environmental impact of the electrode manufacturing step. However it is not always straightforward to prepare high quality, reliable electrodes out of the most promising new active materials. The following challenges have to be solved to succeed: (1) High capacitysilicon-containing anode aqueous processing to deliver electrodes capable to absorb variable particle size materials – new binders. (2) High voltage cathodes water processing: solution for high pH related issues, transition metal leaching from NMC and Ni-rich layered oxides and spinel type (LNMO) materials. Current R&D and selected results in these water-based electrode production achieved at CIDETEC will be presented.

Advanced battery electrode production for next-generation battery technologies: Solvent-free cathode processing and melt deposition of Lithium-metal anodes

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The next generation of lithium-based batteries involves materials with new requirements, e.g. on material processing or electrode layout. In our presentation we show two advanced next-generation electrode processing concepts: a solvent-free dryfilm approach for cathode production and a liquid lithium coating process for thin metallic lithium anodes.
Slurry-based cathode processing might not be applicable when active materials with sensitive surface chemistries are used. Moreover, slurry processing includes intensive drying steps leading to high investment and running costs. With the Fraunhofer IWS dryfilm process dry cathode manufacturing becomes possible with benefits for State of the Art lithium-ion cathode materials and next-generation technologies such as lithium-sulfur and all solid state batteries. In the presentation we show our approaches for dry electrode manufacturing from lab-scale sheet manufacturing to pilot powder-to-roll scale level. The process itself is based on dry fibrillized PTFE binder, which allows high-quality electrode processing with below 3% of binder content. Furthermore, the process involves calendering as a film-forming step. The influence of process parameters such as roll rotation velocity and nip pressure on electrode density, thickness etc. is discussed.
On anode side metallic lithium films have been discussed for various next-generation lithium battery technology concepts. Especially when it comes to technologies aiming for high volumetric energy density thin lithium films between 2 and 20 µm are of interest. However, existing rolling technologies for lithium-metal foils do not provide the desired lithium thickness, homogeneity and purity. In the presentation we will introduce the Fraunhofer IWS melt deposition process for defined thin lithium deposition, e.g. on thin copper foils. The importance of lithiophilic substrate surface functionalization for lithium melt wetting and liquid coating is discussed. Double sided coatings with film thicknesses of 5 – 20 µm can be realized on 6 µm copper foils, so far with high lithium utilization.
In summary, two innovative processes are presented showing high potential for next-generation lithium battery electrode production.

Battery Safety

Safety of lithium ion batteries – Between myth and reality

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Technische Hochschule Ingolstadt, CARISSMA, Technologiefeld Sichere Elektromobilität

Efficient and safe electrochemical storage systems are of central importance for a successful energy transition and electromobility. However, the ever-increasing energy densities of the systems pose risks in production, storage and operation. Related incidents usually draw high public attention, which may be severed by incomplete knowledge among stakeholders.
Thus, select safety aspects of lithium ion batteries like the chemical safety or handling in case of failure will be discussed and evaluated.

Fire protection in handling lithium-ion batteries

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There is no question about the fact, that Lithium-ion batteries are the number one in mobile electrical energy storage systems. But their cell structure and high electrical energy density are a potential risk in terms of fire protection, especially when treated improperly or under inconvenient conditions. On the one hand, due to a volatile and highly flammable electrolyte, Lithium-ion batteries represent a substantial fire load. On the other hand, they are an ignition source considering their stored

electrical energy.
Since the inherent ignition source is often supplemented by combustible housings and/or locally surrounding fire loads, these batteries can be a trigger of fires. In consequence of this, large Lithium-ion batteries, such as those used in electric cars and stationary electric storage units, will play a special role. Once set on fire, they cannot simply be extinguished by oxygen deprivation.
Therefore, the prevention and the extinguishing of Lithium-ion battery fires set various demands on the involved actors.

Practical experience with triggering the thermal runaway of large Li-ion cells

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One of the main safety concerns during production and use of Li-ion batteries is to prevent conditions leading to a thermal runaway rection. In this presentation we will show, how much effort is needed to trigger a thermal runaway of a large automotive pouch cell: how the cell reacts to overcharge, inserting foreign materials, even heating of the whole cell and localized heating (hot-spot).
One of the lessons learned is that cells can be surprisingly resilient against hot spots and localized damage, as long as a hard internal short circuit is prevented. On the other hand, if the whole cell is heated above a certain temperature, then a thermal runaway is inavitable.

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