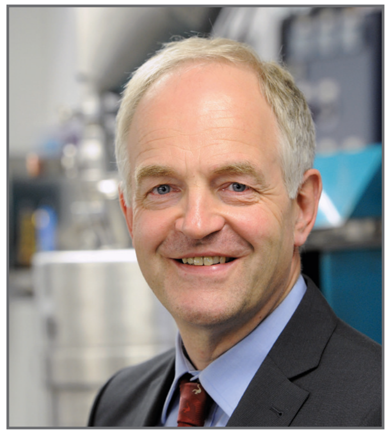
INTERNATIONAL BATTERY PRODUCTION CONFERENCE

5 to 6 November 2025

CONFERENCE BROCHURE

WELCOME



Dear IBPC 2025 participants,

Lithium- and recently also sodium-based batteries are key drivers of the global mobility revolution and the core of the energy transition. Their applications range from electric vehicles and renewable energy storage to portable electronics and industrial systems, making them a cornerstone technology across multiple sectors. In recent years, the battery industry has made major progress in production capacities, energy density, fast charging ability, cost reduction, and raw material efficiency. An end to this innovation pipeline is not yet in sight. Consequently, we are seeing rapid advances in new materials, production technologies, and cell and pack designs that must be scaled from lab to industrial production. At the same time, reducing energy consumption, raw material demand, and the overall carbon footprint across the value chain is becoming increasingly urgent. The new EU Battery Regulation strongly emphasizes circular economy principles, underlining the need for efficient recycling of both production scrap and end-of-life batteries to keep materials in use. In light of growing geopolitical challenges and rising demand, building a resilient European battery ecosystem is gaining momentum – as a key foundation for a sustainable, secure, and competitive energy future.

Thrilled with the success of the last seven IBPCs with each having around 260 participants and about 50 exciting presentations on recent advancements in circular battery production, we are delighted to welcome you to the IBPC 2025 in Braunschweig. We will provide a platform for industry and academics to discuss recent developments and research around circular battery production including recycling and circular economy, taking into account that battery research has an important place within the Hightech Agenda Germany. This year's plenary talks, presentations and poster sessions address innovative electrode and cell production processes of classical lithium-ion batteries (LIBs) as well as of next-generation and solid-state batteries, cell design and safety, cell performance and diagnostics, formation and aging, sustainable and scalable production, circular economy, recycling processes and battery factory design with associated supply chains. Regarding cell production, this year's programme places a special emphasis on dry coating topics as well as next-generation batteries, as these are becoming increasingly important in the industry and require innovative solutions.

We are delighted to welcome speakers and their presentations that deal with the entire battery value chain up to battery recycling, and are looking forward to their contribution to the battery production community. We are particularly thankful for the support of our partners, especially VDMA Battery Production. A special thank goes to our gold sponsors BioLogic Science Instruments GmbH, Bühler AG, Coperion GmbH, Maschinenfabrik Gustav Eirich GmbH & Co KG, Netzsch Feinmahltechnik GmbH, NETZSCH-Gerätebau GmbH, NETZSCH Pumpen & Systeme GmbH, Volkswagen AG, Retsch GmbH, FOM Technologies and our silver sponsors Bühler Group, Carl Zeiss Microscopy Deutschland GmbH, Horiba Europe GmbH, No Canary GmbH, Stat Peel AG, Sympatec GmbH, Rheonics, WATTICAL Energon Tech GmbH, Zeppelin Systems GmbH. Their support enables us to maintain the high quality of the conference.

We warmly welcome you and wish you a pleasant stay in Braunschweig with many interesting talks and exciting discussions

Prof. Dr.-Ing. Christoph Herrmann & Prof. Dr.-Ing. Arno Kwade

BATTERY LABFACTORY

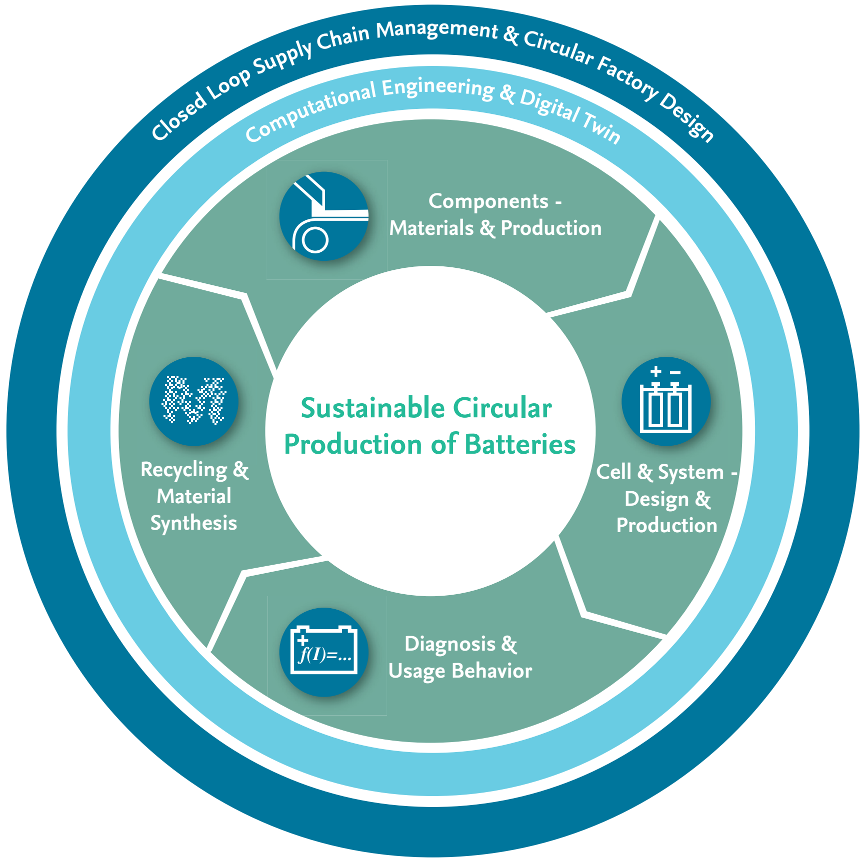
BLB+ is a regional alliance of research institutions in the Braunschweig area, uniting expertise from Technische Universität Braunschweig and local Fraunhofer partners, including the Fraunhofer Institute for Surface Engineering and Thin Films (IST) and the Fraunhofer Center for Energy Storage and Systems (ZESS). It serves as a collaborative platform to coordinate battery research, enhance visibility, and drive innovation in energy storage technologies.

Within BLB+, the Battery LabFactory Braunschweig (BLB) builds on over a decade of battery research in the region, focusing on the entire value chain- from material development and cell production to recycling and active material resynthesis from recycled raw materials. It provides a state-of-the-art environment for R&D on electrochemical storage devices, spanning laboratory to pilot plant scales. BLB's mission is to advance sustainable and circular battery cell production.

BLB+ partners collectively offer infrastructure to develop and characterize large-sized batteries, modules, and packs. This supports both fundamental and application-oriented research. Over the coming years, more than €100M will be invested in cutting-edge infrastructure across the BLB+ network, enabling exploration of advanced lithium-ion and solid-state batteries, fuel cells, and energy converters.

BLB+ Braunschweig Labfactories for Batteries and more

Sustainable circular production of battery cells



CONTENT

PARTNERS

BioLogic designs, manufactures and markets ultra-precise and ultra-accurate measurement instruments and their control and analysis software, in particular for the battery industry.

A product portfolio of potentiostat-galvanostats, battery cyclers and impedance analyzers satisfies the needs of industrial R&D in new energy storage technologies, fuel cells, photovoltaics, corrosion and biosensors.

Our user-friendly instruments and dedicated software have been developed in partnership with the scientists and R&D laboratories that develop and test batteries worldwide.

www.biologic.net

Every day, billions of people come into contact with Bühler solutions to cover their basic needs for food and mobility and more. Our technologies are in your smartphone, solar panels, diapers, lipstick, banknotes, the foods you eat, and the vehicles you drive. Bühler offers a wide range of solutions for the crucial process steps in LIB cell production. As a global leader in wet grinding and dispersing technologies, Bühler provides reliable, scalable and industry-proven solutions for wet grinding of active materials and precursors as well as continuous mixing of electrode slurries for lab, pilot and large-scale production.

www.buhlergroup.com

About Coperion

Coperion is a global industry and technology leader in compounding and extrusion systems, sorting, size reduction and washing systems, feeding systems, bulk material handling and services. Coperion develops, produces, and services plants, machinery, and components for various industries and employs 5,000 people in its three divisions and in its 50 sales and service companies worldwide.

Coperion supports Li-ion battery manufacturers in cost-effectively producing high-quality batteries. Our extensive range of proven first-class technology and products, spanning from single components to complete systems, coupled with expertise in designing individual machines and years of process experience, are the key factors contributing to the successful planning and building of systems in various areas of battery manufacturing.

www.coperion.com/batteries

Whether you manufacture lithium/sodium ion batteries for electric vehicles or develop electrical energy storage systems, Eirich offers you solutions for the entire mixing process in electrode production. Due to their unique functional principle, Eirich mixers have been successfully used along the entire production chain for electrical energy storage systems for decades. Mixer are installed for preparation of anode and cathode raw materials, the production of coating slurries for electrodes and separators, semi-dry, paste-like mixes to powdered and structured dry mixes for dry electrode production (DBE). With a network of competent partners, we also supply turnkey systems from raw material preparation to the interface in electrode production. As a technology partner with proven material and process expertise for the battery cells of today and tomorrow and many years of experience in laboratory and production applications, you can trust us. Challenge us- we will be happy to help you design your manufacturing process optimally.

www.eirich.com

Founded as a spin-off from Risø/DTU (Danish Technical University) in 2012, FOM Technologies has developed into a leading supplier of lab- and pilot-scale slot-die coating solutions for thin film materials research. We provide precise, flexible, user-friendly equipment to the world's finest companies and universities to advance their research efforts. We work closely with our clients and suppliers to deliver high quality, cutting-edge solutions to coat smart materials for the future.

FOM has continuously expanded, including the creation of FOM Technologies Inc. in Seattle to extend our US reach (2020) and FOM Technologies AB in Sweden (2024). FOM Technologies is a publicly traded company, listed on the NASDAQ First North Growth Market since June 2020 (ticker: FOM), backed by leading institutional investors.

www.fomtechnologies.com

HORIBA is a global leader in the development and manufacture of analytical measuring instruments for materials science and life science, supporting research, laboratory analysis, and quality control. For battery production, HORIBA offers specialized equipment such as particle analyzers for slurry characterization, Raman and XRF spectrometers for electrode material analysis, and fluorescence systems for electrolyte studies. Our technologies span particle size distribution from nanometers to millimeters using laser diffraction, dynamic light scattering, and nanotracking. Additionally, HORIBA provides high-performance optical components like monochromators and detectors, also available for OEM integration.

www.horiba.com/int/

PARTNERS

Werner Mathis AG, a known player in the Battery sector, designs and manufactures R&D and Pilot Scale coating and drying machinery in Switzerland. Our special designed coating head offers a variety of coating technologies, such as slot die and knife coating, movable cart includes vessel, filters, pump, and control system. Coat weight measurement, surface inspection, laser marking, thickness measurement, OPC UA and data management. Mathis dryer includes other technologies which can be combined allowing energy efficiency, different atmospheres as argon, dry air, LEL control, microenvironment available. Mathis offers solvent recovery system technologies, regenerative thermal oxidation (RTO) and catalytic oxidation system (CT).

www.mathisag.com

NETZSCH Technology is a world leader in the field of thermal characterization of almost all materials. We offer complete solutions for thermal analysis, calorimetry (adiabatic and reaction calorimetry), the determinaton of thermophysical properties, rheology and fire testing.

www.grinding.netzsch.com

No Canary offers highly efficient and particularly clean and safe, plug-and-play recycling systems for lithium-ion batteries.

Our engineers have gained the most valuable experiences in developing and realizing battery recycling processes since 2008 in R&D projects, building and running recycling and discharging lines. This is why we are technology leader in battery-to-black mass technology.

We are supplying our customers with:

- Battery Deactivation by Zero-Volt-Discharging Lines and Equipment
- Battery-to-Black-Mass-Lines
- Pre-Modules (a Modular Crushing and Drying-Solution)
- Vacuum Crushers and Vacuum Intensive Dryers
- Battery Desagglomerator Lines for Electrodes, Production Scrap and Direct Recycling
- R&D Lines for Battery Recycling

Over 100 tons of batteries are deactivated every workday with our technology and all our lines – not only the R&D Lines) – produce a lot of very valuable data for our customers to develop and improve recycling processes.

www.nocanary.com/

True to the guiding principle "Enabling Progress", VERDER SCIENTIFIC sets standards in high-tech equipment for solid matter quality control and continuously improves battery technology for a more efficient use of resources and securing maximum sustainability.

The well-known scientific companies under the umbrella of VERDER SCIENTIFIC offer sophisticated and reliable products, providing one-stop solutions in various applications. RETSCH, one scientific manufacturer, is the leading provider for neutral-to-analysis sample preparation and characterization of solids. Having a century of experience under its belt, RETSCH offers equipment with unparalleled performance, operating convenience, safety, and longevity.

www.retsch.com

At Rheonics, we're bringing a new level of precision and reliability to battery manufacturing. Our inline sensor technology measures viscosity and density in real time, giving producers a clear view of what's happening inside their process. They are developed specifically for repeatable and reproducible measurements of non-Newtonian fluids like battery slurry.

In electrode production, even small variations can affect quality. By continuously monitoring slurry properties during mixing, storage, and coating, our sensors help keep formulations stable and coatings uniform. This leads to less waste, higher yields, and batteries that perform as expected.

We design our sensors to be robust, compact, and easy to integrate into existing lines. They can handle demanding environments with minimal maintenance and no frequent recalibration, making it simple for manufacturers to scale up production while improving consistency and efficiency.

Swiss engineering and a focus on precision are what make Rheonics solutions a trusted choice for advanced battery production.

www.rheonics.com

Stat Peel is a Swiss manufacturer of advanced analytical instruments designed to inspect particles in laboratory and production environments. The first Identifier system was developed to detect and quantify airborne CNTs among other carbon particles. Our fully automated Raman-spectroscopy based detection system can quantify a wide range of materials. With different system configurations you can:

•Monitor aerosol particles using wearable air sampling badges to detect cross-contamination and protect the health and safety of workers. You can quantify different nanofibers such as CNTs, or other harmful materials, among the many other aerosol particles in your lab and production environment.

•Inspect particles in liquids to quantify materials of concern in process- and wastewater.

•Use swabs to inspect potentially contaminated surfaces.

•Inspect powders and coated foils to perform quality control tasks.

With Stat Peel's high-sensitivity Raman systems you can monitor particles in the air, liquids, powders and on coated foils for contamination, health & safety and quality control tasks. Use our sampling kit to test the capabilities of the Identifier.

www.statpeel.com

PARTNERS

Sympatec GmbH
System | Partikel | Technik

Sympatec develops, manufactures, sells, services and supports an innovative range of best instruments for particle size and shape analysis in laboratory and process for customers worldwide.

With continuous innovations in the technological fields of laser diffraction, dynamic image analysis, ultrasonic extinction and photon cross-correlation spectroscopy (PCCS), Sympatec makes a prominent contribution to the development, production and quality control of most challenging particulate systems.

Typical applications cover dry powders and granules, fibres, suspensions, emulsions, gels, sprays and inhalants within a size range from 0.5 nm to 34,000 µm. Modular instruments show great versatility and can be adapted to the specific task within your laboratory. The proven measurement technologies are also available for integration into your process. Moreover, all instruments reliably deliver most accurate, reproducible and comparable results at shortest measuring times.

Sympatec – The Particle People.

www.sympatec.com

Battery Production

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 machinery, 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.

www.vdma.org/batterieproduktionsmittel

The world's changing – and we're changing with it. We're placing the focus on e-mobility, the digital transformation of our brand and smart mobility. But we want to be more than Europe's largest carmaker. We want to deliver the ideas and solutions for resource-friendly mobility and networked traffic systems in big cities and small towns all over the world.

The Volkswagen Passenger Cars brand is present in more than 150 markets throughout the world, produces at over 30 locations in 13 countries and delivered around 4.9 million vehicles in 2021. Around 184,000 people currently work at Volkswagen worldwide. And we want you to be one of them.

www.volkswagen-karriere.de/de.html

Wattical Energon Tech GmbH is a leading provider of advanced battery cycling and energy storage solutions, driving innovation and sustainability in the energy industry. With a strong focus on precision, adaptability and eco-friendly battery technology, we help clients meet the evolving demands of modern energy systems. Our battery cycling systems enable high-precision testing of individual battery cells, modules, pack or cluster, ensuring accurate performance evaluation, extended lifespan and compliance with industry standards. Backed by an international team with over 25 years of expertise, we also provide comprehensive battery testing laboratory setup services and advanced turn-key solutions for global battery manufacturers, research institutions, OEMs, and system integrators.

www.wattical.com

Seeing beyond

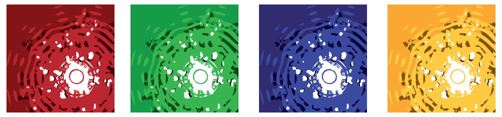
ZEISS Microscopy is the world's only one-stop manufacturer of light, electron, X-ray and ion microscope systems and offers solutions for correlative microscopy. The portfolio comprises of products and services for life sciences, materials and industrial research, as well as education and clinical practice.

With its unique portfolio, constant innovations and strong partnerships, ZEISS Microscopy enables leading researchers to find answers to our society's most pressing challenges and drive scientific discovery forward. A dedicated and well-trained sales force and a responsive service team enable customers to use their ZEISS microscopes to their full potential.

www.zeiss.com

Zeppelin Systems specializes in the design, construction, and technological modernization of industrial plants for storing, conveying, mixing, dosing, and weighing high-quality bulk and raw materials. With around 1,800 employees worldwide, the company delivers tailored solutions for customers in the plastics, chemicals, rubber, and tire industries. Customers in the food industry also benefit from Zeppelin Systems' decades of technological expertise and experience in providing turnkey solutions. From plant design and project execution to after-sales service and process optimization, Zeppelin Systems offers integrated solutions from a single source. As an international plant engineering specialist, Zeppelin Systems understands the specific requirements of battery mass production — whether wet or dry. The FM high-intensity mixer ensures precise and efficient production by providing reliable raw material handling, accurate premixing, and optimal active material distribution for superior battery mass quality. We Create Solutions — every day.

www.zeppelin-systems.com



VDMA
Battery Production

VDMA Battery Production

The VDMA department is the network of European battery production innovators. We provide direct contact for all questions relating to machine and plant construction. The member companies of the department supply machinery, plants, machine components, tools and services for the entire process chain of battery production – from raw material preparation, electrode and cell production, through module and packaging assembly, all the way to battery recycling. The current focus of VDMA Battery Production is on Li-ion technology. Our activities:

- We research **technology and market information**: Roadmap Battery Production Equipment 2030, process brochures, business climate survey.
- We operate the **Online Industry Guide**, where you can find the expertise of our members in the field of battery production: https://vdma-industryguide.com/
- We supervise fairs (CIBF, Battery Show) and hold our own events, such as the **VDMA Battery Production Annual Conference**.
- We are in dialogue with research and science on **joint industrial research** and we have a cooperation with the Fraunhofer Research Institution for Battery Cell Production FFB.
- We **advocate for our industry** in political and public spheres, supported by representatives in key locations such as Berlin and Brussels.

If you have any questions, please feel free to contact us.

Website: https://vdma.eu/en-GB/battery-production-equipment

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PROGRAMME

CONFERENCE DAY 1 | Nov. 5th

8:00 I Arrival of Attendees

9:00 I Welcome by the Conference Chairs

9:20 I Morning adress by Dr. Stefan Jung (BMFTR)

9:40 I Keynote by Prof. Dr.-Ing. Arno Kwade and Prof. Dr.-Ing. Sabrina Zellmer (BLB+)
"Learnings from the Lithium-Ion Battery Value Chain for the Circular Production of Solid-State Batteries"

10:25 I **Parallel Sessions**

Dry Coating 1: Advanced Processing Strategies
Room Maschinenhalle I Chair: Rüdiger Daub

Advances in continuous extrusion-mixing of dry electrode masses – how to tackle the challenges with LFP-based formulations
Adrian Spillmann, Bühler AG

Process Interactions in Dry Coating: From Mixing Mode to Line Load Requirements
Julius Gerk, Franziska Beverborg, TU Braunschweig I iPAT

DRYtraec® Process: Shear-Based Dry Electrode Manufacturing for LIB and Next-Gen. Battery Technologies
Arthur Dupuy, Fraunhofer IWS

Novel Materials
Room Nimes I Chair: René Wilhelm

Investigations of organic coverage (OC) design on lithium-ion battery and the beyond
Fu Ming Wang, National Taiwan University of Science and Technology

Upscaling Aqueous Generation 3b Battery Chemistry
Frode Fagerli, SINTEF AS

Multifunctional structural battery composites: Production and characterisation of fiber-reinforced cathodes and separators
Daniel Vogt, TU Braunschweig I iPAT

11:10 I Discussion

11:25 I Poster Session & Break

11:55 I **Parallel Sessions**

European Battery Supply Chain Challenges
Room Maschinenhalle I Chair: Thomas Spengler

The Tipping Point: Why Europe's Battery Ambitions Are at Risk—and How to Save Them
Joscha Schnell, P3 automotive GmbH

Team Design & Manufacturing- How DfM can improve the current situation of EU cell production?
Luke Hu, Electroder

Cathode Materials Pilot-Plant "Powder-Up!! in Operation First Experiences with Scaling
Peter Axmann, ZSW

Modelling & Investigation of Battery Safety
Room Nimes I Chair: Thomas Turek

Explainable Deep Learning Enables Accurate Battery Cycle Life Predictions
Hamidreza Eivazi Kourabbaslou, TU Clausthal

Metrology and Safety for Batteries at Physikalisch-Technische Bundesanstalt (PTB)
Fabian Plag, PTB

Scaling of Cathode Paste Dispersion Processes in Small-Scale Applications Using Stress-Based Principles
Tim Grenda, TU Braunschweig I iPAT

12:40 I Discussion

12:55 I Lunch Break

14:00 I Keynote by Dr.-Ing. Hannes Wolf, BASF
"New Cathode Material Solutions for Lithium Ion and Sodium Ion Batteries – Challenges for Production or Opportunities for Lowering Cost?"

14:30 I Keynote by Dr. Misae Otoyama, AIST
"Visualization of Reactions in Sulfide All-Solid-State Lithium Batteries"

15:00 I Break

15:15 I **Parallel Sessions**

Manufacturing & Processing of Solid State Electrolytes / Batteries
Room Maschinenhalle I Chair: Holger Althues

Impact of extrusion parameters on polymer and composite electrolyte membranes via melt-processing
Dane Sotta, University Grenoble Alpes & CEA-Liten

Manufacturing of polymer-based solid state battery electrolytes and electrodes via spray coating
Jonas Morgenstern, Fraunhofer ICT

Mixing Composite Cathodes for Solid-State Batteries: The Key to Reliable High Performance
Maximilian Kissel, University of Giessen

Coating and Drying of Battery Electrodes
Room Nimes I Chair: Georg Garnweitner

About Humidity Management and Post Drying for different Battery Electrode Materials: Sorption and Kinetics
Philipp Barbig, KIT

Slot die designs – comparison fix lips vs. flex lips / T-Bar
Harald Doell, TSE Troller AG

IR-assisted vacuum drying to remove water from Prussian Blue cathodes in sodium-ion batteries.
Thorsten Mally, Excelitas Noblelight

16:00 I Discussion

16:15 I Poster Session & Break

16:45 I **Parallel Sessions**

Battery Recycling & Repurposing, Material Recovery
Room Maschinenhalle I Chair: Bengi Yagmurlu

Influence of the drying temperature on the recovery of electrolyte components in battery recycling
Jannik Born, TU Braunschweig I iPAT

Challenges of Using Recycled Ethyl Methyl Carbonate in Lithium-Ion Batteries
Valerie Mohni, TU Braunschweig I InES

Process failure mode- product failure mechanism-effect analysis ((PFM)²EA): A novel risk assessment methodology for automated battery disassembly-Integrating process and product safety in repurposing
Stefan Grollitsch, Graz University of Technology

Battery Cell Inspection and Monitoring
Room Nimes I Chair: Carsten Schilde

Monitoring exposure to airborne particulates along the value chain of Li-ion batteries
Kevin Sparwasser, Stat Peel AG

Non-Destructive Characterization of Projection Welding for Battery Cell Interconnection with Scanning Acoustic Microscopy and X-Ray Computer Tomography
Felix Thurn, Fraunhofer ISE

From molecule to module – the Lund University ecosystem for battery safety characterization and fire hazard assessment
Elna Heimdal Nilsson, LTH, Lund University

PROGRAMME

17:30 I Discussion

17:45 I Break

18:00 I Conversion for Dinner

Industriesession I

Room Nimes I Chair: Arno Kwade

From Battery to Black Mass: Practical Insights to LabScale Milling and Sieving
Dr. Lena Weigold, Retsch

Giga-Odenwald 2.0 – a modularized, standardized, and scalable mixing plant on a gigafactory scale
Dr. Stefan Gerl, Eirich

XRF-Based Quality Classification of Lithium-Ion Battery Black Mass
Jana Kalbáčová, HORIBA Jobin Yvon GmbH

Continuous Mixing of Electrode Masses by Extrusion- On the Way to Dry Electrodes
Markus Lehmann, Coperion

Trajectory Mixing for Wet and Dry Electrode Processing – Opportunities and Challenges in Battery Slurry Production
Andreas Leitze, Tumbler

19:05 I Break and Reception

19:45 I Gala Dinner

PROGRAMME

CONFERENCE DAY 2 | Nov. 6th

8:30 I Keynote by Prof. Dr. Jürgen Janek, Center for Materials Research, Justus Liebig University Giessen
"Optimizing Cathode Composites for Solid-State Batteries"

9:00 I Keynote by Dr.-Ing. Jochen Eser & Nils Barenthin, VARTA Microbattery GmbH
"Experiences and challenges in scaling new technologies into mass production"

9:30 I Poster Session & Break

10:00 I **Parallel Sessions**

Dry Coating 2: Novel Binder Systems
Room Maschinenhalle I Chair: Klaus Dilger

Investigating the mechanical and electrochemical performance of polymer binder composites for fibrillated free-standing dry electrode films
Rajasekar Krishnamoorthy, University of Sheffield

Toward PFAS-Free Lithium-Ion Batteries: Fluorine-Free Binders and Scalable Dry Coating Technologies
Minwon Suh, CNP Solutions

Dry Electrode Processing for Sodium-Ion Batteries: Transition from PFAS-Based to PFAS-Free Binders
Oliver Fitz, Fraunhofer ISE

Modelling Battery Production & Processing
Room Nimes I Chair: Sebastian Thiede

Model-Based Assessment of Energy and Material Efficiency for Sustainable Battery Cell Production
Gabriela Ventura Silva, TU Braunschweig I IWF

Model-based prediction of SEI growth and formation metrics for a knowledge-based process design
Felix Schomburg, Bavarian Center for Battery Technology

Cell and system level models integration in battery cell formation
Cihan Yurtsever, Comau SpA

10:45 I Discussion

11:00 I Break

11:15 I **Parallel Sessions**

Advanced Production of Conventional and Novel Batteries
Room Maschinenhalle I Chair: Peter Axmann

Particle-based magnetic additives as information providers in lithium-ion cells
Jakob Endres, Fraunhofer ISC

Dry electrode processing of electrodes and recent advancements in multi-layer pouch cell development of sodium ion batteries
Tom Boenke, Fraunhofer IWS

Advancing Sulfur–Carbon Composite Production: Industrial and Lab-Scale Infiltration Techniques for Metal–Sulfur Batteries
Marina Schwan, German Aerospace Center (DLR)

Dry Coating 3: Characterization & Innovative Approaches
Room Nimes I Chair: Sabrina Zellmer

Multi-Technique Characterization of PTFE-Containing Dry Electrode Mixtures for Lithium-Ion Battery Applications
Tamara Ebner, Anton Paar GmbH

Investigation of PTFE fibrillation in continuous twin-screw dry processing of graphite anodes
Annika Völp, Thermo Fisher Scientific

Effect of Dry Surfactant-Modified Carbon Additives on the Electrical Conductivity and Powder Flow Behavior of Dry Battery Electrode Mix
Rajasekar Krishnamoorthy, University of Sheffield

12:00 I Discussion

12:15 I Lunch Break

13:15 I Panel Discussion "Circular Battery Production" by Dr. Tobias Elwert (cylib), Dr. André Mecklenburg (PowerCo), Dr. Katja Kretschmer (IBU-tec), Christian Hanisch (No Canary) moderated by Prof. Dr. Thomas S. Spengler (BLB+)

14:00 I **Parallel Sessions**

Industry Session II
Room Maschinenhalle I Chair: Michael Kurrat

Smart Mixing for Battery Slurries: NETZSCH Planetary System with Real-Time Absolute Viscosity Analysis
Maximilian Münzner-Schmiedel, Netzsch

Introducing the Center of Excellence Battery: Cell – and Battery Development for the Volkswagen-Group
Dominik Koll, Volkswagen AG

Measurement automation in battery research and production
Julian Diener, BioLogic

Dry Mixing and Post Processing for Reliable Dry Coating
Hans Schneider, Zeppelin

Enabling Battery Circularity
Room Nimes I Chair: Thomas Vietor

Fast and Safe Electrical Characterization for Second-Life Battery Modules Across Diverse Testing Conditions
Simeon Kremzow-Tennie Keysight Technologies Deutschland GmbH

Solving the environmental challenges of cathode active materials for Li-ion batteries – the CALISMAT process
Shun Takano, Proterial Ltd., Japan

Enabling circular battery manufacturing through digital technologies
Sebastian Thiede, University of Twente

14:45 I Discussion

15:00 I Poster Session & Break

15:30 I Poster Prizes

15:50 I Break

15:55 I **Parallel Sessions**

Next-gen Battery Production
Room Maschinenhalle I Chair: Sabrina Zellmer

Mechanofusion-derived cathode composite microstructures for solid-state batteries: A scalable mixed conducting matrix coating approach
Finn Frankenberg, TU Braunschweig I iPAT

Upscaling sulfide-based solid-state batteries
Sahin Cangaz, Fraunhofer IWS

Solvent-Free Processed Polymer Electrolyte for Li-Metal Batteries
Laida Otaegui, Centre for Cooperative Research on Alternative Energies CIC energiGUNE

Advanced Electrode & Cell Production
Room Nimes I Chair: Marcus Jahn

Polyvinylene carbonate in anodes as strategy to form a stable SEI in Lithium-Ion-Batteries
Nina Philipp, TU Braunschweig I iPAT

Continuous processing and characterization of Si anode and aqueous LFP cathode slurries via twin-screw extrusion
Kevin Raczka, Karlsruhe Institute of Technology (KIT)

Materials and Interfaces Design for Next-Generation Solid-state Na Batteries
Yang Zhao, University of Western Ontario, Canada

16:40 I Discussion

16:55 I Goodbye speech

18:00 I Exhibition of EU-Projects

PRESENTATION ABSTRACTS

Dry Coating 1: Advanced Processing Strategies

Advances in continuous extrusion-mixing of dry electrode masses – how to tackle the challenges with LFP-based formulations

Adrian Spillmann
Bühler AG

Dry Battery Electrode (DBE) technology is emerging as a transformative solution in battery manufacturing by replacing traditional solvent-based processes with a more sustainable, cost-efficient approach. While DBE has demonstrated significant benefits at academic and small to pilot scales- such as reduction in production footprint and energy demand- the transition to industrial-scale application faces challenges in process scalability and optimization of process interfaces affecting battery performance. As industry expectations for DBE include substantial cost savings while maintaining or improving electrode quality, further research and development will be critical to fully realize its industrial potential.
The fully continuous extrusion-mixing technology effectively addresses these challenges. The fully continuous approach ensures high and consistent product quality, eliminating the risk of batch-to-batch variations. Scaling across different extruder sizes enables seamless translation of lab findings to production scale. The extruder's small mixing volume allows for precise control of shear forces and temperature along the entire mixing zone. The precise control of such process parameters enables efficient fine tuning of the PTFE structure and additive dispersion as well as macroscopic granular appearance of different dry-mixed electrode systems (Fig 1). Controlling and tuning these microscopic as well as macroscopic dry electrode mass characteristics is key in optimizing and scaling the DBE value chain from the initial raw materials to the final electrode.
This presentation will highlight the impact of various mixing conditions on the microscopic and macroscopic characteristics of dry LFP-based electrode masses and their implications for dry coating. Such insights are helpful in a holistic optimization of the mixing/calendaring interface and crucial in scaling the DBE process.

Process Interactions in Dry Coating: From Mixing Mode to Line Load Requirements

Julius Gerk, Franziska Beverborg,
TU Braunschweig I Institute for Particle Technology (iPAT)

Solvent-free dry coating offers significant potential to improve energy and resource efficiency in electrode manufacturing by eliminating the drying step, thereby also reducing the required production space. However, the material–process–structure–property relationships governing this technology are still not sufficiently understood, limiting the development of a knowledge-based manufacturing approach. The complex interdependencies between material selection, the mixing process (whether batch-based systems such as Zeppelin or Eirich mixers, or con-tinuous systems such as extruders), and film formation during calendering present substan-tial challenges. Different materials influence the dry mixing behavior, and the choice between batch and continuous processes results in powders with distinct characteristics that directly affect film formation during calendering. In this presentation, we address these interdependencies by systematically comparing batch and continuous dry mixing processes and investigating their effects on subsequent calender-ing, with particular emphasis on the required line load during film formation. Furthermore, we discuss scale-up strategies for both the dry mixing and calendering steps, presenting the lat-est findings from the dry coating research group at our institute.

DRYtraec® Process: Shear-Based Dry Electrode Manufacturing for LIB and Next-Gen. Battery Technologies

Arthur Dupuy
Fraunhofer Institute for Material and Beam Technology IWS

In the quest for advanced energy storage solutions, dry electrode manufacturing has emerged as a promising technology for lithium-ion and solid-state batteries[1]. This innovative approach addresses the environmental and economic drawbacks of traditional wet-chemical methods, which rely on toxic solvents and energy-intensive drying processes[2].
Thereby, dry electrode process offers several advantages such as reduced manufacturing costs[3], but also enhanced electrode porosity, improved mass transport properties and increased energy density[4]. However, this technology still faces significant limitation in scaling up production, ensuring defect-free manufacturing, and maintaining cost-effectiveness at industrial scales[5; 6].
DRYtraec® process, developed by Fraunhofer IWS, offers a versatile solution for producing electrodes across various battery chemistries and generations[7]. Through differential roll speed calendering, a broad range of shear modulus can be applied to any powder composite, allowing high quality electrodes production with comparable electrochemical properties to slurry methods. The versatility and scalability of DRYtraec® process position it as a promising solution for sustainable and efficient battery production across multiple industries.
This presentation will then discuss the principles behind the DRYtraec® process, its advantages over conventional methods, and its recent results in numerous battery technologies applications such as lithium-ion, lithium-sulfur, sodium-ion, and solid-state batteries.

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Novel Materials

Investigations of organic coverage (OC) design on lithium-ion battery and the beyond

Fu Ming Wang
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Ni-rich layered cathodes have a high practical capacity (>200 mAh·g−1) and tapped density (>3.6 mg·cm-2), thus attracting wide attention in large applications such as electric vehicles and energy storage. However, high surface reactivity of these cathodes promote the decomposition of carbonates solvents, which contributes to the growth of the cathode–electrolyte interphase (CEI) as well as rapid fading of the battery's capacity during long-term cycle. Carbonates are favorable for deprotonation reaction by the oxygen atom in the Ni-rich layered cathode and further in the formation of the CEI. In this study, the deprotonation mechanism of cyclic and linear carbonates on a Ni-rich layered cathode was thoroughly investigated using operando Fourier-transfer infrared spectroscopy, and the reasons for cathode fading could be confirmed in terms of the carbonate structures. In addition, a new maleimide oligomer was developed and covered on a Ni-rich layered cathode to inhibit the deprotonation of the carbonates. The maleimide oligomer acts as a cis isomerism that provides a bridge function for reacting with oxygen on the cathode surface by its cis formulation. Moreover, this bridge function will keep the carbonates away from the cathode surface for further decomposition during cycling. On the contrary, the battery performance exhibited a cycling ability at a high rate, and the new cis isomerism maleimide oligomer helped improve the rate capability. A full-cell (>3 Ah) test containing graphite as the anode with a cis formulation of the maleimide oligomer coverage was completed.

Upscaling Aqueous Generation 3b Battery Chemistry

Frode Fagerli
SINTEF AS

In a world with an ever-increasing demand for Li-ion batteries, there is a need for improvement in battery sustainability. Among various ways to address this, two key approaches involve changing the materials used and modifying the battery manufacturing process. In this work, we have addressed both by demonstrating industrial scale production of high-loading LNMO cathodes through aqueous processing. With its higher voltage, LNMO stands out as one of the main contenders to NMC for high-energy applications. This again comes without the use of Co and with less Ni and Li required for comparable capacity to NMC, making it a more sustainable choice than NMC-based cathodes. Together with the omission of NMP solvent, using instead aqueous binders, the production cost and energy requirement are also greatly reduced. In addition to various mass loadings, more than 100 m of double sided high-loading (4.0 mAh/cm2) LNMO cathodes have been successfully fabricated. The electrodes have been characterized for mechanical, morphological and electrical properties, and their electrochemical performance has been verified in various sized full cells. These cells have been tested and systematically compared with conventional NMP-based LNMO electrodes. Overall, the work presented demonstrates a leap towards commercialization of sustainable LNMO cathodes.

Multifunctional structural battery composites: Production and characterisation of fiber-reinforced cathodes and separators

Daniel Vogt
TU Braunschweig I Institute for Particle Technology (iPAT)

To achieve a significant reduction of greenhouse gas emissions until 2050, the development of full electric and hybrid electric propulsion technologies is crucial. Given the high energy demands of long-range flights, fully electric propulsion may not be feasible for long-haul air travel. However, for regional and short-range flights, as well as for transport drones, electric solutions present promising opportunities. Addressing the energy storage limitations in these applications requires reducing parasitic mass and volume through the multifunctional design of energy storage components: So-called structural battery composites can store electrical energy while bearing mechanical loads.
In this study, the electrical energy storage is enabled in fiber-reinforced composites commonly used for load-bearing parts in aircraft design by substituting the epoxy resin with the materials of an all-solid-state battery. The research focuses on the production and characterization of carbon fiber-based structural electrodes and glass fiber-based structural separators. To produce structural cathodes, a slurry composed of LFP, PEO, LiTFSI and carbon black was coated on carbon fiber textiles. The impact of the fibre reinforcement on the ionic conductivity of structural separators prepared by melt infiltration of glass fiber textiles with a PEO- and LiTFSI-based electrolyte was investigated by EIS measurements. Specific capacities over 110 mAh/g demonstrate good utilisation of the active material in cells with structural cathode and separator. At low areal loadings of 1.2 mAh/cm^2, an excellent capacity retention of 94 % was achieved after 100 cycles at 0.1C. The areal loading could be increased up to 2.6 mAh/cm^2 without a significant decrease of the active material utilisation, however, the capacity fading increased. Based on stack level a maximum specific power of 96 W/kg and specific energy of 65 Wh/kg were achieved.

European Battery Supply Chain Challenges

The Tipping Point: Why Europe's Battery Ambitions Are at Risk—and How to Save Them

Joscha Schnell
P3 automotive GmbH

Europe's battery industry is facing a severe crisis. Despite years of strategic initiatives and investment, the sector struggles with high scrap rates, frequent production stoppages, and a slow manufacturing ramp-up. These inefficiencies drive up costs and hinder competitiveness, particularly against more mature ecosystems in Asia. At the same time, the slower-than-expected growth of e-mobility has led to underutilized production capacities and delayed market demand. This mismatch between supply readiness and actual uptake creates strategic uncertainty for manufacturers and suppliers alike. Political headwinds in the US and the weakening of EU vehicle emissions targets risk undermining long-term planning and public trust in the transition to electromobility. As a result, investor confidence is waning. Capital is becoming scarce, and several European cell producers face serious liquidity challenges. The sector risks fragmentation just as it needs scale and stability.
This presentation provides a critical overview of these challenges and proposes actionable solutions: improving manufacturing efficiency through automation and digital tools, building up resilient supply chains to ensure geopolitical independence, aligning capacity planning with realistic EV market scenarios, securing long-term policy frameworks, and introducing targeted financial instruments to stabilize strategic players. Without coordinated, bold action, Europe risks losing its technological and industrial foothold. But with the right mix of policy, investment, and innovation, the battery industry can still become a pillar of European sovereignty and sustainability.

Team Design & Manufacturing - How DfM can improve the current situation of EU cell production?

Luke Hu
Electroder

European battery cell production faces considerable challenges, including cost pressures, equipment complexities, and difficult ramping up to target yield. A significant improvement can be achieved by integrating Design for Manufacturing (DfM) methodologies, ensuring that design and manufacturing teams collaborate closely from the earliest development phases.
By applying DfM principles, cell designs can directly address manufacturing constraints, significantly increasing production success rates and mitigating risks related to equipment ordering, machine design, and operational implementation. Moreover, involving manufacturing considerations at the design stage fosters early customer acceptance by aligning final products closely with market requirements and practical feasibility.
To achieve manufacturing excellence, line building processes must rigorously follow validated procedures, informed by real-world best practices. This session will share key insights and actionable strategies derived from recent successful European projects. Particular attention will be given to best practices in effectively collaborating with Chinese equipment and material suppliers, offering practical guidance to bridge cultural, technical, and operational differences.
This presentation is particularly beneficial for professionals in battery cell design, manufacturing, supply chain management, and business development, providing valuable insights on enhancing collaboration, reducing production risks, and elevating overall competitiveness of EU battery cell production.

Cathode Materials Pilot-Plant “Powder-Up!! in Operation First Experiences with Scaling

Peter Axmann
Center for Solar Energy and Hydrogen Research Baden Württemberg (ZSW)

The global demand for batteries is dynamically increasing, driven by the imperative to electrify vehicles and to store renewable energy in order to reduce CO2 emissions. Cathode materials are the dominant component of a Lithium Ion Battery (LIB). They determine key battery parameters such as energy content or battery safety and contribute with more than 50% to the overall material cost of LIB cells. New, high-performance, cost-efficient and sustainable materials are needed. The current speed of materials development and its transfer into industrial application is however limited due to a scaling-gap between laboratory- and technical-scale research that often causes a stop in the industrialization of new materials. New developments from research institutes are usually available only on a gram scale – insufficient for technical research or real-size battery cells or to answer production related questions which can only be addressed with morphologically optimized materials on a scale of several kg. This especially affects the supply of existing pilot plants for battery cell production, e. g. the FPL at the ZSW, or the FFB. Therefore, closing this material scaling-gap is an absolutely necessary prerequisite to establish an internationally competitive battery industry research and production environment in Germany and Europe. After a three-year design and construction period, ZSW has successfully started this year the operation of its new synthesis pilot-plant in Ulm called “Powder-Up!“, a modern and efficient technical center for the synthesis and upscaling of cathode materials along the 1 kg- 10 kg- up to 100 kg scale. Tailor-made powders can now be provided on a pilot-scale to research partners and industrial partners for cell development. The presentation will provide an overview about the concept and individual process steps and will also showcase available equipment ready for the scale-up of new materials. The integration of Powder-Up! in the BMBF Umbrella Concept Battery Research will be shown. Finally, results and challenges from first scaling experiments will be presented and discussed. Special focus will be on the transferability of new materials from lab-scale into technical scale. Powder-up! is supported by the BMFTR under the Umbrella Concept Battery Research, Funding Programme ForBatt (03XP0448), and by the Ministry of Economics of the State of Baden-Württemberg (WM3-4332-155/70).

Modelling & Investigation of Battery Safety

Explainable Deep Learning Enables Accurate Battery Cycle Life Predictions

Hamidreza Eivazi Kourabbaslou
Clausthal University of Technology

With climate change becoming an increasingly urgent issue, there is a growing interest in renewable technologies. Batteries have emerged as a cornerstone of modern innovation, with vast applications from electric vehicles to energy storage systems. Battery capacity degradation over time is a critical issue influenced by various mechanisms, including the formation of solid electrolyte interphase, electrolyte breakdown, and the growth of lithium plating. Although significant research efforts have been made, reliably forecasting the rate of capacity decline remains a challenging task. Recently, data-driven methods have gained research interest as an effective approach to modeling battery degradation [1]. However, deep-learning models, despite their complexity, often underperform compared to more traditional statistical methods and exhibit a lack of consistency in their performance [2]. In this work, we employ explainable artificial intelligence (XAI) to gain insights into model behavior, revealing distinct attention patterns that offer a deeper understanding of the prediction mechanisms. Through XAI, we identify three failure modes in which the deep-learning model fails to provide accurate and consistent predictions of the remaining useful life (RUL). To address these issues, we propose targeted remedies and incorporate attention mechanisms into the model architecture, enabling accurate RUL predictions.

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Metrology and Safety for Batteries at Physikalisch-Technische Bundesanstalt (PTB)

Fabian Plag
Physikalisch-Technische Bundesanstalt (PTB)

The PTB is Germany's national metrology institute, providing internationally recognised calibration and measurement services. With its expertise, we support industry and society with accuracy and quality assurance in battery cell production by means of traceable, quantitative methods for characterising key performance and safety parameters across the battery lifecycle.
We use Electrochemical Impedance Spectroscopy for non-destructive evaluation of battery state-of- charge and state-of-health. This fast, and cost-effective method provides insights into internal battery processes in a non-invasive way. Under well-defined conditions, EIS delivers reproducible results with uncertainties as low as 1–3 %, making it a promising tool for quality assurance in production, workshops, and even in-vehicle diagnostics.
Additionally, we will show how magnetic field sensors—such as fluxgates and optically pumped magnetometers—enable spatially resolved imaging of current density during charging, discharging, and relaxation. This technique may allow to detect irregularities occurring during cell production. These measurements support the optimisation of cell design and performance.
We outline thermal investigations using calorimetry methods to determine heat generation, flux, capacity, and thermal behaviour of battery cells. In addition, we investigate the battery runaway and investigate its consequences. These results contribute to safety assessments and thermal management strategies.
We present quantitative and traceable operando X-ray spectrometry as a powerful tool to gain chemical insights into battery materials during operation. Using techniques such as X-ray fluorescence, we investigate changes in material composition and obtain time resolved information on relevant species while cycling the battery cells. We will show how this approach helps to understand ageing mechanisms and supports the development of more durable battery

Scaling of Cathode Paste Dispersion Processes in Small-Scale Applications Using Stress-Based Principles

Tim Grenda
TU Braunschweig I Institute for Particle Technology (iPAT)

Lithium-ion batteries are of critical importance in a variety of electrical devices and vehicles in the present day, with their use increasing rapidly, particularly in the context of electric vehicles. In order to further increase the range of electric cars, research is being intensified on batteries, with a particular focus on the formulation and processing of the electrodes. Given the scarcity of new active materials, it is imperative to optimize smaller batches with regard to suspension and electrode properties prior to their transfer to larger batches, thereby minimizing material wastage and improving quality and robustness of transfer to large scale. [1,2]
The slurry mixing process, particularly with regard to specific energy input and the intensity of stresses acting on the particles, exerts a significant influence on the effective dispersion of materials like carbon black (CB). Furthermore, the active stress volume in the dissolver plays a pivotal role, as it describes the stress frequency and thus exerts a significant influence on scaling. The specific energy inputs previously mentioned are calculated and introduced as scaling parameters for the process description. Finally, a characteristic property parameter of the suspension, such as the 'Dispersion Index of Carbon Black' (DICB) [3], is correlated with the specific energies applied at the various process parameters and batch sizes. The stress energy, stress intensity, and stress frequency are then used to derive a model-based correlation between active volume, batch size, and dissolver disk selection. Subsequently, the model parameter can be employed to predict a specific CB decomposition according to energy or torque control. The investigations are primarily conducted on the cathode side. The demonstration is made that the DI can be deployed as a characteristic variable, and that a scalable relationship between specific energy resp. stress intensity input, CB decomposition and active volume prevails.

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Manufacturing & Processing of Solid State Electrolytes / Batteries

Impact of extrusion parameters on polymer and composite electrolyte membranes via melt-processing

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To address the safety challenges induced by the ever-growing demand of mobile and stationary energy storage systems, numerous studies have been conducted on the development of solid polymer or composite electrolytes (SPE/SCE) to replace the flammable liquid electrolytes currently used in Li-ion batteries1. These studies focusing on many different systems (polymer matrix, lithium salt, additives) are predominantly carried out via liquid casting. However, this requires a huge quantity of solvent that must be removed during drying and retreated as effluent (48 % of the total energy consumption of a production plant2). Thus, twin-screw extrusion (TSE) has been identified as a promising process for "all-solid-state" batteries components manufacturing as it allows the elimination of dissolution, evaporation, and drying steps of standard wet processing methods. It is particularly adapted to highly filled mixtures such as SPE, SCE or composite electrodes and is already used by BlueSolutions company at industrial scale. However, TSE is a complex process with numerous adjustable parameters such as processing temperature, material flow rate, screw profiles and rotational speed. All these variables can dramatically influence the quality of the mixture and its performances. In this work, SPE and SCE mixtures consisting of polycaprolactone (PCL) polymer matrix3, LiTFSI salt and ZrO2 mechanical reinforcement, were chosen for their low cost and availability in high volume. Analysis was conducted on several formulations to identify and understand the impact of processing conditions on final components properties (salt dissociation, filler dispersion, ionic conductivity, etc.). 1D process modelling of TSE was also used to get better understanding of operational parameters (residence time, specific mechanical energy) as well as predict optimized formulations with minimal extrusion trials.

Manufacturing of polymer-based solid state battery electrolytes and electrodes via spray coating

Jonas Morgenstern
Fraunhofer Institute for Chemical Technology ICT

This presentation explores the manufacturing of polymer-based solid-state Battery (SSB) electrolytes and electrodes using a spray coating process, emphasizing its potential for large-scale production. The method´s flexibility in terms of slurry composition, substrate selection and template design enables the production of polymer SSB components with tailored properties such as precise thickness and high homogeneity. The spray coating technique facilitates the creation of self-standing polymer electrolytes and electrodes, which can also be directly layered to minimize interfacial resistance and improve component contact. A comparative analysis with the doctor blade technique is presented, highlighting differences in the manufacturing processes, investigating the process-property-relations and the characteristics of the resulting polymer SSB components. To characterize the components, various analytical methods are used, including light microscopy, confocal microscopy, and SEM for assessing thickness, surface properties, and uniformity. Electrochemical performance is evaluated through EIS, CV and capacitance measurements examining the influence of different manufacturing process parameters on cell performance and electrochemical properties. The results demonstrate that spray-coated polymer-based SSB components exhibit a homogeneous structure with adjustable thickness achieved by varying the number of layers applied or process parameters. In addition, the performance of the spray-coated electrolytes and electrodes is comparable to components produced via doctor blade technique. This study establishes spray coating as a versatile and scalable method for producing high-quality polymer-based SSB electrolytes and electrodes. The process offers significant flexibility in slurry composition, component geometry and thickness. Further optimization of spray parameters and slurry formulation is expected to enhance properties and performance of the polymer-based SSB components.

Mixing Composite Cathodes for Solid-State Batteries: The Key to Reliable High Performance

Maximilian Kissel
University of Giessen

Solid-state batteries (SSBs) are being extensively studied for their potential to deliver higher energy and power densities and improved safety compared to liquid-electrolyte lithium-ion batteries. Lab-scale research often relies on pelletized press-cell studies; in this context, a recent interlaboratory round-robin study revealed significant discrepancies in cell assembly and performance across research groups. We investigated a state-of-the-art material system comprising a composite cathode with single-crystalline cathode active material (CAM), a sulfide solid electrolyte, and carbon nanofibers. The dry-particle mixing process used to prepare the cathode composite is found to be crucial for reproducibility and cell performance. It accounts for many of the discrepancies observed in the achievable specific capacities of different cells prepared from identical materials and cell-assembly parameters. The use of conventional hand mortaring resulted in unsatisfactorily large variations in capacity, whereas machine-produced composites using a mini vibrating mill significantly improved reproducibility. We introduce Coulometric Titration Comparison (CTC) as an in situ electrochemical method that quantifies the static cathode active material (CAM) utilization as a valuable metric for assessing the mixing quality of composite cathodes. Using CTC on a large parameter set, we show that connecting all CAM particles into an electronic network is not self-evident in SSB composite cathodes. The method is applicable to a wide range of studies and is also valid for pouch cells, enabling a clearer distinction between static and kinetic microstructural limitations. Examples of such limitations are briefly outlined, posing challenges for upscaled production. Overall, the results emphasize the crucial role of the mixing process, even at the lab scale, in ensuring reliable electrochemical analyses and achieving high-performance SSBs.

Coating and Drying of Battery Electrodes

About Humidity Management and Post Drying for different Battery Electrode Materials: Sorption and Kinetics

Philipp Barbig
Karlsruhe Institute of Technology (KIT) I Thin Film Technology (TFT)

Energy efficiency in cell production is a key factor in the cost-effective manufacturing of competitive lithium-ion batteries. Among the most significant cost drivers of production are the energy intensive humidity management and post-drying processes. Humidity management refers to the control of the production environment to minimize residual moisture in the cells and prevent degradation of active materials. Depending on the type of active material, various sorption mechanisms may occur during production. Polymeric binders, for instance, tend to absorb substantial amounts of moisture even at low relative humidity levels. Cathode active materials, on the other hand, undergo chemisorption reactions with atmospheric species like CO2, leading to lithium loss and associated capacity fade. As shown in Fig. 1, beyond sorption, mass transport mechanisms are crucial, particularly in the post-drying process. A fundamental understanding of both sorption equilibria and mass transfer kinetics are essential to remove residual moisture efficiently. Advanced simulations offer valuable insights for optimizing energy consumption and accelerating post-drying processes.This work combines experimental and numerical approaches to investigate sorption and mass transport mechanisms in porous electrodes during humidity management and post-drying. Time-resolved sorption and drying kinetics are measured using a magnetic suspension balance under varying temperatures, pressures, and electrode geometries. The post-drying process is analyzed with focus on mass transport resistances at both micro- and macro-scale, as influenced by electrode configurations such as free-standing films, coils, or stacked assemblies. Limiting mechanisms—such as diffusion through hydrophilic polymer binders or gas-phase transport through porous structures—are identified and incorporated into a transient simulation model.

Slot die designs – comparison fix lips vs. flex lips / T-Bar

Harald Doell
TSE Troller AG

Premetered coating in the slot format is an attractive method to apply single or multilayer structures to continuously running substrates, namely in the battery electrode production.
Performance of slot dies:
The internal design of slot dies is influencing the distribution of the fluid in cross-web direction. For optimizing the design for different coating slurries, it is important to understand the behaviour of the fluids, particularly the rheology behaviour. With optimized dual cavity design it is possible to distribute different slurries under various flow-rate conditions without compromising the CD uniformity! The main impact to the cross-web uniformity is coming from the flatness of the exit slot surfaces.
In industries using slot dies and other premetered coating dies for decades, the best results in terms of CD- uniformity have been achieved by precisely manufactured die plates.
Comparison of fix lip dies vs. flex lip or T-Bar design:
With optimized internal distribution system, and with high precision level of the internal surfaces, the start-up time for fixed lip slot dies is of truly short time. Setting all parameters like coating gap, flow rate and web speed is mandatory before starting and after moving to the coating position, it takes only a few metres to establish steady conditions and proper distribution. The CD uniformity of the coated layer is mainly influenced by parallelism of the coating gap, but not of the slot flatness.
In case of flex-lip or T-Bar slot dies the coated layer must be measured in CD after coating and then the calibration either of the lips or the T-Bar must be started, manually or automated. Comparing the results is needed before finding the best spot for a uniform distribution, which easily can take between minutes until half an hour or more. During this process high value material is coated onto the metal foils under production conditions, which is time- and mainly cost- consuming. Calculations can be done easily.

IR-assisted vacuum drying to remove water from Prussian Blue cathodes in sodium-ion batteries.

Thorsten Mally
Excelitas Noblelight

The subject of the current presentation is a study that investigates the impact of infrared assistance in the process of vacuum drying. The objective of the study is the development of a method to eliminate interstitial water from Prussian blue cathodes in sodium-ion batteries in a controlled manner and with a significant time reduction. A comparison is made between experimental results obtained from IR drying trials conducted under vacuum conditions and theoretical results generated in the framework of microscopical simulation based on computational chemistry. The implementation of the findings in the pilot and production lines of the gigafactory, including the design of machinery, will serve to complement the presentation.

Battery Recycling & Repurposing, Material Recovery

Influence of the drying temperature on the recovery of electrolyte components in battery recycling

Jannik Born
TU Braunschweig I Institute for Particle Technology (iPAT)

The growth of electric vehicles and renewable energy has led to a sharp rise in lithium-ion battery (LIB) use, with a significant increase in spent LIBs expected soon. These batteries pose environmental and safety risks but contain valuable materials like lithium, nickel, and cobalt, which must be recovered for economic and regulatory reasons. Due to potential shortages—especially of cobalt—developing secondary sources through recycling is crucial, driving strong interest in LIB recycling across academia and industry.
In order to improve sustainability, the recycling quota for end-of-life (EoL) batteries is aimed to surpass 70% by 2030. The push for higher recycling efficiency extends beyond the core components of batteries to include the recovery of other vital materials. For example, certain processes can now recover electrolyte components that are usually lost during current recycling methods due to thermal decomposition.
Advanced recycling methods, such as dry mechanical recycling, involve gentle vacuum-assisted drying of crushed battery materials. The aim is to recover the highly volatile electrolyte components. However, the low thermal stability of the conductive salt (LiPF6) poses a challenge, as it may decompose into hydrogen fluoride gas. Therefore, this study investigates the influence of the drying temperature on the decomposition of LiPF6 in a vacuum, and on the composition of the resulting electrolyte condensate. Moreover, the amount of conductive salt and less volatile components, such as EC, within the black mass are determined. The later aim is to recover as many electrolyte components as possible and to produce a new electrolyte mixture from the recovered components. Tests at the pilot recycling plant at TU Braunschweig will demonstrate that dry mechanical recycling can be scaled up, and that increased recycling quotas are possible through the recovery of electrolyte components and undecomposed conductive salt.

Challenges of Using Recycled Ethyl Methyl Carbonate in Lithium-Ion Batteries

Valerie Mohni
TU Braunschweig | Institute of Energy and Process Systems Engineering (InES)

The reuse of organic solvents like ethyl methyl carbonate (EMC) is essential for improving the sustainability of lithium-ion battery production. However, residual protic impurities – particularly alcohols – introduced during the recycling process can interfere with electrolyte stability and solid electrolyte interphase (SEI) formation.
In this work, we systematically investigated the effect of alcohol residues on the electrochemical performance of NCM811/graphite coin cells using both model electrolytes spiked with methanol or ethanol (0.01–1wt%) and real recycled EMC samples with purities of 98–99%. Electrochemical tests included formation profiling, impedance analysis, and long-term cycling over 250 cycles.
Our results show that even low concentrations of alcohols delay SEI passivation and increase irreversible capacity losses during formation. At higher concentrations, cell resistance increased significantly and continuous side reactions impaired SEI stability. Nevertheless, all cells with alcohol concentrations below 0.2wt% demonstrated stable long-term cycling when subjected to low-current formation protocols.
These findings underline the importance of stringent impurity control in recycled solvents. At the same time, our findings demonstrate that, under defined conditions, EMC recovered through thermal drying and rectification can be reused in lithium-ion batteries for less demanding applications – provided that the formation process is sufficiently adapted. This work contributes to defining impurity thresholds and offers valuable guidance for integrating recycled electrolytes into future cell manufacturing.

Process failure mode - product failure mechanism - effect analysis ((PFM)²EA): A novel risk assessment methodology for automated battery disassembly - Integrating process and product safety in repurposing

Stefan Grollitsch
Vehicle Safety Institute, Graz University of Technology

This study introduces a novel risk assessment methodology, the process failure mode- product failure mechanism- effect analysis ((PFM)²EA), designed to evaluate safety risks in automated battery disassembly processes. The (PFM)²EA method combines two established risk analysis approaches: one focused on manufacturing processes (PFMEA) and another on product failure behaviors (FMMEA). By linking these perspectives, the method addresses the critical gap between process and product risks in separation processes for battery repurposing. Our approach employs a tripartite risk categorization framework, distinguishing between immediate safety hazards, long-term safety risks, and potential performance issues of reused components. The method introduces a fourth variable to the traditional scoring system, which considers severity, likelihood of occurrence, and detectability of a product failure, by adding a fourth factor: the likelihood of process failure. The determination of which was simplified by implementing an analytic hierarchy process. This enhancement allows for a more comprehensive assessment of potential hazards originating from product failure mechanisms triggered by process faults. To validate the (PFM)²EA method, a preemptive risk assessment of theoretical automated disassembly processes for three battery systems has been conducted. The study focused on processes aimed at extracting energy storage components for reuse and repurposing, examining how safety considerations influence process selection. The findings demonstrate the effectiveness of the (PFM)²EA method in identifying and prioritizing safety risks in battery disassembly processes. A Monte Carlo Simulation confirmed the robustness of the risk evaluations under input uncertainty, reinforcing the method's reliability. This research contributes to the development of safer and more efficient battery repurposing strategies, addressing critical challenges in the circular economy of energy storage systems.

Battery Cell Inspection and Monitoring

Monitoring exposure to airborne particulates along the value chain of Li-ion batteries

Kevin Sparwasser
Stat Peel AG

Handling Li-ion batteries (LIBs) bears the risk of exposure to the hazardous materials they are made of, practically along their entire value chain, ranging from raw material production, cell manufacturing, to battery recycling at the end of their lifetime. Lithium nickel cobalt manganese oxides (NMC) are among the dominant active cathode materials for high-performance batteries and pose a serious health hazard due to their nickel and cobalt content. Further, advanced nanomaterial additives such as carbon black, silicon, or carbon nanotubes (CNT) are increasingly added to electrodes to enhance their electrical and mechanical properties. Exposure monitoring is imperative to establish sustainable and safe work practices.
In this contribution, we present results from validating the Stat Peel method for quantifying NMC concentrations in battery environments. The employed Stat Peel Identifier C2 instrument, originally developed to measure CNT concentrations, consists of respirable air samplers and an automated Raman spectroscopy-based reader. The validation study revealed that the method

is fit to assess the occupational exposure to respirable Co in short-term and task-related samplings (German limit value: 5 µg/m3). The method shows encouraging agreement with state-of-the-art ICP-MS analysis in comparison measurements.
We further present findings from recent case studies in which we employed the method in the workplace (e.g., cathode material mixing or recycling) to evaluate the plausibility and performance of the method in real environments.
The obtained data showcase the potential of the Identifier C2 as a fast-screening tool to obtain reliable end-of-shift results on exposures to various battery materials, including NMC, CNTs, and other carbonaceous species, without requiring expertise in analytics or data processing.

Non-Destructive Characterization of Projection Welding for Battery Cell Interconnection with Scanning Acoustic Microscopy and X-Ray Computer Tomography

Felix Thurn
Fraunhofer-Institut für Solare Energiesysteme ISE

The interconnection of cylindrical battery cells to larger modules is typically performed by welding techniques [1]. Facing increasing current of high-performance battery cells, copper connectors with high conductivity are best suited [2]. A commonly used technique is projection welding, where two projections are stamped into a connector sheet on each side of a punched-out slot [3]. The welding electrodes are positioned onto the projections, resulting in a current path across the projections and the cell case between the electrodes. Due to the increased conductivity of copper, such geometries are not suitable, as the welding current would mainly flow through the connector sheet. Therefore, the process of step welding is developed for battery connections, where four projections are placed below one electrode while the other electrode is in direct contact with the cell case to force the current through the projections. This method requires a special arrangement and geometry of the projections. To ensure an identical and reproducible welding of the interconnectors to the battery cell, it is crucial to verify uniform connection of all projections. Typically, the welded area is assessed through destructive testing, being very time-consuming. Therefore, two methods are developed for a non-destructive characterization of the contact area. With scanning acoustic microscopy (SAM), the interface layer between cell case and connector is scanned to determine the area of the welded projections. As a second method, an X-ray micro-CT is chosen to measure the contact area. For the final publication, both techniques will be compared against the conventional destructive characterization method. It will be shown that the non-destructive characterization methods provide a fast and reliable determination of the welded contact area. These fast and non-destructive methods have the potential to support the quality control of the welding process for battery module manufacturing.

From molecule to module – the Lund University ecosystem for battery safety characterization and fire hazard assessment

Elna Heimdal Nilsson
LTH, Lund University

Lund University offers a uniquely integrated and interdisciplinary research ecosystem for the comprehensive study of battery safety, reliability, and thermal management. Spanning from fundamental chemical processes at the molecular level to full-scale fire testing of production vehicles, our approach affords a holistic understanding of battery behaviour under both routine and extreme conditions. Thermal runaway (TR), fire propagation, gas emissions, and system-level failure modes present significant risks to users, manufacturers, and emergency responders. This presentation outlines the capabilities, methodologies, and collaborative framework that make Lund University a leading hub for battery safety research in Europe.
Addressing these challenges necessitates a multiscale, multidisciplinary approach that bridges the divide between fundamental science and practical application. We have established a comprehensive research platform that synthesises expertise in combustion physics, fire safety engineering, chemical analysis, heat transfer and flow modelling, advanced imaging, and systems engineering. This ecosystem enables the study of battery behaviour from the molecular level—where decomposition reactions and gas formation originate—to the module and pack level, where thermal propagation and fire hazards emerge in full complexity.
By combining advanced diagnostics, simulation, and large-scale testing, we aim to enhance the safety and reliability of battery systems, contribute to the development of international safety standards, and facilitate the safer integration of batteries into vehicles, and other energy systems. We maintain active collaborations with all major stakeholders in the Swedish electric vehicle industry.
We warmly welcome new partnerships with academic institutions, industrial actors, and governmental bodies who address issues of battery safety and fire hazard assessment.

Industry Session I

From Battery to Black Mass: Practical Insights to Lab-Scale Milling and Sieving

Dr. Lena Weigold
Retsch GmbH

Practical insights to Lab-Scale Milling and Sieving Recovering valuable materials from lithium-ion batteries starts with effective mechanical pre-treatment. This contribution presents practical lab-scale solutions for sample preparation, sieving, and mechanochemical processing, with a special focus on black mass. After mechanical crushing, sieving enables targeted fractionation and quality control, improving material flow and the efficiency of subsequent processing steps. Homogeneous sample preparation is essential for accurate analysis and is achieved using ball mills and alternative milling techniques. The combination of these steps provides a reliable foundation for the precise characterization and further optimization of battery recycling processes.

Giga-Odenwald 2.0 – a modularized, standardized, and scalable mixing plant on a gigafactory scale

Dr. Stefan Gerl
Maschinenfabrik Gustav Eirich GmbH & Co. KG

The “Giga-Odenwald” (1.0) was introduced in the 1/2023 issue of the journal “Schüttgut.” This is a core plant based on a 500-liter RV12Vac mixer. It was installed at the Eirich test center in Hardheim in the Odenwald region. The aim was to demonstrate the scale-up and performance of the plant technology to a key Eirich customer in test operation. After the trials were successfully completed and the customer had commissioned its own Giga pilot plant with a comparable concept, the test plant was then sold to Asia for the production of LFP cells, in order to further expand the existing production capacities of a long-standing Eirich customer.
In order to test innovative approaches and convince further customers of Eirich mixing technology, the shareholders of Eirich have decided to build a new plant that represents the latest state of the art. The new “Giga-Odenwald 2.0,” the heart of all future Eirich production plants on a gigafactory scale, consisting of a mixer, pump module, and tank module in a fixed arrangement, direct piping and pigging line as well as plant control system, is currently under construction. The revised concept implements a number of improvements, particularly in plant and control technology. Eirich's experience with numerous OEMs and customers from the non-automotive sector in the planning and implementation of Giga pilot plants and Gigafactories has been consistently taken into account in order to reduce investment costs, and above all commissioning and ramp-up costs, to a minimum. Examples of this include:
- Consistent modularization of peripherals in the form of pump and tank modules, which are prefabricated and tested and can be assembled and commissioned on site in the shortest possible time using plug-and-produce technology.
- Standardization of operating components in all plant parts based on OEM requirements in order to minimize the variety of sensors and actuators in all plant parts during planning and execution.
- Machine and plant control based on the Siemens Xcelerator and the Siemens Battery Style Guidelines so that our customers are optimally equipped factory automation and for the Battery Pass.
The presentation explains the concept of “Giga-Odenwald 2.0” and the implementation of the core module through parallelization in gigafactories with up to 20 GWh per line.
Stairs up to the future: This is where the new Eirich mixing plant for lithium-ion battery masses is located.

XRF-Based Quality Classification of Lithium-Ion Battery Black Mass

Jana Kalbáčová
HORIBA Jobin Yvon GmbH

The recovery of critical elements from Li-ion batteries (LIB) is a key challenge for sustainable recycling. The presented study addresses two main issues regarding the characterization and quality classification of LIB black mass (BM): (1) the reliable quantification of contamination elements such as Al, Cu and other transition metals, as well as (2) the determination of fluorine as residual of $LiPF_6$ electrolyte and PVDF binder that can hinder downstream hydrometallurgical processing.

To address these goals, X-ray fluorescence (XRF) spectroscopy is employed as a rapid, non-destructive technique for determining elemental compositions. Performed under vacuum or He-atmosphere, light elements, such as F, Al or P will be analyzed. Fluorine is of particular interest, as residual $LiPF_6$ decomposition products can form insoluble fluorides that impair leaching efficiency. Therefore, our measurements are used to evaluate the feasibility of fluorine quantification. Additionally, comparative measurements under ambient (non-vacuum) conditions are used to assess the capabilities of in-line XRF– a method that can be applied for real-time monitoring of elements in black mass.

The investigated samples are NMC-BM sourced from the pilot recycling plant at the TU Braunschweig and were produced at different drying temperatures. The aim is to study the decomposition of electrolyte components as a function of selected process parameters with a focus on the conductive salt $LiPF_6$. Due to the challenging quantification of F in the LIB-BM, it is further assessed whether P is a suitable proxy element for F. In addition, the contamination elements Al, Fe and Cu are examined in relation to the main elements Ni, Mn and Co.

With the application of XRF analyses to LIB-BM, we present a versatile solution not only for detailed laboratory characterization but also with the potential for real-time process control, thus supporting a more efficient and high-purity recycling of LIBs.

Continuous Mixing of Electrode Masses by Extrusion – On the way to dry electrode

Markus Lehmann
Coperion

The conventional batch process for mixing electrode masses has long been the standard in the battery industry. However, as a technology provider for mixing and compounding systems, we are seeing a growing interest in continuous electrode mixing. This shift is driven by significant cost and process advantages, including a more compact design, reduced footprint, minimized waste materials, enhanced productivity, and a higher degree of automation. Our presentation will dive into the continuous mixing process, emphasizing the critical interlocking of various system elements that contribute to its efficiency.

We will explore the benefits of extrusion in the continuous mixing of electrode materials, highlighting how this method can streamline production and improve material consistency. Additionally, we will address the challenges associated with the dosing of PTFE, a crucial component in dry electrode formulations, and discuss effective strategies for managing coating mass handling. The role of the roller feeder in optimizing the continuous mixing process will also be examined.

By showcasing the advantages of continuous mixing this presentation aims to provide valuable insights for industry professionals seeking to enhance their production processes and transition towards dry electrode manufacturing.

Trajectory Mixing for Wet and Dry Electrode Processing – Opportunities and Challenges in Battery Slurry Production

Andreas Leitze
Tumbler

Trajectory Mixing (TM) is a novel high-speed mixing technology that induces intensive internal flow by moving a closed container along a programmable two-dimensional Lissajous trajectory. In contrast to conventional batch mixers or extruders, no active mechanical agitator or screw is required. The resulting self-mixing motion generates high shear forces while eliminating dead zones, material losses, and cross-contamination.

Dry Coating 2: Novel Binder Systems

Investigating the mechanical and electrochemical performance of polymer binder composites for fibrillated free-standing dry electrode films

Rajasekar Krishnamoorthy
The University of Sheffield, United Kingdom

In dry processing the active material, conductive agent and binder are combined in the absence of a solvent, eliminating the need for costly/energy demanding drying stages and potential toxic emissions in traditional slurry cast processing. Compared to wet processing, dry processing inherently achieves a more homogenous distribution of electrode components, circumventing a limitation of slurry cast processes in which binder components separate in the drying process of thicker electrodes linked to issues with capacity fading and delamination.

Polymer fibrillation is one of the most widely used dry processing techniques. This technique is heavily reliant on PTFE as a binder due to its ability to fibrillate with very few true fibrillating alternatives present. Typically, a polymer is plastically deformed under applied heat and/or shear mixing to form thin, interconnecting fibrils which act as the binder material. However, poor adhesion between PTFE and the current collector necessitates the need for a primer coating on the current collector and the inherent hydrophobicity of PTFE can create issues with electrolyte wettability. Additionally, fluoropolymers are becoming increasing unpopular choices as binders due to environmental concerns of PFAS pollution.

Here, we investigate alternative non-fluorinated binder candidates for use in dry electrodes. We explore the lowering the overall PTFE content used as a binder for dry electrode processing through complexing it with several other promising non-fluorinated binder alternatives. Our results demonstrate that electrodes made from composite binder mixtures can maintain the structural integrity of the free-standing film while simultaneously delivering high performance as an electrode. Importantly, the results presented here constitute major steps towards lowering the reliance of dry electrode fibrillization on PTFE, a significant advancement for optimising dry electrode performance and mitigating environmental impact

Toward PFAS-Free Lithium-Ion Batteries: Fluorine-Free Binders and Scalable Dry Coating Technologies

Minwon Suh
CNP Solutions

The drive toward environmentally responsible and cost-efficient lithium-ion battery (LIB) production has accelerated the development of alternative materials and processing technologies. Particularly, growing regulatory pressure to phase out per- and polyfluoroalkyl substances (PFAS), including fluorinated polymers such as polyvinylidene fluoride (PVDF) and polytetrafluoroethylene (PTFE), has intensified the need for sustainable binder alternatives. In response, we present molecular design strategies for reducing fluorine content specifically engineerged to perform in both wet and dry electrode processes without compromising electrochemical performance. The newly developed PVDF alternative is a class of polyarcrylonitrile-based copolymers (so-called PAM) with enhanced ionic conductivity and strong affinity to various nano-materials.[1] PAM is a 0% fluorine polymeric binder offering not only binding function but excellent carbon nanotube (CNT) dispersion capability, therefore enables high active material content up to 98% without the use of typical insulating dispersing agents. The slurry shows better rehological properties, such as lower initial viscosity as well as improved slurry stability over time. The electrochecmial cells with PAM exceeds those of PVDF or PVDF with commercial CNT dispersant combinations. We present low-fluorinated dry binder materials by combining PAM and PTFE (PAM/PTFE). This unique polymer complex provides added functionality with various tunable features including change in polymer composition and control of micro-morphology for different chemistries. PAM/PTFE is advantageous over PTFE in that it displays faster electrolyte absorption, higher adhesion, and better electrochemical stability while having lower fluorine content. In terms of processibility, PAM/PTFE does not necessaryily requires keading process, which renders a simple high-speed mixing to complete the preparation of dry electrode mixture. Our preliminary test results show a potential in direct lamination of dry cathode electrode on a bare Al foil without the presence of adhesion-promoting primer layer. Further optimisation of the polymer composition of PAM/PTFE and process parameters in dry coating need to be investigated. Lastly, the development of multi-roll dry coating euqipment is one of our key activities. We demonstrated continuous processing of dry electrode from powder feeding, electrode sheet formation and electrode/foil lamination in a single equipment on different scales. The smallest version is suitable on a lab table for rapid experiment tasks with minimal material loss. The larger machine is designed to produce dry electrode product with precise control of mass loading and coating width for pouch cell fabrication. Our technologies offer a scalable and regulatory-compliant alternative to conventional approaches and marks a significant step toward greener and cost-competitive LIB production. The details of our work will be discussed at the conference.

Dry Electrode Processing for Sodium-Ion Batteries: Transition from PFAS-Based to PFAS-Free Binders

Oliver Fitz
Fraunhofer Institute for Solar Energy Systems ISE

The growing demand for advanced energy storage systems to address future challenges has intensified the search for alternative battery technologies. Sodium-ion batteries (SIB) have garnered significant attention due to their cost-effectiveness, evenly distributed raw materials, potential low cost, similarity to

Lithium-ion-battery (LIB) chemistries, and convincing performance.[1] The optimization of the manufacturing process of SIBs can further increase economic and environmental competitiveness with modern LiFePO4-based batteries, e.g., by transitioning to low solvent or solvent-free processes.

At the Fraunhofer ISE, by employing different innovative dry or semi-dry electrode processing techniques, we are able to demonstrate that PFAS-free binders can achieve comparable or superior electrochemical performance compared to PFAS-containing electrodes. The resulting electrodes exhibit tunable morphologies, including porosity control, adjustable layer thicknesses from µm to mm scale, and good structural stability.

The developed (semi-)dry coating process for battery electrodes reduces the environmental impact associated with fluorinated materials. Overall, within this presentation, the findings highlight the effectiveness of PFAS-free binders in maintaining electrode integrity and enhancing overall battery performance.

Modelling Battery Production & Processing

Model-Based Assessment of Energy and Material Efficiency for Sustainable Battery Cell Production

Gabriela Ventura Silva
TU Braunschweig | Institute of Machine Tools and Production Technology (IWF)

Battery cell production is composed of numerous heterogeneous processes and interdependencies across different production levels. The growing demand for batteries further increases this complexity, as it requires scaling existing processes and integrating new technologies. As the material and energy flows affect both the technosphere and the ecosphere, achieving environmental sustainability requires a comprehensive understanding of these flows and their environmental implications. To meet this need, this work presents a model-based methodology for digitally investigating battery cell production, assessing energy and material efficiency while considering interdependencies between different elements of production systems. The modularity of the approach allows diverse stakeholders to identify unknown interdependencies and support knowledge-based decision-making. The flexible modeling accounts for differences in production, including process technologies and production capacities. The dynamic material flow modeling enables tracking of materials used in production and the assessment of how product quality influence material efficiency. Similarly, the dynamic energy flow modeling allows the reproduction of weather-related variations in energy demand and the impact of dynamic events (e.g., bottlenecks). To exemplify the methodology's application, a case study investigating production system design is presented and compares two production locations (Germany and Brazil), accounting for the effects of weather conditions and energy mix. The simulation comprehends an annual large-scale production and considers different temporal resolutions, focusing on product, dry room, and production system levels. The results can support environmental experts in deriving best practices in responding to climate regulations, such as the battery passport. Furthermore, they support strategic decision-making by production designers, such as the planning of new production facilities.

Model-based prediction of SEI growth and formation metrics for a knowledge-based process design

Felix Schomburg
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The formation process is a crucial step in the production of lithium-ion batteries. It impacts production metrics, such as process duration, energy consumption, and cost, as well as cell performance metrics, such as capacity and lifetime [1]. However, the design of the formation protocol is challenging due to the vast number of influencing factors, making an experimental optimisation resource- and time-intensive. Model-based approaches and methods for their parameterization are needed to enable an efficient multi-objective optimization.

Here, we present a method to identify electrolyte-dependent solid electrolyte interface (SEI) growth trends and use them to parametrize a mechanistic SEI growth model. SEI growth curves are determined using a novel approach based on a differential voltage analysis (DVA) with three-electrode cells [2]. These curves reveal electrolyte-specific differences and are used for model parameter identification. The parameterized model is applied for four distinct formation protocols and captures cell-specific post-formation capacity losses. Coupling the SEI model with a pseudo two-dimensional (P2D) battery model framework enables the simulation of further key formation metrics, including coulombic efficiency, process duration, and energy loss. Simulated values align well with most experimental results, supporting the validity of the model-based approach.

In summary, a method to parameterize mechanistic SEI growth models based on electrolyte-specific SEI capacitiy trends, identified via DVA, is presented. The model predicts cell-specific capacity losses during and post formation. When coupled with a P2D framework, key formation metrics can be simulated, marking a step towards a model-based multi-objective process optimization.

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Cell and system level models integration in battery cell formation

Cihan Yurtsever
Comau SpA

Physics-based computational modeling has become a powerful tool for simulating complex electrochemical systems, particularly in industrial-scale battery manufacturing processes such as the cell formation step. Although existing models effectively address formation at the individual cell and pack levels, there remains a critical gap in modeling at the full production scale, specifically within COMAU formation chambers.

This work introduces a weakly coupled simulation framework for assessing the energy demands of environmental chambers during battery formation. The approach integrates COMAU system-level analysis tools with cell-level multiphysics simulations from the PROTEO platform via data exchange. PROTEO contributes detailed electrochemical degradation models tailored to the formation stage, allowing for high-fidelity cell behavior modeling within a broader system context. In parallel, COMAU system-level analysis tools handle the cell model deployment, calculates losses from electrical elements using physical datasheets values and computes the total energy consumption under dynamic operation of the cell formation process.

The loosely coupled design enables comprehensive energy consumption analysis while maintaining the integrity of cell-level degradation dynamics alongside the physical behavior of the COMAU formation chamber. Targeted toward industrial deployment, the framework offers a practical solution for optimizing energy efficiency and process performance in temperature-controlled formation protocols. The weak coupling strategy proves particularly effective in maintaining simulation stability across the disparate time scales of COMAU formation chamber operations and electrochemical processes.

Advanced Production of Conventional and Novel Batteries

Particle-based magnetic additives as information providers in lithium-ion cells

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Magnetic particles are a versatile class of materials that can be precisely tailored in composition, structure, and function to act as intelligent information carriers [1, 2]. Their powder-like morphology enables integration into complex systems such as lithium-ion batteries, while preserving structural and operational characteristics [3]. This study investigates superparamagnetic nanoparticles (SpNp) as smart additives in lithium iron phosphate cathodes. These SpNp are detectable via magnetic particle spectroscopy, providing unique magnetic codes, for cell identification and information transfer to support direct recycling pathways. Spray-drying of oleic acid and silica-functionalized nanoparticles and a subsequent heat treatment, yields micrometer-sized supraparticles with stable and defined magnetic properties. These supraparticles remain mechanically and magnetically unaffected during electrode fabrication and electrochemical cycling. Importantly, their magnetic signature persists even after battery end-of-life allowing contactless cell identification through magnetic particle spectroscopy. Further electrochemical analysis confirms that the presence of supraparticles does not significantly affect cell performance or cycling stability. However, the recovery of SpNp during recycling processes has not yet been investigated.

This work demonstrates the SpNp can be magnetically separated through direct recycling routines using external magnetic fields. The recovered particles retain their functionality and can be reused as magnetic code carriers in a second battery lifecycle. This recyclability and material compatibility highlights the potential of supraparticles to enhance traceability and automation in battery disassembly and refurbishment processes.

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Dry electrode processing of electrodes and recent advancements in multi-layer pouch cell development of sodium ion batteries

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Sodium ion batteries (SIBs) are considered as the cost-effective drop-in technology and com-plementation to Lithium ion batteries (LIBs).[1] To improve performance, R&D activities are carried out for suitable cathode structures, carbonaceous anode materials with fine-tuned in-trinsic porosity as well as stable and beneficial electrolyte components. It is important to trans-fer the results from initial half-cell measurements of single raw material to multi-layer pouch cells to accelerate practice-oriented key performance indicators such as specific energy energy density and cycle life.

Within this work, NFM layered oxide cathodes (Na[NixFeyMnz]O2) were produced by sol-vent-free DRYtraec®[2] process and tested in multi-layered pouch cells. In combination with an ecologically friendly water-based coated hard carbon anodes a capacity retention of 78% after 400 cycles was achieved.[3]

Additionally, the processability and electrochemical performance of different cathode active materials classes and hard carbon anodes are investigated. It is revealed that modified carbon coatings on hard carbon affect the carbon porosity and increase their specific capacity. For reproducibility of cell testing, post-calendaring with a heated four-roll calendar and laser cut-ting of electrodes for accurate stacking in pouch cells are implemented. The most promising electrode and cell configuration was then cycled in varying electrolytes systems and test con-ditions in single- and multi-layered pouch cells.

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Advancing Sulfur–Carbon Composite Production: Industrial and Lab-Scale Infiltration Techniques for Metal–Sulfur Batteries

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In a metal-sulfur battery, the cathode consists of a composite material made from activated carbon and sulfur, which acts as the electrochemically active component. To fill the pores of the activated carbon with sulfur, both melt infiltration and gas infiltration techniques are employed. [1-3] However, the entire procedure, involving heating and cooling phases, is highly time- and energy-consuming. Moreover, the currently established methods allow only very small sample quantities to be processed in batch mode. The cost associated with processing larger volumes is prohibitively high, rendering these methods economically unviable. To optimize the production of sulfur-carbon composites, infiltration techniques that increase material throughput while reducing processing time and energy consumption are essential. For this purpose, various infiltration methods have been tested and their performance thoroughly analyzed. Sulfur is introduced into microporous carbon using different infiltration approaches based on both melt and gas infiltration. Continuous industrial-scale processes and rapid batch methods are evaluated and compared against laboratory-scale techniques. The infiltration experiments were conducted using a carbon aerogel with a micropore volume ranging from 0.27 to 0.45 cm^3/g. The findings demonstrate that the highest sulfur loadings were achieved through gas, extruder and melt infiltrations, with the sulfur predominantly present in the micropores. The composites produced with gas [4], spray-coating [5], and extruder infiltrations [3] exhibit good cycle stability and high discharge capacity. In contrast, open gas infiltration, microwave infiltration and solvent infiltration resulted in lower sulfur loading and inadequate performance in the cell. Depending on the specific battery requirements, the infiltration technique can be chosen between complex, non-scalable methods with outstanding performance and economically efficient offering moderate performance.

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Dry Coating 3: Characterization & Innovative Approaches

Multi-Technique Characterization of PTFE-Containing Dry Electrode Mixtures for Lithium-Ion Battery Applications

Tamara Ebner
Anton Paar GmbH

The rapid growth of the electric vehicle (EV) market is driving demand for high-performance lithium-ion batteries (LIBs). To meet this demand, manufacturers must reduce production costs, enhance battery performance (charging rate, energy density, driving range), and improve the sustainability of processes—especially for electrodes and electrolytes. Dry battery electrode (DBE) coating is a promising alternative to conventional wet coating and is gaining attention not only for current LIBs but also as an enabling technology for future solid-state batteries.

However, DBE presents specific technical challenges. Unlike wet coating, where slurry behavior is well understood, dry processing lacks fundamental insights—particularly regarding powder mixture properties that influence coating quality and processability.

This study systematically compares unfibrillated premixes containing 1–5 wt% PTFE with fibrillated ones, prepared under varied conditions and provided by The Chemours Company. Advanced characterization techniques were used to analyze these materials, including gas pycnometry, nitrogen adsorption (BET), mercury intrusion porosimetry, porosity measurements, dynamic image analysis (DIA), and powder rheology.

Results show that both PTFE content and mixing duration significantly affect material properties, influencing electrode microstructure and handling behavior. For example, in the 5 wt% PTFE sample, fibrillation led to increased particle size and morphological changes (DIA), higher porosity (mercury intrusion), and increased compressibility and Carr index (rheology).

These insights advance understanding of the material-process-structure relationships in DBE systems and support the scalable implementation of dry electrode technology for improved battery performance and more sustainable manufacturing.

Investigation of PTFE fibrillation in continuous twin-screw dry processing of graphite anodes

Annika Völp
Thermo Fisher Scientific

The increasing demand for affordable electromobility highlights the need for optimized battery manufacturing processes, as production costs remain a major challenge in electric vehicle development. A promising approach is the solvent-free production of lithium-ion battery (LiB) electrodes, eliminating the energy-intensive drying step and supporting sustainable manufacturing. In dry processing, polytetrafluoroethylene (PTFE) serves as a binder, forming fibrils under shear to provide mechanical strength and structural integrity. However, its electrically insulating nature requires precise control, with minimal quantities and uniform distribution critical for maintaining performance.

Previous studies (1,2) have shown that PTFE fibril size and distribution significantly impact battery performance, emphasizing the importance of balanced specific power input during twin-screw mixing. However, a systematic understanding of optimizing the twin-screw mixing process remains incomplete.

This study investigates the continuous dry processing of graphite anodes using a laboratory twin-screw extruder, focusing on PTFE fibrillation behavior under varying conditions. Key parameters, including screw speed, throughput, temperature profile, and screw configuration, were examined to evaluate their influence on fibrillation and mixture homogeneity. Extruder torque and anode granule size distribution dependent on specific feed load and temperature were investigated. Granule flowability was correlated to its size distribution using powder shear rheometry. Scanning electron microscopy (SEM) provided insights into PTFE fibrillation and binder distribution. The findings reveal how processing conditions govern the quality of dry-processed electrodes, offering a framework for optimizing twin-screw compounding parameters and advancing sustainable LiB manufacturing.

Effect of Dry Surfactant-Modified Carbon Additives on the Electrical Conductivity and Powder Flow Behavior of Dry Battery Electrode Mix

Rajasekar Krishnamoorthy
The University of Sheffield

Electrical conductivity and the rearrangement of active material particles during calendaring play a vital role in determining the flow and electrochemical properties of dry-coated electrodes. Due to their high surface energy and strong Van der Waals forces, carbon black particles tend to form agglomerates, both among themselves and with binder particles. The amphiphilic nature of the surfactants helps modify the carbon additives and their interaction with the active material. The present study used sodium dodecyl sulfate as a surfactant due to its interaction with carbon additives that favor the situation. Initially, the carbon additive is subjected to mechanical modification using the surfactant before it's added to the active material. The mix of surfactant-modified carbon additive, active material, and binder was subjected to high shear through a conventional dry mixing procedure with Nobilta mechano-fusion. The formulated dry mix was then tested for its resistivity. Compared to the conventional dry mix, it exhibited a 20–30% lower volumetric resistivity across various densities.

Industry Session II

Smart Mixing for Battery Slurries: NETZSCH Planetary System with Real-Time Absolute Viscosity Analysis

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The mixing process is a critical first step in the production of lithium-ion battery slurries, directly influencing cell performance and overall battery quality. To address the growing demands for efficiency, consistency, and scalability in battery manufacturing, NETZSCH has developed advanced mixing solutions tailored to the unique challenges of slurry production.

At the forefront is the NETZSCH PMH system, which reduces process times by a factor of 2–3 while significantly enhancing slurry homogeneity. This improvement translates into a measurable performance gain of up to 7% in the final battery cells. The PMH's optimized mixing design ensures efficient energy input, gentle yet thorough dispersion of sensitive materials, and seamless scalability from laboratory to full-scale production—making it a future-ready solution for manufacturers prioritizing quality, reliability, and cost-effectiveness.

Beyond performance, NETZSCH sets a new industry benchmark with the PMH 4000, the largest planetary mixer on the market. While conventional mixers offer a usable volume of around 1,600 liters, the PMH 4000 nearly doubles this capacity to over 3,350 liters per batch. This leap in scale, combined with faster mixing times, drastically reduces the number of mixers required for high-capacity plants. For example, a Gigafactory producing 20 GWh annually would need only 6 mixers for anodes and 3 for cathodes, compared to 24 and 12 respectively with traditional systems. Moreover, the plant can be equipped with an inline rheometer from NETZSCH to track the quality and optimize the process.

This consolidation leads to substantial cost savings in equipment, powder dosing systems, sensors, tanks, and labor. Additionally, the smaller footprint of the PMH system accelerates installation and commissioning—an essential advantage for battery manufacturers operating under tight timelines.

Introducing the Center of Excellence Battery: Cell- and Battery Development for the Volkswagen-Group

Dominik Koll
Volkswagen AG

The Center of Excellence Battery gives an introduction to the exciting world of cell- and battery development in the Volkswagen Group. With our young and innovative team we are working at the heart and soul for VWs' transformation towards electromobility. We would like to show you our tasks, portfolio and give a glimpse to what the future has in store for us.

Measurement automation in battery research and production

Julian Diener
BioLogic

Automated measurement processes in battery research and production can shorten development cycles, improve data quality and make manufacturing processes more efficient. The use of robotic and networked measurement- and sensor systems as well as AI-based data analysis enable continuous process- and laboratory measurements- from material development to series production.

Enabling Battery Circularity

Fast and Safe Electrical Characterization for Second-Life Battery Modules Across Diverse Testing Conditions

Simeon Kremzow-Tennie
Keysight Technologies Deutschland GmbH

A consequence of rising electric vehicle (EV) adoption is the growing volume of end-of-first-life battery modules needing classification for 2nd-life or recycling. Accurate state of health (SOH) estimation is vital for battery logistics and repurposing, especially under constraints like unknown state of charge (SOC), absent usage history, and uncontrolled ambient conditions.

This presentation evaluates electrical diagnostic methods—open circuit voltage (OCV), AC/DC internal resistance (ACIR, DCIR), electrochemical impedance spectroscopy (EIS), partial discharge (PD), and full capacity testing—on lithium-ion battery modules. Each method is assessed for diagnostic resolution, test duration, thermal/electrical stress, safety, ease of use, and flexibility. Their robustness under varying environmental conditions and suitability for high-throughput testing are also analyzed.

To improve interpretability, SOH is split into resistive (SOHR) and capacitive (SOHC) components, enabling multidimensional degradation assessment. Correlation between SOHR and SOHC is explored to support cross-validation, reduce false results, and enhance classification accuracy. A tiered testing protocol is proposed: fast, low-stress diagnostics for initial screening, followed by slower methods like capacity testing for detailed classification.

This work offers a comparative framework for selecting and integrating diagnostics in 2nd-life battery workflows. Results provide actionable insights to optimize safety, throughput, and accuracy in industrial battery processing. This supports not only recycling vs. 2nd-life decisions but also targeted module allocation to maximize value recovery and system reliability.

Solving the environmental challenges of cathode active materials for Li-ion batteries – the CALISMAT process

Shun Takano
Proterial Ltd., Japan

The global production of lithium-ion batteries is increasing steeply, and the environmental footprint of batteries is increasingly coming into focus, in particular CO2 emissions, resource consumption and waste generation. We have developed a cathode active material manufacturing technology, CALISMATTM, which significantly contributes to reducing the environmental footprint of electric vehicle production. Unlike the conventional coprecipitation method, CALISMATTM employs a powder metallurgy process and does not utilize nickel sulfate as a raw material. Consequently, it can substantially reduce CO2 emissions and does not generate sodium sulfate, enabling the establishment of factories in regions with stringent sodium sulfate discharge regulations. Through the evaluation conducted by FEV, we have determined that the application of CALISMATTM can reduce CO2 emissions to less than two-thirds of the conventional method while simultaneously reducing water consumption by over 85% and cost by 6%. In this presentation, we will introduce the value proposition of CALISMATTM and provide an overview of the process. Additionally, we will also discuss the compatibility of this process with direct recycling and its potential to be the missing piece in realizing a circular economy.

Enabling circular battery manufacturing through digital technologies

Sebastian Thiede
University of Twente

The transition towards circular battery value chains is essential to ensure sustainability, and technological sovereignty in the light of rapidly growing electric mobility and energy storage markets. As the volume of second-life batteries rises, closing material loops across all levels- from complete packs and modules down to individual cells and critical raw materials- becomes a strategic necessity. All circularity pathways are relevant, including reuse, remanufacturing, and recycling, each offering distinct challenges and opportunities. This presentation explores how digital technologies can serve as key enablers of circular battery manufacturing. Approaches such as Internet of Things (IoT)-based sensing and tracking, interoperable data platforms, artificial intelligence (AI), and advanced tailored automation- e.g. for disassembly and remanufacturing- can unlock new efficiencies and transparency across the battery value chain. The talk will provide an overview of current developments, emerging opportunities, and future directions for realizing digital-driven circularity in the battery industry.

Next-gen Battery Production

Mechanofusion-derived cathode composite microstructures for solid-state batteries: A scalable mixed conducting matrix coating approach

Finn Frankenberg
TU Braunschweig I Institute for Particle Technology (iPAT)

The successful implementation of solid-state batteries (SSBs) relies not only on high-capacity anodes but also on the development of high-performance composite cathodes. However, fabricating such cathodes remains a major challenge due to microstructural limitations, including insufficient ionic and electronic transport pathways, contact losses, and electrochemical degradation, challenges that become more pronounced at larger production scales.

In this work, we present a scalable, high-intensity mechanofusion process for engineering tailored composite cathode microstructures by coating single-crystalline LiNi0.82Mn0.07Co0.11O2 (NCM) particles with the ductile and oxidative stable halide solid electrolyte Li3InCl6 (LIC). Various processing conditions were systematically investigated by combining experimental techniques, including FIB-SEM imaging, STEM analysis, XPS, particle size distribution, and porosity measurements, with discrete element method (DEM) simulations. These methods enabled a direct correlation between process parameters, such as rotational speed and mixing time (i.e., specific energy input), and key outcomes like NCM surface coverage and morphological evolution, revealing a clear increase in coverage with higher energy input. This approach enables the formation of both nanometer-thin coatings and thicker matrix coatings.

By incorporating carbon black into the matrix coatings, electronically and ionically conductive tailored composites were realized. Optimized carbon black content enabled stable cycling with a specific discharge capacity of ~100 mAh/g at 1C. While higher CB contents improve active material utilization, they also increase porosity and hinder ionic transport, thus impairing cell kinetics. Overall, our results highlight the potential of the mechanofusion process as a bottom-up, scalable method for designing composite cathodes with tunable microstructures, offering a promising route toward high-performance SSBs.

Upscaling sulfide-based solid-state batteries

Sahin Cangaz
Fraunhofer Institute for Material and Beam Technology IWS

Sulfide-based solid-state batteries (SSBs) attract great R & D attention particulary from automotive industry, as transformative innovation for electric vehicle (EV) applications. Lab-scale cells using bulk-type high-energy anodes like lithium and silicon have already demonstrated enhanced energy density than current lithium-ion batteries (LIBs) [1–3]. The excellent ionic conductivity (> 10-3 mS/cm at 25 °C) and ductile nature of sulfidic solid electrolytes (SSEs) enhance cell kinetics while providing facile electrode and separator processing [4,5], making them particulary favorable for scalable manufacturing.

Unless conventional LIBs, SSBs require a (final) compression step at elavated pressures (> 360 MPa) to establish intimate physical contact between AM and SSE particles and between individual stack layers, activating ionic and electric pathways of cell components. Furthermore, during cell testing, a certain stack pressure (1 – 50 MPa) is needed to preserve interfacial contacts upon breathing of AMs during cycling. Depending on cell material properties (i.e., thickness, particle size and morphology, hardness and adhesion), cell assembly procedures, from component processing to (pre-) stacking and cutting, can differ significantly.
In this work, we focus on critical parameters upon achieving practically applicable SSBs. This includes a systematic study of single-layered pouch cells (SLP) on reducing stack pressure down to 5 MPa and minimizing the solid electrolyte separator layer (SEL) thickness < 50 µm by optimizing stack pressure distribution. Thereby, we demonstrate NCM / Si SLPs with state-of-health (SoH) > 88 % after 1000 cycles as well as an SLP with 35 µm thin SEL achieving > 930 Wh / L and > 350 Wh / kg at stack level. Additionally, we adress cell and process design strategies that realize multi-layered SSB pouch cells.

Solvent-Free Processed Polymer Electrolyte for Li-Metal Batteries

Laida Otaegui
Centre for Cooperative Research on Alternative Energies CIC energiGUNE

Several polymer electrolyte compositions have been proposed in the literature as candidates for next generation Li solid state batteries. Among them, PEO-based ones are the current state-of-the-art. Indeed, solvent free processing, which is beneficial in terms of performance and cost, has been reported for PEO1. PVdF and its copolymers are also interesting as polymer matrices owing to their high polarity, oxidative stability, and mechanical strength2. However, the studies based on the solvent free processing of alternative polymers are less abundant.
In this work (see Figure 1), we processed PVDF-HFP based gel polymer electrolytes using LiTFSI as the lithium salt and an ionic liquid as a plasticizer. In addition to this, PEO was also added to some of the compositions with the aim to improve ionic conductivity. The effect of processing conditions using an internal mixer was evaluated in the characteristics of the obtained mixtures. Moreover, after defining the optimum processing conditions, self-standing membranes with several compositions were prepared by hot calendering. Produced membranes were chemical, mechanical and electrochemically characterized and full cells with solid state NMC-811 based cathodes were tested using the best performing gel polymer electrolyte composition.

Advanced Electrode & Cell Production

Polyvinylene carbonate in anodes as strategy to form a stable SEI in Lithium-Ion-Batteries

Nina Philipp
TU Braunschweig I Institute for Particle Technology (iPAT)

In an increasingly electrified and digitalized world, lithium-ion batteries play a central role. For use in mobility applications, high energy and power densities, long lifetime and high cycle stability are required. To achieve these goals, the formation of a protective solid electrolyte interphase (SEI) is essential. Vinylene carbonate (VC) is often added to liquid electrolytes as an additive to facilitate the formation of a stable SEI. However, VC is electrochemically unstable on the surface of high-voltage cathode materials such as NMC and nickel-doped LMO, leading to undesirable side reactions at the cathode. Therefore, new strategies, such as the formation of an artificial SEI, must be developed to enable the use of high-voltage cathode materials.
This study investigates and evaluates various methods for forming an artificial SEI based on VC. To obtain an artificial SEI, the active materials (such as graphite, silicon and graphite/silicon composites) are coated with polyvinylene carbonate (PVC) in a fluidized bed process and then processed into electrodes. This is compared to the in-situ polymerization of vinylene carbonate during the dispersion process and subsequent electrode fabrication. Both approaches promise a reduction in the amount of vinylene carbonate required and a tailor-made SEI, while preventing VC migration to the cathode.
The process parameters and formulations are evaluated based on viscosity, particle size distribution, Hansen solubility parameters and pH value. In addition, the influence of the coating and drying parameters of the electrode foils on the resulting electrochemical properties is investigated.

Continuous processing and characterization of Si anode and aqueous LFP cathode slurries via twin-screw extrusion

Kevin Raczka
Karlsruhe Institute of Technology (KIT)

Electromobility and the storage of regeneratively generated electrical energy place significant demands on the performance and costs of lithium-ion cells. Achieving these goals necessitates a deep understanding of the material properties of raw materials and manufacturing processes for electrodes. Product development and production require precise measurement and control of numerous parameters to tailor cell properties while ensuring a stable manufacturing process. Thus, the objective of this research project remains focused on lowering production costs and enhancing battery cell performance.
The approach hinges on innovative and agile plant technology capable of accommodating flexible formats and rapid recipe changes for continuous cell production. A twin-screw extruder is used for the production of the desired electrode slurry which corresponds to the first manufacturing step. The process control strategy of the extruder system is based on an adaptive, digital concept to ensure high quality battery slurries with the highest degree of automation and minimum energy input with the aim of minimizing raw material wastage or electrode slurry losses. Efficient and sustainable process control aims to decrease downtime and setup times by up to 20 % compared to conventional batch processes.
The presentation will provide insights into key quality criteria for electrode slurries and offer an overview of the lithium-ion battery manufacturing chain. A high-performance silicon-based anode material and an alternative, water-based LFP cathode are investigated. Beginning with fundamental slurry parameters such as viscosity and particle size distribution, the study proceeds to examine the electrical properties of the coated electrodes. Finally, coin cells were assembled to assess electrochemical performance. The study investigated how the extruder's energy input, controlled through screw design and rotation speed, affects the dispersion quality of the slurries.

Materials and Interfaces Design for Next-Generation Solid-state Na Batteries

Yang Zhao
University of Western Ontario

Solid-state Na batteries (SSNBs) attract increasing attention because of the high abundance, low cost, and suitable redox potential of Na [1]. In this presentation, I will introduce our research that contributed to the design of materials and interfaces for the next-generation solid-state Na batteries.
i) The cation and anion co-doping approach for sulfide-based solid-state Na electrolytes. The optimized W and Cl co-doping Na3SbS4 (NAS) present a significantly enhanced room temperature ionic conductivity of 6.4 mS cm-1. In addition, as prepared W/Cl co-doped NAS SSEs have been used for solid-state Na-S batteries with remarkable electrochemical performances, especially at high current density [2].
ii) We demonstrated a new sodium superionic glass, Na-Ta-O-Cl, based on a dual-anion sublattice of oxychlorides. The unique local structures with abundant bridging and non-bridging oxygen atoms contribute to a highly disordered Na-ion distribution as well as a low Na- ion migration barrier within Na-Ta-O-Cl [3-4].
iii) Another sulfide-chloride solid-state electrolyte was reported with high ionic conductivity and good electrochemical stability with various cathodes [5-6]
iv) We have overturned and re-investigated the application of Na3SbS4 in solid-state Na-S batteries. We first reveal the novel mechanism of self-sacrificed and decomposition of sulfide SE for achieving high-performance and stable solid-state Na-S batteries. Benefiting from decompositions, the NAS-aided solid-state Na-S batteries can deliver an ultra-high initial specific capacity of 1975.7 mAh g-1 with a capacity retention of 1294.6 mAh g-1 after 140 cycles, at a current density of 0.127 mA cm-2 . [7]
v) Interface engineering for sulfide-based solid-state Na batteries. A molecular layer deposition alucone film is employed to stabilize the active Na anode/electrolyte interface in the SSNBs, limiting the decomposition of the sulfide-based electrolytes and Na dendrite growth. [7].

Get ahead.
Break the Limits.

Production of lithium-ion batteries

Trailblazing process technology for perfect electrode mixes

Gigafactories for battery production place new demands on processes - especially in the processing of electrodes. The quality of the electrodes influences the performance of your storage cells. The processing of a first-class electrode mix - slurry, plastic body or even structured dry mix - is a demanding task. Trust a technology partner with in-depth material and process knowledge as well as decades of experience.

EIRICH

Eirich Mixer and MixSolver® with EvacMix® technology and you benefit from:

Perfect coating slurry
Agglomerate- and bubble-free

Homogeneous powder and structured dry mixes
For powder electrode coating up to free standing films

Easy scale-up
From lab scale to gigafactory

Sustainable single-pot process
Efficient and environmentally friendly

High-performance batteries
Mixing technology for highly reproducible processes

Clean turnkey solution
Strong capabilities for metering and handling

Continuous coater supply
The best of batch and conti

Highly dosable structured dry mixes
With optimal active material carbon coating and binder fibrillation

Future-oriented concept
For wet- and dry-processed electrodes

Unique mixing technology

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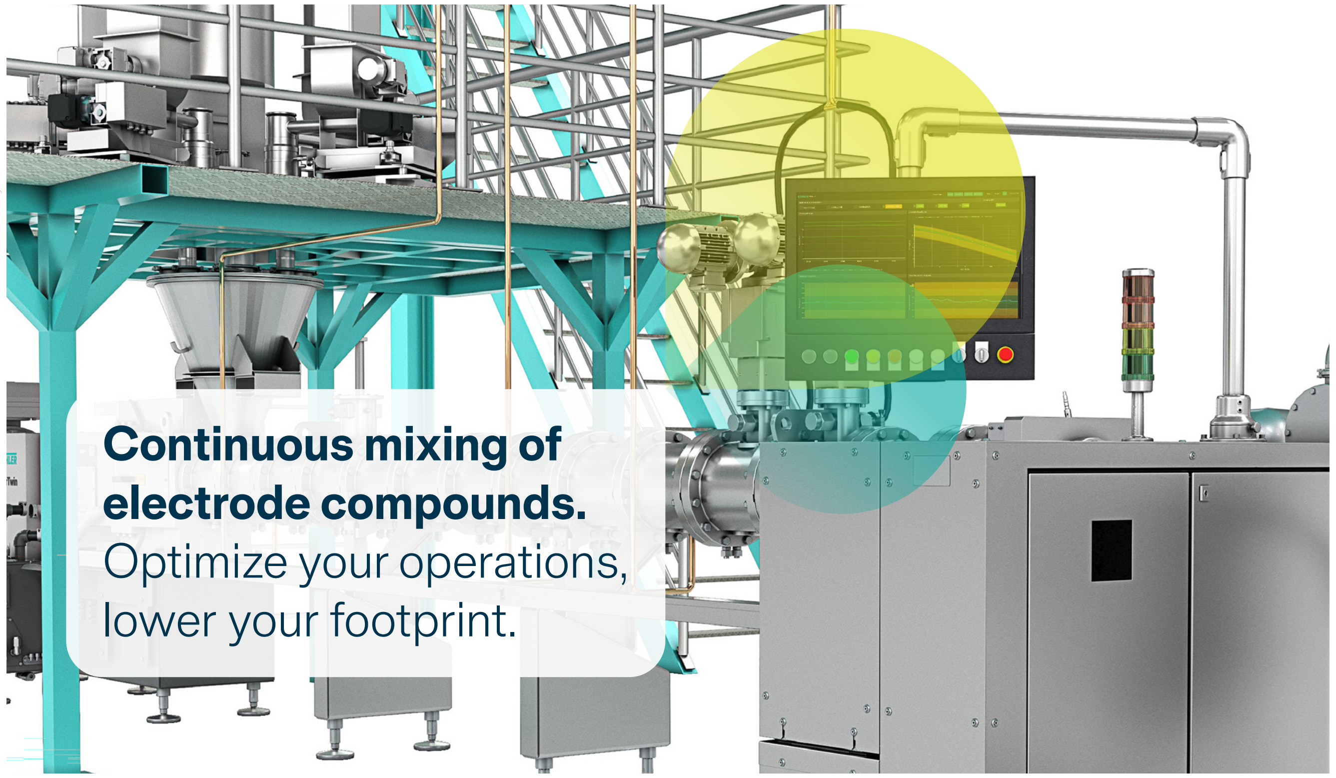


Continuous mixing of electrode compounds.
Optimize your operations, lower your footprint.

Fully continuous mixing solutions for both, conventional slurries and dry electrode compounds.

Bühler offers a wide range of solutions for the crucial process steps in LIB cell production. As a global leader in wet grinding and dispersing technologies, Bühler provides reliable, scalable, and industry-proven solutions for wet grinding of active materials and precursors as well as continuous mixing of wet and dry electrode compounds for lab, pilot, and large-scale production.

Large-scale electrode slurry production

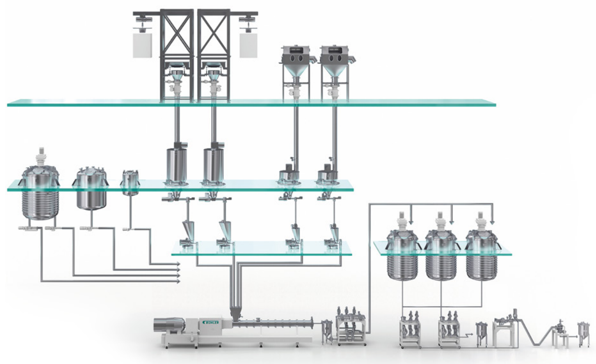
Due to fully automated operation and inline quality control (QualiB), the Bühler continuous electrode slurry mixing process enables a significant reduction in energy consumption and increase in the production yield of the electrode production. In addition, the technology is proven for the dry electrode manufacturing process (DBE).

> 15 years of battery application related process and engineering know-how and > 100 continuous mixing lines in operation in LIB industry from lab to gigafactory scale.

Proven for the conventional slurry process and ready for future manufacturing technologies such as the dry coating of electrodes.

TCO saving potential of continuous mixing process compared to planetary mixer

- **SCRAP** -75%
- **Manpower** -50%
- **Energy** -75%
- **Factory** -50% building area, -20% building height
- **ROI** < 1 year



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BÜHLER

POSTER SESSION I Day 1

Development and production of innovative and next-generation batteries: Material development and usage of innovative materials

MDP_1.1 Optimized binder- and conductive additive systems within SPAN cathodes enabling enhanced performance in Li-S batteries
Tom Boenke, Fraunhofer IWS

MDP_1.2 Performance Evaluation of Commercial Sodium-Ion Batteries
Cedric Jackmann, TU Braunschweig I elenia

MDP_1.3 Aqueous Processing of Prussian White Cathode for Sodium-ion batteries- Pre-treatment and Its Influence on Electrochemical Performance
Xuebin Wu, KIT

MDP_1.4 Hidden heroes in Li-Ion batteries – the role of polymeric binders within the environment of batteries
Maja Kandula, TU Braunschweig I ifs

Development and production of innovative and next-generation batteries: Solid state electrolytes and batteries

SSB_1.1 Optimizing Solvent-Free Production of PVDF-HFP Based Solid-State Battery Cathodes
Rezvan Karimi, TU Braunschweig I iPAT

SSB_1.2 Influence of substrate, layer thickness and surface preparation on the adhesion of magnetron-sputtered silicon anodes for solid-state batteries
Julian Brokmann, Fraunhofer IST

SSB_1.3 Scalable mechanochemical synthesis and thermal post-treatment of Argyrodites
Nina Philipp, Fraunhofer IST

Electrode and cell production: Cell assembly

CA_1.1 Joining of Electrode-Separator Compounds by Applying Electrode Binder
Stefan Gartzke, KIT

CA_1.2 Quantifying the Influence of Geometrical Defects Induced during Electrode Calendering on Ultrasonic Tab Welding
David Kraus, KIT

CA_1.3 Cause-effect relationships – the missing link in understanding electrolyte filling
Michael Hinkers, Fraunhofer FFB

Electrode and cell production: Coating and drying

CAD_1.1 Strategic Ramp-up in Lithium-Ion Battery Production: Optimizing Coating and Drying Process Parameters for Enhanced Electrode Quality
Ezgi Tuna, Fraunhofer FFB

CAD_1.2 Challenges and current goals in coating of battery electrodes
Alexander Hoffmann, KIT

Electrode and cell production: Dry coating + new coating technologies

DCT_1.1 Impact of conductive additives on dry extrusion and performance of NMC cathodes for lithium-ion batteries
Svenja Schreiber, TU Braunschweig I iPAT

DCT_1.2 How measuring pure PTFE powder flowability depending on temperature to optimize its handling
Salvatore Pillitteri, Granutools

DCT_1.3 Characterization of Binders used for Dry Coating
Helena Weingrill, Anton Paar GmbH

DCT_1.4 Vacuum Coating Technologies for Lithium-Ion Batteries
Claus Luber, Fraunhofer FEP

DCT_1.5 Exploring Inductive and Hybrid Inductive-Convective Drying Techniques for Lithium-Ion Battery Anodes
Tobias Krüger, TU Braunschweig I ifs

DCT_1.6 PFAS-free Dry Electrode Processing for Thick Electrodes in Sodium-Ion Batteries for Stationary Applications
Lea Eisele, Fraunhofer ISE

Electrode and cell production: Formation and aging

FA_1.1 Online impedance spectroscopy to monitor the formation procedure of a multi-layered 6,5 Ah LIB pouch cell
Katrin Junghans, University of Münster I MEET

FA_1.2 Formation process for lithium-sulfur batteries with polymer-based electrolyte
Marvin Nebelsiek, TU Braunschweig I elenia

Electrode and cell production: Slurry processing

SP_1.1 Insides into the structures of anode slurries with complex rheology
Felix Möhlen, TU Braunschweig I iPAT

SP_1.2 Evaluating the impact of water quality during aqueous processing of $LiNi_{0.8}Mn_{0.1}Co_{0.1}O_2$- based lithium ion battery electrodes
Vinzenz Göken, University of Münster I MEET

SP_1.3 In-line viscosity and density monitoring and control for battery slurries
Daniel Brunner, Vijoya Sa, Rheonics GmbH

Electrode, cells and systems analytics and applications: Battery production 4.0, modelling, simulation and digital twin

BPM_1.1 Modeling the drying process in hard carbon electrodes based on the phase-field method
Marcel Weichel, KIT

BPM_1.2 Smart Battery Innovations for a Sustainable Future: The PHOENIX Project and Leclanché’s Role in Feasibility and Cost Assessment
Luca Schneider, Leclanché GmbH

POSTER SESSION I Day 1

Electrode, cells and systems analytics and applications: Diagnostics during production- and use-phase

DDP_1.1 Self-Influence of Electrochemical Diagnostics in LIB: The Role of Separator and Time
Anna Rollin, TU Braunschweig I elenia

DDP_1.2 Efficient Quality Assessment of Cylindrical Battery Cells through Contactless Measurement Techniques
Daniel Nusko, Fraunhofer ISE

DDP_1.3 Defect Detection in Lithium-Ion Battery Cells using Scanning Acoustic Microscopy
Nicolas Wilhelm, Fraunhofer ISE

Recycling & Sustainability: Circular economy, battery supply chains and factory designs

BSC_1.1 Efficient and Scalable Battery Production: Energy-Based Evaluation of Microenvironments
Jan-Niklas Sturm, KIT

BSC_1.2 A Simulation Approach for the Sustainable and Resilient Spare Parts Management of Batteries in the Commercial Vehicle Sector
Marius Hermsen, TU Braunschweig I IWF

BSC_1.3 Advanced Training for Adressing the Personnel Skills Shortage
Wolfgang Brehm, TU Berlin I EET

Recycling & Sustainability: Synthesis, (direct) recycling, second use and resynthesis

SDR_1.1 Aqueous Lithium Recovery from Sulfidic Solid-state Battery Components and H2S Investigations in the Recycling Context
Ruben Schwabauer, University of Münster I MEET

SDR_1.2 Resynthesis of nickel-rich cathode active materials from recycled batteries
Martin Menzler, Fraunhofer IST

SDR_1.3 Manufacturing and Validation of NMC622 Cathodes with Artificial Impurities
Mattes Renner, KIT

SDR_1.4 Automated disassembly system for variant-flexible battery recycling
Leif Tönjes, TU Braunschweig I IWF

POSTER SESSION I Day 2

Development and production of innovative and next-generation batteries: Material development and usage of innovative materials

MDP_2.1 Fabrication of Sulfur-Aerogel-basedCathode Materials via Aqueous Wet Coating Method and Their Electrochemical Evaluation Against Magnesium Anodes
Eren Gayretli, Fraunhofer ISIT

MDP_2.2 Synthesis of mesoporous activated carbon for application in Lithium Sulfur batteries
Fabisch Kilonzi, TU Braunschweig I iPAT

MDP_2.3 Processing and Electrochemical Performance of Silicon Oxide/Graphite Composite Electrodes Across Application-Relevant Mass Loadings
Anna Gerlitz, University of Münster I MEET

MDP_2.4 Sodium-Ion Batteries: Drop-in ability in the context of industrie relevant process routes
Kriss-Kevin Daniel Kasten, TU Braunschweig I iPAT

MDP_2.5 Development of a hybrid supercapacitor combining the qualities of an Electric Double Layer Capacitor and a Lithium-ion battery
Stefano Paradiso, Novac Srl

Development and production of innovative and next-generation batteries: Solid state electrolytes and batteries

SSB_2.1 Investigating Ionic Conductivity of Tailored Composite Electrolytes for Solid-State Batteries
Marvin Freser, Fraunhofer ISC

SSB_2.2 Optimization of SPAN Cathodes with Polymer Electrolytes for Solid-State Lithium-Sulfur Batteries
Mahsa Hokmabadi, TU Braunschweig I iPAT

SSB_2.3 Quasi-solid electrolytes using single cation ionic liquids
Yuta Ito, AIST Osaka

SSB_2.4 Upscaling and Advanced Extrusion as Enablers for Efficient Solid Polymer Electrolyte Development
Felix Scharf, Jülich GmbH

SSB_2.5 Fast-Charging of Solid-State Batteries Enabled by Functional Additives Infused into High-Mass-Loading NMC Cathodes
Pascal J. Glomb, Jülich GmbH

SSB_2.6 Impact of Li6PS5Cl Comminution on the Densification and Cell Performance of Solid-State Cathodes
Carina Heck, TU Braunschweig I iPAT

Electrode and cell production: Cell assembly

CA_2.1 Modelling the multi-layer electrode of solid-state battery and validation of handling process
Sen Bai, Politecnico di Milano

CA_2.2 Enhanced Modulated Laser Processing Techniques for Lithium Metal Anodes
Paul Härtel, Fraunhofer IWS

POSTER SESSION I Day 2

Electrode and cell production: Dry coating + new coating technologies

DCT_2.1 Investigating the influence of the residence time distribution in a twin-screw extruder on dry coated granules for electrode production
Julius Gerk, TU Braunschweig I iPAT

DCT_2.2 Effect of LFP particle sizes on the pore structure of semi-dry processed lithium-ion battery cathodes
Niclas Hornischer, TU Braunschweig I iPAT

DCT_2.3 Challenges of Dry Coating: How Does Scale-Up Affect Powder and Electrode Properties?
Franziska Beverborg, TU Braunschweig I iPAT

Electrode and cell production: Slurry processing

SP_2.1 Solvent-Reduced Continuous Processing of Lithium-Ion Battery Cathodes
Niklas Penningh, TU Braunschweig I iPAT

SP_2.2 Influence of stress mechanism on slurry mixing in stirred media mills
Marcel Filipe Möller, TU Braunschweig I iPAT

Electrode, cells and systems analytics and applications: Battery production 4.0, modelling, simulation and digital twin

BPM_2.1 Electro-chemo-mechanical modelling of cathode in sodium-nickel chloride batteries using PyBaMM
Cerun Alex Varkey, Fraunhofer IST

BPM_2.2 Modeling Swelling Behavior in Nano-Silicon Coated Graphite Anodes Using Discrete Element Method: Insights into Particle-Level Interactions and Irreversible Volume Changes
Kashfia Mahin, TU Braunschweig I iPAT

BPM_2.3 Development tool for sustainable and repairable battery systems for electric and hybrid powertrains
Robert Kretschmann, Otto-von-Guericke-University Magdeburg

BPM_2.4 Smart Machinery & Digital Tools for Energy?Efficient, Scalable Battery Cell Manufacturing (BATMACHINE)
Kamil Burak DERMENCI, Vrije Universiteit Brussel

BPM_2.5 Sustainable and digitalized GIGAfactory for BATtery production with made-in-Europe machinery (GIGABAT)
Iker Boyano, Cidetec

Electrode, cells and systems analytics and applications: Diagnostics during production- and use-phase

DDP_2.1 Ensuring the highest quality in Battery Cell Manufacturing through advanced sensors
Florian Hermann, Precitec GmbH & Co. KG

DDP_2.2 Aging Behavior of Sodium-Ion Batteries
Merit Holdorf, TU Braunschweig I elenia

Recycling & Sustainability: Circular economy, battery supply chains and factory designs

BSC_2.1 AI-Optimized Recycling of Lithium-Ion Batteries: Enhancing Sustainability and Circularity through Intelligent Process Control
Steffen Fischer, TU Braunschweig I iPAT

BSC_2.2 Metrology for Eco-Assessments of Batteries
Olav Werhahn, PTB

BSC_2.3 LiPLANET – From EU-Project to Pan-European Innovation Network for Lithium-Ion Cell Production
Payam Hashemi, TU Braunschweig I iPAT

Recycling & Sustainability: Synthesis, (direct) recycling, second use and resynthesis

SDR_2.1 Joint-adapted separation processes for the automated disassembly of battery systems
Malte Mund, TU Braunschweig I ifs

SDR_2.2 Reviving Production Scrap and End-of-Life Anodes
Hannes Bauer, Fraunhofer ISC

SDR_2.3 Recycling of NMC: How Synthesis Methods Influence the Effect of Impurities
Markus Rojer, TU Braunschweig I iPAT

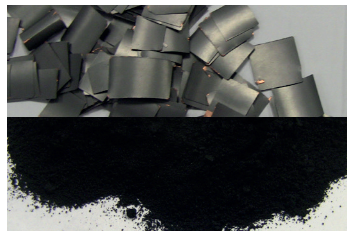
SDR_2.4 Recovery of LIB electrolyte from blackmass by solvent-extraction
Kai Schröder, TU Braunschweig I ICTV

SDR_2.5 Balancing Efficiency and Composition in the Recovery of Black Mass from Lithium-Ion Battery Recycling
Marcelo Oliveira, CeNTI

Retsch
a VERDER company

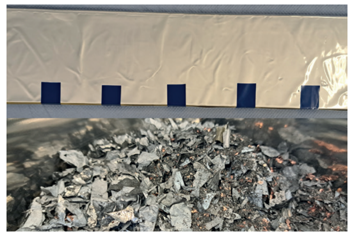
At **RETSCH**, we provide the tools you need to master every step of the battery value chain, from research and development to quality control, and recycling. Our **laboratory mills** enable precise particle size reduction and reliable homogenization for material analysis of all battery-relevant materials. RETSCH solutions cover every step, from initial shredding and cutting to fine grinding and homogenization for chemical analysis.

BALL MILLS
and cryogenic grinding technologies are suitable for fine grinding or for mechanochemical synthesis of battery materials.



Milling of electrodes

CUTTING MILLS
are ideal for cutting cells and battery components in a laboratory scale.



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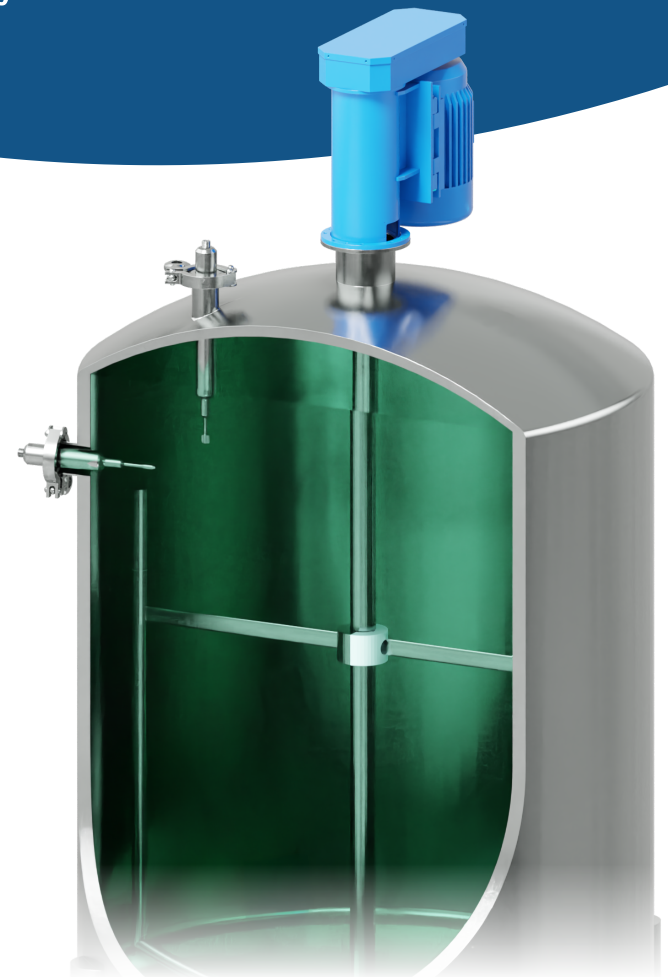

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POSTER ABSTRACTS I Day 1

Development and production of innovative and next-generation batteries: Material development and usage of innovative materials

Optimized binder- and conductive additive systems within SPAN cathodes enabling enhanced performance in Li-S batteries

Tom Boenke
Fraunhofer-Institute for Material and Beam Technology IWS

The lithium sulfur (Li-S) cell chemistry is promising due to the high specific capacity of its active materials resulting in high specific energy cells. Consequently, this battery type is notably suitable for lightweight applications such as aviation. Sulfurized polyacrylonitrile (SPAN) is an emerging material offering the advantages of sulfur with the absence of dissolved polysulfides. Those are known to cause the so-called shuttle effect usually resulting in a rapid capacity decay due to electrolyte depletion and corrosion reactions at the Li anode surface. Owing to the comparably low active material content (around 40 %) in SPAN, optimization (e.g. densification) on electrode level is a crucial aspect for maximizing the energy density on cell level. In the project SulForFlight, industrially produced SPAN material is used for manufacturing Li-S battery cathodes. Herby, the scalable production of electrodes as well as their mechanical properties were investigated. In this work, the optimization of the electrode behavior after compacting was investigated by varying the binder- and conductive additive systems. For characterization, optical and mechanical measurements were done as well as electrochemical tests using coin cells and multi-layered pouch cells. Recent electrodes achieved discharge capacities up to 1400 mAh g(S)-1 and high rate capabilities up to 3C even after a densification of 50 %. Additionally, first prototype cells could exceed 200 Wh kg-1 over 70 cycles demonstrating the potential for usage in aviation applications.

Performance Evaluation of Commercial Sodium-Ion Batteries

Cedric Jackmann
TU Braunschweig I elenia Institute for High Voltage Technology and Power Systems

Lithium-ion batteries (LIBs) are renowned for their high energy density and excellent performance, currently making them the dominant technology on the market. However, they are increasingly subject to criticism due to the limited availability of raw materials, the presence of toxic components, and various safety concerns. As a result, sodium-ion batteries (SIBs) are being intensively investigated as a promising alternative.

Although SIBs generally exhibit lower energy densities and reduced performance within the same temperature range compared to LIBs, they offer several notable advantages. Sodium is one of the most abundant elements in the Earth's crust, and the use of sodium in cell production, operation, and recycling is associated with significantly lower environmental and health risks. Moreover, SIBs can be operated across a wider temperature range, and the risk of thermal runaway is lower and less hazardous than in LIBs. Currently, the availability of commercial SIBs is still limited and predominantly restricted to products from Asia.

This study investigates the electrochemical properties of selected commercially available SIBs. Key parameters such as capacity, internal resistance, long-term stability (aging behavior), and electrochemical impedance spectroscopy (EIS) are analyzed. The results are compared with manufacturer datasheets and literature data on commercial LIBs to assess the performance and potential of SIBs as an alternative energy storage technology.

Aqueous Processing of Prussian White Cathode for Sodium-ion batteries - Pre-treatment and Its Influence on Electrochemical Performance

Xuebin Wu
Karlsruhe Institute of Technology (KIT)

Sodium manganese hexacyanoferrate ($Na_{2-x}Mn[Fe(CN)_6]_y$), commonly known as Prussian white (PW), is a promising cathode material for sodium-ion batteries due to its high theoretical capacity, earth-abundant composition, and facile synthesis without the need for high-temperature calcination. To fully realize its cost-effectiveness, aqueous electrode processing is essential. However, the effects of aqueous processing on the structure and performance of Prussian white remain insufficiently understood. In this work, we investigate the phase transitions and porosity evolution of manganese PW during aqueous slurry processing, and their implications for sodium-ion battery performance. Structural characterization reveals that hydration and dehydration induce significant morphological change in PW particles and increases their porosity. Despite reduced mechanical stability, the aqueous-processed electrodes exhibit markedly improved rate capability compared to those fabricated using N-methyl-2-pyrrolidone and conventional polyvinylidene difluoride binder. Furthermore, a pre-dehydration step prior to slurry preparation is found to enhance rate performance and extend cycle life. Post-mortem analysis shows the porosity generated during the aqueous processing of the pre-dehydrated PW helps mitigate crack formation associated with phase transition during electrochemical cycling. These findings provide insight into the interplay between processing and electrochemical performance, supporting the advancement of greener and more cost-effective manufacturing strategies for Prussian white-based sodium-ion batteries.

Hidden heroes in Li-Ion batteries – the role of polymeric binders within the environment of batteries

Maja Kandula
TU Braunschweig I Institute of Joining and Welding (ifs)

Binder materials play an increasingly important role in battery technology, substantially influ- encing the performance and lifetime behaviour of batteries. Consequently, a comprehensive knowledge of the behaviour of binders in a battery system and the associated optimization of binder properties, which is essential for the development of sustainable battery materials, is the goal for sustainable energy materials. Nowadays there are a variety of alternatives to car- boxymethyl cellulose (CMC) and polyvinyliden fluoride (PVDF) as binding materials. Neverthe- less, what are the defining features of a good binder, and what are the features that are less important? Various aspects, from the molecular structure and mechanical properties of the material to the processing interaction with the various battery components, are important factors that influence the service life of the battery. The aim of this work is to investigate how a new binder system can influence the processing parameters, electrode properties and electrochemical performance. The investigation of rheological behaviour, adhesion and cohesion characteristics of new binder systems were characterized with a combination of mechanical measure- ments, spectroscopic analysis and electrochemical characterization like EIS (electrochemical impedance spectroscopy) to study the binder influence on the battery cell. This research deals with sustainable battery materials by using bio-based polymeric binders and the application in energy storage systems. However, there are not only advantages for ecological footprint reasons. In the results we see a lot of advantages regarding a higher adhesion of the composite material, better capacity performance and interesting resistance properties caused by a new binder and active material interaction. The mechanical and electro physical tasks of the binder are very diverse and grow with the increase of new materials, as active materials e.g., and processing methods. We will have to deal with new fluorine-free polymer components in the future, so it is important to find new substitutes as quickly as possible.

Development and production of innovative and next-generation batteries: Solid state electrolytes and batteries

Optimizing Solvent-Free Production of PVDF-HFP Based Solid-State Battery Cathodes

Rezvan Karimi
TU Braunschweig I Institute for Particle Technology (iPAT)

Nowadays, solid-state batteries (SSB) are considered as a promising future energy storage technology. Among different types of solid electrolytes (SE) for SSBs, polymeric SEs have the advantages of higher mechanical stability and acceptable electrochemical stability. Regarding their production process, solvent-free methods are environmentally friendly and cost-effective. However, open questions remain regarding mixing of components in order to maximize all conduction paths within the battery.
In this regard, we investigate the cathode production using a solvent-free method that consists of a mixing procedure using a kneader device followed by direct calendaring. The kneader device can be used at high temperatures allowing the polymers to melt and encapsulate other cathode materials. In the next step, the achieved mixture is inserted in the calender device to form a free-standing film which is laminated onto current collector.
In this study, single-crystal NMC811, C45 and LiTFSI were used as active material, electrical conductive additive and ion conducting salt, respectively. PVDF-HFP was used as basis for the polymer electrolyte due to its high thermal, mechanical and electrochemical stability. Yet, it has some drawbacks regarding like high melting temperature and negligible ionic conductivity. To overcome these limitations, PEO is used to enhance the ionic conductivity and reduce the processing temperature. As an additive, PYR14TFSI will be employed to aid lithium salt dissociation and the ion mobility.
Key parameters including the barrel temperature, screw speed and residence time in the kneader can ensure a uniform mixing without thermal degradation. Therefore, the aim of this study was to optimize the process parameters for the material system under investigation. For each condition electronic and ionic conductivity were examined. Then cathode sheets were cycled at 80 °C and 0.1C against metallic Lithium anode to investigate the electrochemical performance.

Influence of substrate, layer thickness and surface preparation on the adhesion of magnetron-sputtered silicon anodes for solid-state batteries

Julian Brokmann
Fraunhofer Institute for Surface Engineering and Thin Films IST

Solid-state batteries (SSBs) are a key technology for next-generation energy storage. They offer improved safety, higher energy density and better thermal stability than conventional lithium-ion systems. However, their performance depends heavily on the stability and quality of interfaces. While silicon is an extremely promising anode material thanks to its exceptional theoretical capacity, its practical use is limited by volumetric expansion and poor adhesion to current collectors, particularly in solid-state systems. Therefore, improving adhesion is crucial to enhancing the mechanical integrity and overall performance of silicon anodes in SSBs.
In this study, we investigated how substrate selection, film thickness, and surface pre-treatment influence the adhesion and surface characteristics of DC magnetron-sputtered silicon anodes. Prior to deposition, the substrates were modified using various methods to increase surface roughness and interfacial reactivity, including mechanical, chemical, and plasma-based treatments. In some cases, an additional interlayer material was introduced to promote stronger bonding between the silicon film and the underlying substrate.
A wide range of characterisation techniques were employed to investigate surface and interface properties relevant to cell performance. These included mechanical tests to evaluate adhesion strength, as well as microscopic and spectroscopic methods to assess morphology and composition. Surface analysis techniques were also employed to probe roughness and interfacial structure. By comparing the results, we were able to identify how these properties were influenced by the processing conditions, and how they contributed to improved electrochemical stability and overall performance in solid-state battery configurations.

Scalable mechanochemical synthesis and thermal post-treatment of Argyrodites

Nina Philipp
Fraunhofer Institute for Surface Engineering and Thin Films IST

Solid-state batteries are considered one of the most promising technologies for the next generation of energy storage devices. The benefits of solid-state batteries with sulfide-based solid electrolytes include higher energy densities with new anode concepts and high performance due to high ionic conductivities. Improved safety features also reduce the risk of battery thermal runaways and expand the range of possible uses in various applications, from electric vehicles to renewable energy systems. In order to further improve the properties of sulfide-based solid electrolytes, the focus is on adapting the material composition, scaling the synthesis processes and thermal post-treatment.
A scalable synthesis route for sulfide-based solid electrolytes is mechanochemical synthesis via ball milling. Compared to the more established solvent-bases synthesis, the mechanochemical synthesis provides the benefit that no solvents are required. Consequently, the purity of the solid electrolytes and the performance can be increased. The subsequent thermal post-treatment is required to improve the crystallinity and the electrochemical properties. The process parameters, such as temperature, residence time, and heating rate, of the thermal post-treatment have a crucial impact on the properties of the solid electrolyte. In this study, the mechanochemical synthesis are compared and the heat treatment processes for adjusting product properties through variation of mechanochemical and thermal process parameters and variation of reactants (stoichiometry and resulting phase composition) are examined, and the products are characterized using Raman, PXRD, and EIS.

Electrode and cell production: Cell assembly

Joining of Electrode-Separator Compounds by Applying Electrode Binder

Stefan Gartzke
Karlsruhe Institute of Technology (KIT)

In current battery production, technical throughput limitation represents an unsolved challenge. The throughput limitation in the production process is particularly evident in the manufacturing of the electrode-separator-assemblies (ESA) using Z-folding or stacking processes. There is a physical limitation to the handling of individual electrode sheets that limits the ability to increase process speed. Using multi-layer, joined pre-products made of electrodes and separators with the same process time per handling object enables an increase in throughput. Alternatively, the processing time can be reduced by a continuous process (roll to roll) that does not require discrete handling steps. To do this, individual electrode sheets must be joined to a continuous material web in an upstream process step.
To date, thermally activated hot-joining processes (lamination) have been used for ESA production. In addition to this energy-intensive and material-dependent composite manufacturing process, a material bond between the electrode coating and the separator can also be produced by the metered application of a mixture of solvent and cell-own binder. This work presents a systematic investigation of the influence of different binder mixtures and process parameters on the process quality. In particular, the adhesive force achieved between the electrode sheets and the separator was examined. The approach is based on a design of experiments. For each specified experiment, electrode sheets were joined to the separator material under defined process conditions. The adhesive force was then quantitatively investigated based on peel tests.
This optimization of the joining process can enable new, continuous and therefore more productive stacking processes.

Quantifying the Influence of Geometrical Defects Induced during Electrode Calendering on Ultrasonic Tab Welding

David Kraus
Karlsruhe Institute of Technology (KIT)

Cell contacting is a key process in the production of lithium-ion batteries, with ultrasonic welding being one of the prominent joining technologies. Weld quality depends on the surface quality of the electrode substrate foil at the welding position, with more even surfaces generally leading to better welding results. Substrate evenness is influenced by the upstream production step of calendering, especially since higher compaction rates may produce geometrical defects in the substrate foil, such as foil embossing and longitudinal wrinkles, which can impair the welding process.

This work focuses on calendered NMC622 cathode webs and specifically analyses the occurrence and impact of geometrical defects in the current collector region designated for tab welding. To assess their influence on ultrasonic welding quality, samples were extracted from electrode webs calendered at different sets of parameters. The material strength under the influence of various defect patterns was compared using tensile tests. The strength of the welding spots was evaluated using T-peel tests. Calendering orientation and structural weak points, such as the coating edge, were considered during sampling and orientation-dependent results were compared to quantify the directional influence of calendering on material behavior. The mechanical strength of welded joints was evaluated as a function of defect type, location and orientation.

This study attempts to quantify the effect of geometrical defects on weld strength and quality. This can lead to better welding results when using more highly compacted electrode material. The insights enable precise control of the welding parameters needed to achieve durable welds at higher compaction rates during calendering.

Cause-effect relationships – the missing link in understanding electrolyte filling

Michael Hinkers
Fraunhofer research institution for Battery Cell Production FFB

In order to meet consumer demand for more affordable electric cars, battery cell production processes must be continuously optimised, alongside other factors such as material prices or cell integration. With a throughput of 0.6 to 0.7 GWh/a per electrolyte filling system (compared to 5 GWh for the coater)1, the process is a bottleneck in cell assembly and must be highly parallelized to keep up with the throughput of a gigafactory. Additionally, electrolyte filling is decisive for the quality and safety of the cell, as complete wetting of the cell must be guaranteed to maximize performance and prevent formation of high surface area Li deposits due to local current differences[1]. Considering the current trend of producing larger battery cells formats, especially in the automotive sector, the bottleneck in production capacity represented by electrolyte filling becomes even more critical due to the increase in wetting time[2]. Consequently, there is substantial potential for identifying process optimizations in the electrolyte filling process to save costs and resources. However, process optimization requires knowledge of complex cause-effect relationships, which are not fully understood.

Therefore, in this study, we show how to identify and assess the factors and cause-effect relationships influencing the electrolyte filling process based on a systematic literature search and expert knowledge. These findings enable us to identify the most important limitations of electrolyte filling to develop possible solutions for process optimization. In addition, initial results from these analyses will be presented, which will be validated in the future during the ramp-up phase of electrolyte filling in the Fraunhofer FFB pilot plant.

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Electrode and cell production: Coating and drying

Strategic Ramp-up in Lithium-Ion Battery Production: Optimizing Coating and Drying Process Parameters for Enhanced Electrode Quality

Ezgi Tuna
Fraunhofer research institution for Battery Cell Production FFB

The global demand for batteries is growing due to advancements in electric vehicles and renewable energy. This demand, not only for quantity but also for low-cost and high-performance batteries, highlights the critical need for efficient production and enhanced research in battery technologies. To enable the scaling up of innovations to industrial Technology Readiness Level (TRL), Fraunhofer Research Institution for Battery Cell Production FFB is strategically ramping up its pilot line and establishing a battery research factory. The scale-up in production capacity is essential for optimizing resource efficiency in terms of time, materials, and costs. Coating and drying processes are critical in battery production as they significantly affect the quality and performance of electrodes. The uniformity of coatings influences electrochemical properties, while drying impacts structural integrity and overall efficiency of the batteries. Therefore, defining the framework conditions for optimal coating and drying processes is essential. In the ramp-up studies at Fraunhofer FFB, Key Performance Indicators (KPIs) are defined as critical parameters in large-scale lithium-ion battery (LIB) production. A KPI matrix is then created for a clear, quantifiable evaluation of process results. By systematically varying these key factors, particularly drying process parameters, observations are made on their impact on the mechanical and electrochemical properties of the electrodes. Furthermore, a correlation model is developed to understand the relationships between coating and drying process settings and quality parameters. This model predicts the settings and quality parameters of the electrode from input variables of the process through established cause-and-effect relationships. By integrating specific parameters into the overall framework, the target is to optimize electrode production, ensuring that the resulting batteries are high-performing and reliable in their applications.

Challenges and current goals in coating of battery electrodes

Alexander Hoffmann
Karlsruhe Institute of Technology (KIT)

In conventional battery electrode manufacturing, at least two sequential coating and drying steps are required to apply active materials to both sides of the substrate. In contrast, the simultaneous double-sided coating process applies battery slurries to both sides of the current collector before entering the dryer. This coating process comprises two sub-steps, with potentially different coating methods. Notably, the tensioned-web process is employed at one stage, where the web is pulled under tension over the nozzle lips without a fixed backing roller. Both sides of the substrate are coated with wet films, complicating web handling and necessitating a floatation dryer to prevent contact with machinery [1].

The differing coating methods for each side in this process variant lead to variations in coating stability, quality, wet film profiles, and edge geometries. Without further optimization, the coating quality on both sides remains insufficient to meet the stringent requirements of the battery industry [2]. Thus, a detailed understanding of the fixed-gap and tensioned-web processes, along with their influencing factors, is critical.

This study presents recent findings from cause-and-effect investigations, focusing on:

- Mechanisms governing edge geometry formation and strategies for their control and alignment.
- Modified stability ranges of coatings and their interdependencies.
- Opportunities for predictive analysis and simulation.
- Prospects for multilayer and intermittent coating technologies.

Electrode and cell production: Dry coating + new coating technologies

Impact of conductive additives on dry extrusion and performance of NMC cathodes for lithium-ion batteries

Svenja Schreiber
TU Braunschweig I Institute for Particle Technology (iPAT)

Compared to wet coating, the solvent-free production of battery electrodes offers considerable potential to improve the energy and resource efficiency of the electrode production process, since the entire drying step can be omitted. Cross-linking of the individual particles is achieved through the PTFE which fibrillates under the influence of shear stress. The properties of the pre-fibrillated powders, such as their morphology and processability in the subsequent calendering step, as well as their electrochemical behavior, are significantly influenced by the material characteristics and the ratio of conductive carbon black and binder. The formulation, material composition and processing conditions of lithium-ion battery electrodes are critical to their structural integrity and performance. Variations in these parameters can impose different levels of mechanical stress on the active material and its supporting binder matrix during the manufacturing process.

The present study investigates how these variations impact the dry extrusion process, focusing particularly on the effect of conductive additives, such as conductive graphite and carbon black, and their impact on the morphology, cohesion, and functionality of extruded granules used in NMC cathode production. The effect of different additive formulations on granule homogeneity, flow behavior, and stress distribution during extrusion was investigated to achieve a stable process and improved electrode properties. The granules are then subjected to a multi-roll calendering process for further evaluation and fabrication of electrodes. The microstructure of the electrode is analyzed using a combination of methods, including scanning electron microscopy (SEM) images, particle size distribution, and compaction behavior. Additionally, the mechanical and electrochemical properties are evaluated. This enables the correlation of formulation and processing variables and cell-level performance.

How measuring pure PTFE powder flowability depending on temperature to optimize its handling

Salvatore Pillitteri
Granutools

Polytetrafluoroethylene (PTFE) is largely used for dry processes. Its plasticizing behaviour is used to transform the powder blend containing the active material and the conductive additive into a free-standing film after calendering. Although fibrillation of PTFE is required for the dry-process, beforehand, pure PTFE powder has to be handled and conveyed to be mixed with the active material and the conductive additive, and then fibrillated. For this handling, fibrillation must be avoided since it reduces PTFE flowability and degrades its initial properties. Since it is known that PTFE starts to significantly fibrillate at temperatures beyond 19°C, it is generally recommended to handle it at temperatures below this critical threshold. Nevertheless, little is known about the evolution of flowability with temperature, while the challenge and the price for cooling a production line or a laboratory can rapidly increase for each degree less. This can lead to overcooling and unnecessary expenses if the flowability is still sufficient at higher temperatures. Therefore, a method for quantifying flowability evolution with temperature is necessary.

In this work, we present how pure PTFE flowability can be characterized according to temperature. Two grades of PTFE powder were tested with the GranuDrum at room or at cool temperatures to evaluate the effect of temperature on flowability. Significant differences in flowability are seen between room and cool temperatures and are quantified by the Cohesive Index of the GranuDrum. Furthermore, it is observed that the dependency of PTFE flowability is not linear with temperature, highlighting the importance of quantifying this dependency. Therefore, it is possible to define the highest temperature at which the powder flow is sufficient for processability. This solves the compromise between the cooling and the handling of the PTFE powder and removes doubt about the optimal temperature to adopt.

Characterization of Binders used for Dry Coating

Helena Weingrill
Anton Paar GmbH

The principal constituents of dry battery electrodes (DBE) generally comprise an active ingredient, a conductive additive and a binder (most often polytetrafluoroethylene (PTFE) is used). Coming from different suppliers and/or undergoing varying process routes, available PTFE grades can vary in their ability to fibrillate. Interestingly, not only the fibrillation ability of the pure PTFE but also the PTFE's interaction with the other constituents of the premix during fibrillation can impact the premix's overall fibrillation behaviour as shown in a comprehensive study by Horst et al [1]. Therefore, the present study demonstrates how to determine the fibrillation ability of pure PTFE as well as of premixes thereof with small-volume samples in a rheometer.

The first part of the study focuses on investigating the fibrillation ability of three PTFE types, which differ in their fibrillation properties. Temperature-controlled wall friction measurements with an underlying normal stress ramp are applied to fibrillate PTFE in a powder shear cell. A newly developed evaluation for assessing their fibrillation ability is successfully applied and confirmed by the indication provided by the manufacturer.

The second part covers the fibrillation ability of anode premixes. Premixes with two of the above-mentioned PTFE types and two different battery-grade graphite types (natural and artificial) are fibrillated in a powder flow cell equipped with a specialized measuring system and a newly developed measurement method. By differences in the torque evolution, the fibrillation ability can be successfully assessed. The main impact comes from the utilized PTFE, however, the incorporated graphite type also affects the premix's fibrillation ability.

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Vacuum Coating Technologies for Lithium-Ion Batteries

Claus Luber
Fraunhofer Institute for Electron Beam and Plasma Technology FEP

The demand for high-energy-density lithium-ion batteries (LIBs) is increasing due to the growing need for portable electronic devices and electric vehicles. The fabrication of these batteries is mainly based on slurry processes with the subsequent need for solvent reclaim and long drying processes consuming a lot of time and energy.

Within this work, we show innovative approaches for parts of the battery that are based on physical vapour deposition processes, thus cancelling the need for solvents and costly drying steps.

For the anode, two different approaches based on vacuum technology are pursued:

-Synthesis of structured silicon thin film anodes by physical vapor deposition (PVD)

-Deposition of lithium-silicon compound layers to prepare a pre-lithiated Si anodes by PVD

We furthermore show processes for the preparation of a light-weight current collectors by metallization polymer films and the synthesis of pure silicon anodes by physical vapor deposition (PVD).

We believe that from the production point of view, vacuum thin film technologies can offer process alternatives for battery anodes. Fraunhofer FEP offers several technologies and development platforms to provide innovative approaches inside the battery eco-system.

Exploring Inductive and Hybrid Inductive-Convective Drying Techniques for Lithium-Ion Battery Anodes

Tobias Krüger
TU Braunschweig I Institute of Joining and Welding (ifs)

This study investigates the applicability of inductive heating as a novel drying technique for water-based graphite anodes used in lithium-ion battery (LIB) manufacturing. Despite its promising potential, the use of inductive heating for electrode drying remains largely unexplored. The aim is to assess its feasibility both as a stand-alone method and as part of a hybrid approach in combination with conventional convective drying. To this end, laboratory-scale experiments were conducted using different process configurations: purely inductive drying and hybrid inductive-convective drying with varying air flow velocities, heat transfer coefficients, and overall drying intensities.
The temperature distribution and evolution within the electrode coatings during the drying process were monitored using infrared thermography to capture spatial and temporal heating behavior. Drying rates were determined gravimetrically and correlated with the specific power input. Furthermore, the resulting electrodes were characterized with respect to key quality parameters such as adhesion strength, microstructural integrity, and electrochemical performance. These were compared against conventionally convectively dried reference electrodes to evaluate potential differences and trade-offs.
By systematically varying the drying conditions, this study provides insights into the effect of inductive heating on electrode quality and performance. Particular attention is paid to potential challenges such as binder migration and particle segregation, which are known to occur at high drying rates. The results contribute to a better understanding of whether established correlations from conventional drying processes are transferable to inductive or hybrid drying approaches and highlight the potential of inductive heating to improve energy efficiency and process speed in LIB electrode production.

PFAS-free Dry Electrode Processing for Thick Electrodes in Sodium-Ion Batteries for Stationary Applications

Lea Eisele
Fraunhofer Institute for Solar Energy Systems ISE

Sodium-ion batteries (SIBs) have recently attracted rising attention due to the use of highly available and globally evenly distributed raw materials, potential low cost, similarity to Lithium-ion-battery (LIB) chemistries, and convincing performance.[1] The optimization of the manufacturing process of SIBs can further increase economic and environmental competitiveness with modern LiFePO4-based batteries, e.g., by transitioning to low solvent or solvent-free processes. Additionally, the possibility of such processes to obtain an increase of the electrode thickness can be an important opportunity for increased energy densities of SIBs, reducing the share of components that do not directly contribute to the charge storage process. The areal loading of most commercial cells is typically limited to 3.5 mAh cm-2 due to the limitations of the slurry-based process.[2]
Especially for stationary battery applications the use of thicker electrodes is very suitable, as diffusion-limited power performance is not necessarily an issue at such scale (or can be addressed by combining SIBs with power sources such as super caps). This poster provides insights into the feasibility of using (semi)-dry-processed thick electrodes in SIBs. Notably, the usage of PFAS-free binders in a dry coating process is successfully demonstrated with superior performance compared to the fluorinated binder for P2-Na2/3Fe1/2Mn1/2O2 cathode material and Hard Carbon anode materials. The resulting electrodes exhibit tunable morphologies, including porosity control, good structural stability, ultra-high areal capacities up to 10 mAh cm-2 and high energy densities. Full-Cell tests with different electrolytes highlight the importance of electrolyte engineering tailored to the high loading electrodes to avoid Sodium plating. The results show that such thick electrodes with very high areal capacity und good performance can be successfully produced using a hot-pressing process and without fluorinated binders.

Electrode and cell production: Formation and aging

Online impedance spectroscopy to monitor the formation procedure of a multi-layered 6,5 Ah LIB pouch cell

Katrin Junghans
University of Münster I MEET

Lithium ion battery formation is an important and time-consuming step in battery production, affecting quality, lifetime and battery safety. The formed solid electrolyte interphase is determined in structure and composition by the initial charge-discharge-cycle. This SEI build-up and its effect on the battery quality are in the focus of many studies. While the formation is running an Inline-battery-analysis could be a fast quality control and tool for process optimization.
Without interrupting the current flow of the formation of a multi-layered pouch cell multiple real-time impedance spectra are measured. This allows insights into various interface and charge transfer resistances, as well as their evolution and enabling the determination of SEI formation completion or potential lithium plating effects. Measuring an impedance spectrum with one-minute intervals, state of charge, voltage and time dependent effects could be analysed additionally with an electrical circuit.
In the formation cycles of a multi-layered pouch cell with NMC811||C this study characterizes voltage regions based on impedance spectra changes. The voltage ranges correlate with the differential capacity test for the formation cycles. To determine cell quality parameters during cell finalization the online impedance spectroscopy technique.

Formation process for lithium-sulfur batteries with polymer-based electrolyte

Marvin Nebelsiek
TU Braunschweig I elenia Institute for High Voltage Technology and Power Systems

The lithium-sulfur (Li-S) battery is a promising battery technology because it has a potential higher theoretical energy density (~2,500 Wh/kg) than the lithium-ion battery technology (400 – <800 Wh/kg). Nevertheless, the Li-S battery has the disadvantage that it suffers a significant loss of capacity after just a few charging cycles, which limits its applicability in most cases. However, improved cycle stability would significantly increase the potential of this technology. To achieve this the formation process is crucial as it determines the subsequent performance during operation.
In this study, different Li-S cells are subjected to different formation processes, and the resulting performance is investigated through cycling and electrochemical characterization methods, i.e., electrochemical impedance spectroscopy (EIS) and differential voltage analysis (DVA).
Content of the poster will be:
- Specification of the formation processes
- Description of the test environment
- Comparison of the results of the characterization methods
The aim of these investigations is to find a formation procedure that extends the lifetime of Li-S batteries.

Electrode and cell production: Slurry processing

Insides into the structures of anode slurries with complex rheology

Felix Möhlen
TU Braunschweig I Institute for Particle Technology (iPAT)

Batteries play a vital role in the energy transformation from fossil fuels towards more sustainable electrochemical storage systems. In the future, the cell performance increases constantly and new material compounds need to be available.
In the area of battery research, the electrode slurry rheology is an important property. Not only for the applicability in the production steps e.g. the coating, but also for the later electrochemical performance of the cell. In the battery process chain the dispersing of the materials is the first crucial step towards a highly functional cell. The process-structure-property-interactions must be fully understood in order to achieve an optimal result.
This presentation sheds light on the structure within anode suspensions. Due to the large number of components (carbons, polymers, stabilisers, ...), the resulting structure is a complex construct. An understanding of the interactions is not fully understood. Classical rotational measurements only allow the control of process parameters, whereas oscillatory measurements provide an insight into the material behaviour. The oscillatory analysis of suspensions is not yet established in battery research. In the lecture, the measurement procedure and analytical/algebraic evaluation methods will be discussed and the correlations and further potentials in their application will be presented. Experiments with suspensions and the influence of the respective individual components on the overall material behaviour, such as the flow behaviour or the stability, form the basis. The aim is to differentiate the individual components from a superimposed response signal.

Evaluating the impact of water quality during aqueous processing of LiNi0.8Mn0.1Co0.1O2 - based lithium ion battery electrodes

Vinzenz Göken
University of Münster I MEET

Within lithium ion battery (LIB) positive electrode production, N-methyl-2-pyrrolidone is considered state-of-the-art processing solvent. However, in addition to safety concerns, the environmentally critical NMP has to be recovered during electrode drying in a costly process to avoid environmental contamination. A safe, non-expensive alternative is the implementation of water as a processing solvent instead. Aqueously processed electrodes based on Ni-rich active material still suffer from reduced cycle life. One reason for this are detrimental reactions occurring at the surface of the active material in contact with water such as lithium proton exchange reactions and surface residue dissolution reactions.
To enable aqueous processing of lithium ion battery (LIB) positive electrodes, one aspect that has not yet been investigated in detail is the influence of processing water quality. Conventionally, deionized water is hereby used1.
This study focusses on the impact of water quality during processing and on electrochemical performance of LIB positive electrodes based on deionized and non-deionized water. Via inductively coupled plasma – optical emission spectroscopy (ICP-OES) a deeper understanding about occurring reactions during aqueous processing is gained. Furthermore, it was shown that processing with non-deionized water might not only reduce production cost, but also have a positive impact on the electrochemical performance of LIBs.

(1) Yuan, C.; Cao, H.; Shen, K.; Deng, Y.; Zeng, D.; Dong, Y.; Hauschild, M. Water-based manufacturing of lithium ion battery for life cycle impact mitigation. CIRP Annals 2021, 70 (1), 25–28.

Real-time Battery Electrode Slurry Quality Monitoring

Daniel Brunner, Vijoya Sa
Rheonics GmbH

Coating electrodes with battery slurries requires tight control of slurry consistency. This is important in both the mixing and the coating processes, for both anode and cathode slurries. The highly non-newtonian rheology of these slurries makes inline measurement and control necessary for getting consistent and reliable coatings, since laboratory analysis of samples pulled from the coating line do not necessarily mirror the properties of the slurries during the coating process. The interval between sampling and laboratory report makes it difficult to correct process deviations without risking substantial waste of costly materials. Rheonics SRV and SRD viscosity and density sensors have proven reliable instruments for continuous inline monitoring of battery slurry consistency in both anode and cathode slurries. Field studies have explored laboratory and in-line measurements and determined that inline measurements can more quickly detect viscosity changes to the battery slurries. More importantly, the in-line measurements correlate well with the actual performance of the slurries during the coating process.
The sensors are compact and therefore substantially non-intrusive in the electrode coating lines, allowing easy installation in operators' process lines with only minimal modifications. This opens a path toward full automation of the coating process. Realtime measurements from Rheonics SRV and SRD can be used in predictive controllers to stabilize slurry consistency during the coating process, helping battery manufacturers maintain control of slurry density and viscosity. This can ensure uniform electrode fabrication, reduce waste, and support scalable, high-performance battery production.

Electrode, cells and systems analytics and applications: Battery production 4.0, modelling, simulation and digital twin

Modeling the drying process in hard carbon electrodes based on the phase-field method

Marcel Weichel
Karlsruhe Institute of Technology (KIT)

Both the performance and degradation behavior of battery systems are significantly influenced by the microstructure of the electrodes [1]. As a result, the deliberate and active design of electrode microstructure properties is essential for addressing future challenges regarding capacity and rate capability in both lithium- and post-lithium-based battery systems. The work presented by this poster aims to simulate the drying process of hard carbon electrodes, with the goal of optimizing this crucial production step. Digital representations provide an essential basis for detailed analyses and subsequent insights into the process, as they enable spatially resolved field information, which is difficult to obtain experimentally. This comprises the distribution of binder, the morphology of the liquid-gas interface, and local velocity fields. The drying process encompasses multiple coupled physical phenomena, including multi-phase flow in complex geometries, moving interface tracking, capillary flow, and binder transport. To address these complex effects, the multi-phase field method [2] is applied and extended to model multi-phase flow and wetting behavior based on [3], with further adaptations specific to battery drying described in [4]. Efficient data handling is facilitated by the research data management platform Kadi4Mat [5]. To enable automated analysis of different microstructures and their behavior during drying, a dedicated workflow has been developed using KadiStudio [6]. This integrated workflow allows for the direct import of scanning electron microscope (SEM) images, simulation of the drying process, and automated post-processing analysis. The overarching goal is to demonstrate how variations in material parameters influence the drying process and to support microstructure-driven optimization strategies for battery electrode manufacturing.

Smart Battery Innovations for a Sustainable Future: The PHOENIX Project and Leclanché's Role in Feasibility and Cost Assessment

Luca Schneider
Leclanché GmbH

The EU-funded PHOENIX project is part of the broader BATTERY 2030+ initiative and aims to revolutionize lithium-ion battery technology by integrating smart functionalities such as self-healing, sensing, and triggering mechanisms. These innovations are designed to enhance battery safety, extend operational lifetime, and improve sustainability. Rather than focusing on large-scale manufacturing, PHOENIX emphasizes the development and validation of these functionalities at the materials and component level, laying the groundwork for future industrial implementation.[1]

Within the PHOENIX consortium Leclanché contributes its extensive expertise in battery system design and market-oriented analysis. While not directly involved in cell manufacturing for the project, Leclanché plays a crucial role in conducting cost modelling and feasibility studies. These assessments evaluate the economic and technical viability of integrating PHOENIX's smart functionalities into future battery products. By bridging the gap between research and market application, Leclanché ensures that the project's innovations are aligned with real-world requirements and scalable solutions for e-transport and other sectors. This poster presents an overview of the PHOENIX project and initial results, with a focus on manufacturability and cost analysis.

[1] Homepage PHOENIX Project: https://phoenix-smartbatteries.eu/

Electrode, cells and systems analytics and applications: Diagnostics during production- and use-phase

Self-Influence of Electrochemical Diagnostics in LIB: The Role of Separator and Time

Anna Rollin
TU Braunschweig I elenia Institute for High Voltage Technology and Power Systems

The transition to renewable energy systems has significantly increased the demand for lithium-ion batteries (LiBs), driving parallel efforts in battery diagnostics and recycling. To optimize recycling processes and comply with upcoming EU regulations, accurate performance evaluation of recovered materials is essential. A critical question is whether diagnostic procedures—especially extended or intrusive characterization—alter the true performance or lifetime of the battery.
This study investigates the impact of characterization duration and methodology on the electrochemical performance of Li-ion cells, focusing on separator influence and the effects of prolonged testing. The assessment focuses on whether certain measurement protocols introduce degradation that may obscure or distort the evaluation of recycled materials. Using techniques such as electrochemical impedance spectroscopy (EIS), cyclic voltammetry (CV), differential voltage analysis (DVA), C-rate testing, internal resistance measurements, and post-mortem analyses, different characterization strategies are evaluated how they affect capacity retention and internal resistance. These methods were applied to both two- and three-electrode cell configurations. Additionally, two types of separators were used: a test separator optimized for analytical accessibility but not a standard in commercial batteries, and a conventional separator representative of those in practical pouch cell applications. The findings aim to establish diagnostic best practices that balance comprehensive performance evaluation with minimal cell impairment—crucial for accurately assessing the potential of recycled battery components.

Efficient Quality Assessment of Cylindrical Battery Cells through Contactless Measurement Techniques

Daniel Nusko
Fraunhofer Institute for Solar Energy Systems ISE

The quality assurance of cylindrical battery cells is crucial for ensuring performance, safety, and longevity. State-of-the-art characterization is carried out through battery cycling to determine the discharge capacity of a battery cell. This information is then used to classify the quality as good or bad.
Since this measurement provides a global overview of the quality of the battery cell, the quantification of expansion at various positions on the cells surface during the charging and discharging cycles might provide additional information about the homogeneity of the battery cell. Conventional techniques to characterize reversible and irreversible expansion involve the installation of strain gauges on the cell's surface. However, this approach is labor-intensive and requires specialized hardware as well as software for data collection and analysis. This leads to significant complexity and potential errors.
In contrast, the here presented method utilizes contactless chromatic confocal sensors to measure the expansion at critical points of the battery cell's surface. This non-contact technique simplifies installation by eliminating the need for physical modifications to the battery surface. Preliminary results indicate that this method not only reduces the experimental effort but also provides comparable accuracy. Using chromatic confocal sensors allows for high-resolution measurements of the homogeneity of a battery cell while ensuring minimal interference with its functionality. This innovative quality assurance method can be applied during the formation process and is likely to enhance the safety of cylindrical battery cell manufacturing. Further research and development will focus on validating these findings across various cylindrical cell types, chemical compositions, and operational conditions leading to safer and more reliable batteries in the future.

Defect Detection in Lithium-Ion Battery Cells using Scanning Acoustic Microscopy

Nicolas Wilhelm
Fraunhofer Institute for Solar Energy Systems ISE

Inhomogeneities in battery cells can reduce their life span or even their save operation which can lead to drastic consequences such as fires. While outliers in the production can be detected to a degree using electrochemical methods, other defects can go undetected with the potential to cause threats and harm as well as worsened performance while being operated. That in mind, it proves crucial to develop tools and methods that can shed light on inhomogeneities that so far went undetected.
Here Scanning Acoustic Microscopy (SAM) comes into play as a nondestructive tomographic method, capable of gaining insight into lithium-ion battery cells [1]. To showcase the effectiveness of SAM, several defects of increasingly smaller size in the lower mm and sub-mm range are introduced into a pouch battery cell. This involves particles, cuts and scratches on electrodes or folded edges.
The cell is then inspected through SAM, where a through scan mode is used in which ultrasonic waves in the lower MHz range are introduced into the cell at the top and received at the bottom. The scanning motion and the collection of the resulting signals at every position provide both signal and imagery data. The signal data is further processed through signal analysis methods and machine learning algorithms which show to provide better contrast and enable immediate identification of defects, hence improving the scanning results by a margin.
The success of both detecting introduced defects and inhomogeneities along with the ability to provide good image quality through the signal inspection give prospect to the use of SAM as tomographic method in battery cell inspection using a through mode scanning with combined signal processing.

Recycling & Sustainability: Circular economy, battery supply chains and factory designs

Efficient and Scalable Battery Production: Energy-Based Evaluation of Microenvironments

Jan-Niklas Sturm
Karlsruhe Institute of Technology (KIT)

To reduce energy consumption and increase production flexibility in lithium-ion battery manufacturing, microenvironments have emerged as a promising alternative to conventional large-scale dry rooms [1], [2]. These localized dry zones allow process-specific environmental control while significantly reducing HVAC (Heating, Ventilation, and Air Conditioning)-related energy demands, which can account for up to 50% of total energy consumption in conventional dry room setups [3]. By conditioning only the immediate process space, microenvironments contribute to both ecological sustainability and economic competitiveness. Building on this concept, an automated handling system is required to eliminate humans from the dry zone. To minimize the necessary functional space within the microenvironment, the handling system needs to be modular and space-optimized as well. This system was designed based on a functional decomposition of material flow requirements and optimized through task-specific kinematic planning. This paper presents an experimental energy-based evaluation as a foundation for a future Total Cost of Ownership (TCO) comparison. The analysis is based on experimentally measured energy consumption required to achieve and maintain defined dew point levels, with validation conducted via chilled mirror hygrometry [4]. In addition to the empirical energy data, the approach establishes the basis for integrating detailed cost drivers such as investment, maintenance, personnel, and space utilization in future analyses. Experimental measurements on an industrial microenvironment system demonstrate that the optimized configuration leads to a significant reduction in total operating costs over the ownership period.
To reduce energy consumption and increase production flexibility in lithium-ion battery manufacturing, microenvironments have emerged as a promising alternative to conventional large-scale dry rooms [1], [2]. These localized dry zones allow process-specific environmental control while significantly reducing HVAC (Heating, Ventilation, and Air Conditioning)-related energy demands, which can account for up to 50% of total energy consumption in conventional dry room setups [3]. By conditioning only the immediate process space, microenvironments contribute to both ecological sustainability and economic competitiveness. Building on this concept, an automated handling system is required to eliminate humans from the dry zone. To minimize the necessary functional space within the microenvironment, the handling system needs to be modular and space-optimized as well. This system was designed based on a functional decomposition of material flow requirements and optimized through task-specific kinematic planning. This paper presents an experimental energy-based evaluation as a foundation for a future Total Cost of Ownership (TCO) comparison. The analysis is based on experimentally measured energy consumption required to achieve and maintain defined dew point levels, with validation conducted via chilled mirror hygrometry [4]. In addition to the empirical energy data, the approach establishes the basis for integrating detailed cost drivers such as investment, maintenance, personnel, and space utilization in future analyses. Experimental measurements on an industrial microenvironment system demonstrate that the optimized configuration leads to a significant reduction in total operating costs over the ownership period.

A Simulation Approach for the Sustainable and Resilient Spare Parts Management of Batteries in the Commercial Vehicle Sector

Marius Hermsen
TU Braunschweig | Institute of Machine Tools and Production Technology (IWF)

The electrification of the commercial vehicle sector is a key lever for reducing emissions in freight transport. While previous electrification efforts have primarily focused on battery engineering and production, the after-sales sector is gaining importance as market penetration of electric vehicles rises. Ensuring long-term spare parts availability- often up to 15 years after end-of-production- poses significant challenges for battery systems. Rapid innovation cycles lead to the discontinuation of battery cells and modules, while calendar aging and self-discharge hinder long-term serviceability. Simultaneously, a lack of standardization and compatibility across battery generations limits component interchangeability. Beyond sustainability goals, strengthening supply chain resilience is a central concern in the context of after-sales management. This study presents a concept for a simulation model that supports manufacturers and after-sales-planners in strategic decision-making. The conceptual model focuses on assessing supply strategies for batteries as spare parts, emphasizing circular approaches such as reuse and refurbishment. It incorporates parameters such as future demands for individualized spare parts, return flows, and battery degradation. By simulating future scenarios, the model provides a foundation for assessing both circular and conventional supply strategies under uncertainty and contributes to more resilient and sustainable after-sales management in commercial vehicle electrification.

Advanced Training for Adressing the Personnel Skills Shortage

Wolfgang Brehm
TU Berlin I Institute of Electrical Energy Storage Technology

To strengthen employees' ability to make independent decisions and take responsibility across all stages of battery production and application, we developed targeted qualification measures within the KOMBiH ("Kompetenzaufbau für Batteriezellfertigung in der Hauptstadtregion")project. While the Berlin-Brandenburg capital region offers numerous training opportunities in battery operation, there is a significant shortage of programs covering other parts of the battery value chain—such as raw material processing, recycling, and second-life applications. These areas are also underrepresented in research and development qualifications and largely excluded from existing training formats, which primarily target academically educated personnel and often lack in-person components.

To address this gap, we collaborated with 34 companies to identify qualification needs and define learning objectives. A pilot series of six half-day online courses titled Battery Basics for Industry Specialists reached 186 employees and covered topics such as battery technology, production, applications, handling, logistics, safety, recycling, and circular value creation. The program evaluation, based on 113 online questionnaires (response rate >60%), showed strong participation from professionals with backgrounds in engineering (electrical, mechanical, industrial), chemistry (general and physical), and economics. Vocational qualifications included technicians, foremen, and chemical laboratory staff.

Through this initiative, we identified key qualification fields, including raw material processing, battery fundamentals, cell production, application areas, logistics and safety, and recycling. Based on this feedback, we developed tailored training modules that can be sustainably implemented with the support of company-based trainers.

Our training programs target a broad audience—from technical staff and in-house trainers to decision-makers—across the battery value chain.

Recycling & Sustainability: Synthesis, (direct) recycling, second use and resynthesis

Aqueous Lithium Recovery from Sulfidic Solid-state Battery Components and H2S Investigations in the Recycling Context

Ruben Schwabauer
University of Münster I MEET

Over the last years, the rising awareness as well as political and economic motives led to further regulations regarding the recycling of battery components especially in the European Union. In combination with the promising ongoing research on solid-state batteries, it is crucial to gather important insights into possible recovery methods for valuable materials even before broad commercialization of those technologies. Considering the implementation of a lithium metal anode, the selective recovery of lithium came into focus of recent works.

One of the most promising solid electrolytes is the ceramic argyrodite-based Li6PS5Cl (LPSCl) that is able to reach ionic conductivities comparable to conventional liquid electrolytes. Nevertheless, sulfide-based electrolytes pose a safety risk due to their reactivity in contact with humidity, forming H2S, which is to be considered during every process of the material handling, including recycling steps.

In this work, the H2S formation rates of LPSCl powder under different atmospheres along with the H2S formation of the aqueous dissolution process of LPSCl are investigated. The results show, that even a dry atmosphere leads to a significant gaseous H2S generation, while no H2S release is observed directly after the dissolution in water. Moreover, the successive hydrolysis of the dissolved thiophosphates to orthophosphate is shown, which can be accelerated with an oxidizing agent like H2O2. This enables an easy and safe precipitation of the dissolved lithium as Li3PO4 with recovery rates of >90 %, as presented in this work.

Resynthesis of nickel-rich cathode active materials from recycled batteries

Martin Menzler

Fraunhofer Institute for Surface Engineering and Thin Films IST

Lithiated layered oxides, such as Li[NixCoyMnz]O2 (NCM), are essential in current efforts to electrify the transportation sector. They are commonly used as cathode active materials (CAM) in high-energy-density lithium-ion batteries (LIBs) to provide battery electric vehicles with long driving ranges. Typically, lithiated layered oxides contain critical metals like lithium, nickel, and cobalt, the sourcing of which poses geopolitical challenges and a significant environmental impact. These issues can be mitigated, for example, by establishing a circular economy for cathode active materials, effectively creating a supply of recycled metal salts for CAM production. To achieve this, it is crucial to investigate how these recycled metal salts influence the CAM resynthesis process and the properties of the resulting product. In this context, ongoing research efforts aim to identify impurities present in recycled metal sources (e.g. nickel sulfate) and assess their impact on the physical and electrochemical properties of resynthesized CAM. This study aims to contribute to the aforementioned research by synthesizing nickel-rich cathode active materials using both secondary metal salts and primary (commercially sourced) metal salts as precursors. The applied process chain included a hydroxide coprecipitation process to synthesize a precursor (pCAM), followed by lithiation and calcination steps to convert the precursor into CAM. The produced samples were characterized for their chemical composition (ICP-OES, EDX), morphology (SEM), and particle size distribution (laser diffraction). Furthermore, the synthesized CAM was analyzed for its crystal structure (XRD) and its electrochemical performance in a coin cell. Overall, this study investigates the influence of different precursors from primary and secondary resources on the synthesis process and the resulting product properties.

Manufacturing and Validation of NMC622 Cathodes with Artificial Impurities

Mattes Renner

Karlsruhe Institute of Technology (KIT)

To enable a true circular economy in the battery sector, cathode active materials must be resynthesized from spent cells. Foreign metal impurities introduced during hydrometallurgical recycling have been shown to significantly affect the crystal structure and particle morphology of resynthesized NMC622 materials. These structural changes influence the slurry formulation and electrode manufacturing process, which in turn impact the electrochemical performance of the final cells. This study systematically investigates how varying concentrations of typical recycling-related impurities (i.e. Fe, Al) affect electrode processing and full-cell behavior using industry-relevant formulations in single-layer pouch cells. Electrochemical characterization reveals that even low levels of these foreign metals can lead to measurable changes in cell performance, including reduced capacity and increased aging effects. Post mortem analyses further confirm these findings by identifying structural and compositional changes in aged electrodes. The results aim to pave the way for cells from recycled material and provide critical insights into the tolerable limits of recycling-related impurities and offer guidance for improving recycling protocols to ensure high-quality material recovery for future battery production.

Automated disassembly system for variant-flexible battery recycling

Leif Tönjes

TU Braunschweig | Institute of Machine Tools and Production Technology (IWF)

Due to the steadily increasing number of end-of-life batteries, efficient recycling strategies are becoming increasingly necessary. In industrial practice, recycling is currently carried out in two stages by dismantling the battery systems and then shredding them. However, due to the current lack of standards, the battery systems have a high degree of variance, so that the dismantling processes are characterised by time-consuming manual work. This work is not only questionable from a safety point of view, but also cannot cope with future recycling volumes. In our poster we present the development of a process for the automated and variant-flexible disassembly of battery systems down to cell level. The separation of numerous different joints required in the course of disassembly is realised by a laser cutting process. This works in interaction with a universal gripping system, which securely clamps the components during the separation, handles separated components and removes them. In order to enable a target-oriented cooperation of the end effectors, 3D image processing methods based on machine learning are developed and used for the automated robot-based process. The first step is to clearly identify, classify and categorise the battery system and separated components. Based on this information, the system independently plans adaptive disassembly sequences and trajectories with dynamic collision avoidance in a second step. By integrating these process modules into an overall demonstrator, we plan to evaluate the achievable quality of the dismantled components, the safety, economic efficiency, industrial scalability and the achievable work and process safety. From an economic point of view, the recovery of expensive elements such as lithium and cobalt is essential in order to provide value-creating companies with access to an innovative circular economy with a high proportion of added value in Germany that is competitive with Asian production locations.

POSTER ABSTRACTS I Day 2

Development and production of innovative and next-generation batteries: Material development and usage of innovative materials

Fabrication of Sulfur-Aerogel-basedCathode Materials via Aqueous Wet Coating Method and Their Electrochemical Evaluation Against Magnesium Anodes

Eren Gayretli
Fraunhofer Institute for Silicon Technology

Magnesium–sulfur (Mg–S) batteries are seen as energy storage with promise given magnesium's natural presence and their great theoretical energy density of approximately 1722 Wh kg^{-1}. Magnesium metal anodes, in comparison to lithium, offer an improvement in safety by suppressing dendrite formation. Sulfur, which has a high theoretical capacity of 1672 mAh g^{-1}, is low-cost and environmentally benign, attracting interest as a cathode material. These qualities make Mg–S batteries extremely attractive for clean energy storage applications and electric mobility. However, their more practical deployment now faces some key challenges. For example, sulfur's insulating nature, polysulfide shuttle effects which lead to active material loss, and sluggish magnesium ion kinetics exist around the cathode side. Well-designed cathodes help confine sulfur and maintain structural integrity to address these problems. This is also important because it suppresses polysulfide dissolution. Since the emergence of carbon aerogels, they have become promising cathode hosts due to their high porosity, tunable microstructure, and outstanding electrical conductivity. Their large total surface area improves ion and electron transport and helps to trap soluble polysulfides. In this study, sulfur–aerogel composite cathodes were fabricated using a water-based coating process with CMC/SBR binders, which also provided mechanical flexibility and adhesion. To optimize thickness, the cathodes were calendared, and the aerogel matrix limited polysulfide migration, effectively retaining sulfur. Initial discharge capacities exceeding 900 mAh g^{-1} at C/20 were demonstrated through electrochemical testing, with stable cycling for over 60 cycles in pouch cells containing magnesium metal anodes and a specialized electrolyte developed at KIT.

Synthesis of mesoporous activated carbon for application in Lithium Sulfur batteries

Fabisch Kilonzi
TU Braunschweig I Institute for Particle Technology (iPAT)

Lithium–sulfur (Li–S) batteries offer a compelling alternative to conventional lithium-ion batteries due to their high theoretical energy density of 2600 Wh kg-1, the abundance of sulfur as well as their cost-effectiveness. Nonetheless, their practical deployment is impeded by polysulfide shuttling, volumetric expansion, dendrite formation, and surface passivation, which compromise electrochemical stability and cycle life. The integration of mesoporous carbon as a sulfur host mitigates these issues by providing a confining matrix that adsorbs soluble polysulfides, thereby suppressing their migration and enabling their electrochemical reduction without detrimental cathode degradation. Additionally, mesoporous carbon buffers volumetric changes during cycling, enhancing structural integrity.
In this study, a high-surface area activated mesoporous carbon (specific surface area >1600 m^2 g^{-1}), synthesized via cascaded hydrothermal carbonization followed by chemical activation, was employed as a host matrix for sulfur. Biological materials such as miscanthus X giganteus were used as carbon sources, constituting sustainable resources. Sulfur was incorporated via melt diffusion at 155 o C and ball milling processes. The resultant sulfur-carbon composite cathode demonstrated an initial specific capacity of 718 mAh g^{-1} at 0.1 C, with stable residual capacities exceeding 350 mAh g^{-1} at 0.5 C over 350 cycles. This electrochemical performance surpasses that of comparable biomass-derived carbons with lower surface areas, underscoring the critical role of tailored porosity and structure in advancing Li–S battery technology for practical applications.

Processing and Electrochemical Performance of Silicon Oxide/Graphite Composite Electrodes Across Application-Relevant Mass Loadings

Anna Gerlitz
University of Münster I MEET

Silicon oxide (SiOx)-graphite blend electrodes have emerged as a promising approach to enhance the energy density of LIBs. By partially replacing graphite with SiOx, which has a significantly higher theoretical capacity, the blend combines the high capacity of SiOx with the structural stability and long cycle life of graphite. This synergy enables improved gravimetric and volumetric energy densities while mitigating issues typically associated with pure silicon-based electrodes, such as severe volume expansion, unstable SEI formation and poor cycling stability.[1,2]
Processing SiOx-graphite blend electrodes requires careful control over composition to strike a balance between increased energy density and mechanical integrity.[3] While higher SiOx content enhances capacity, it also introduces challenges such as electrode swelling, internal stress buildup, and unstable SEI for-mation.[4] To address these issues, different SiOx-contents, advanced binder systems—such as PAA or combinations of CMC and SBR—along with con-ductive additives are employed to maintain structural cohesion and electrical conductivity.
SiOx-graphite blend electrodes with increased mass loading were prepared to meet the demands of various application profiles, from high-energy to practical commercial formats. Electrodes were tested in full cells using NMC811 as the cathode material, chosen for its high capacity and voltage stability. Electrochemical analysis demonstrated strong performance with stable long-term cycling and good capacity retention. Even at higher areal loadings, the blend electrodes maintained cycling stability, highlighting their potential for advanced lithium-ion battery systems.

[1] Schwan J. et al. (2020); Nanoscale Advances, 2, 4368-4389
[2] Knorr, J. et al. (2024), Journal of Energy Storage, 86, 111151
[3] Li, P. et al. (2021), Energy Storage Materials, 35, 660-576
[4] Chen, T. et al. (2017), Journal of Power Sources, 363, 126-144

Sodium-Ion Batteries: Drop-in ability in the context of industrie relevant process routes

Kriss-Kevin Daniel Kasten
TU Braunschweig I Institute for Particle Technology (iPAT)

This work investigates the drop-in ability of sodium-ion battery (SIB) active materials and compares different electrode processing routes in the context of industrial scale-up. To evaluate the process compatibility of sodium-based systems, a batch process using a dissolver and a continuous process using an extruder were examined. Both methods were applied to wet, dry and semi-dry processing approaches using NFM424, a representative layered oxide cathode material, and hard carbon as the anode material.
The objective is to assess whether sodium-ion materials can be integrated into existing lithium-ion battery (LIB) production infrastructure without major changes to processing technologies. Extensive raw material characterization was carried out, including measurements of bulk and tap density, specific surface area, moisture content, and flow behavior. Based on these parameters, the formulations were adapted to meet process requirements and ensure a high level of comparability across both routes.
Using standardized process conditions, electrodes were produced and subsequently analyzed for their mechanical integrity, electrical conductivity, and electrochemical performance in half-cell configurations. The results provide insight into the influence of processing method and material properties on electrode performance and scalability. A final comparative assessment with conventional LIB systems places the findings into a broader industrial context, demonstrating the potential of sodium-ion technologies as drop-in alternatives for large-scale, cost-effective energy storage applications.

Development of a hybrid supercapacitor combining the qualities of an Electric Double Layer Capacitor and a Lithium-ion battery

Stefano Paradiso
Novac Srl

Electrochemical Double Layer Capacitors (EDLC), also known generally as supercapacitors, are electrochemical energy storage devices with high power density and rapid charge and discharge capabilities. In recent years, they have gained research interest due to their ability to deliver short bursts of power efficiently without maintenance for millions of cycles. In contrast, Lithium-Ion Batteries (LIBs) operate through faradaic electrochemical reactions, making them more suitable for applications where prolonged energy supply is required rather than high instantaneous power delivery. (Figure 1). Hybrid supercapacitors are a class of electrochemical cell aimed at combining the advantages of both battery and supercapacitor electrodes, achieving a balance between high energy density and high power density. This work focuses on the design and optimisation of a hybrid supercapacitor cell based on activated carbon (AC) and $Li_4Ti_5O_{12}$ lithium titanate (LTO) electrodes, combining a double-layer capacitance mechanism at the cathode with faradaic charge storage at the anode. The goal is to develop a cell capable of reaching 50,000–100,000 charge/discharge cycles at End-of-Life (EoL) and a nominal energy density of 25–30 Wh/kg. The study is initially conducted on coin cells and subsequently scaled-up to single-layer pouch cells, with the LTO-based anode fabricated using a slurry formulation optimized by Novac. Different pre-lithiation strategies are currently being developed in Novac's laboratory to enhance the electrochemical performance of the hybrid energy storage system.

Development and production of innovative and next-generation batteries: Solid state electrolytes and batteries

Investigating Ionic Conductivity of Tailored Composite Electrolytes for Solid-State Batteries

Marvin Freser
Fraunhofer Institute for Silicate Research ISC

Solid-state batteries (SSBs) are regarded as the next generation of batteries due to their enhanced safety and energy density compared to conventional Li-ion batteries. They are particularly relevant for the mobility sector. A key component for high-performance SSBs is the solid-state electrolyte (SSE). However, the use of SSEs presents new challenges regarding ionic conductivity, processability, recyclability, sustainability of SSEs, and the interfaces between the SSE and active materials. Combining organic and inorganic electrolytes is a promising approach to address these challenges. However, these composite electrolytes cannot be produced merely by mixing polymer and inorganic components; both must be specifically tailored to facilitate efficient ionic transport throughout the SSE as a whole. Additionally, there is currently limited data on the recyclability of SSEs and the sustainability of their fabrication. These aspects are often considered retrospectively rather than being evaluated during the material development phase.

These challenges are addressed within the project FUNCY-SSB (FUNctional Coatings of sulfide electrolYtes for lithium Solid-State Batteries). The work presented here includes the results on the functional coating of the electrolyte particle surfaces for the production of an SSE based on a synergistic combination of sulfide electrolytes with different polymers.

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Optimization of SPAN Cathodes with Polymer Electrolytes for Solid-State Lithium-Sulfur Batteries

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Sulfurized polyacrylonitrile (SPAN) is a promising active material for lithium-sulfur batteries, offering improved cycling stability and coulombic efficiency compared to elemental sulfur. In SPAN, sulfur is chemically bonded within the polymer backbone, which effectively mitigates the polysulfide shuttle effect, a major limitation in conventional lithium-sulfur systems [1]. The integration of the SPAN cathodes with solid polymer electrolytes (SPE) not only enhances safety and interfacial stability but also can inhibit the growth of lithium dendrites. Therefore, it can represent a promising direction toward the high-performance battery systems [2].

In this study, we focus on the design, production, and optimization of a SPAN cathode containing 48 wt.% sulfur, in conjunction with a SPE based on poly(ethylene oxide) (PEO) and lithium bis(trifluoromethanesulfonyl)imide (LiTFSI). The electrochemical performance of the SPAN cathode is critically influenced by the composition and proportion of its constituents. A comprehensive study was conducted to identify the optimal composition of the composite cathode, with the goal of achieving a balanced combination of electronic conductivity, ionic mobility, and mechanical stability.

In addition to compositional design, the study assesses the influence of key processing steps, including pre-mixing and mixing parameters, on the electrode's structure and performance. By varying the mixing speed and duration, we examined how these factors affect the homogeneity of the composite, the interfacial adhesion, and, consequently, the electrochemical performance of the battery. Moreover, various characterization techniques were employed to evaluate the performance of the prepared materials. Finally, the study provides a reproducible and scalable processing route for SPAN cathodes and offers deeper insights into both material formulation and process parameters which are crucial for high performance solid-state batteries.

Quasi-solid electrolytes using single cation ionic liquids

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Replacing flammable organic electrolytes with solid electrolytes (SEs) can improve safety of batteries, especially, oxide-based SEs exhibit relatively high air stability and high ionic conductivity 10−4–10−3 S cm−1 at room temperature; however, their poor interfacial contacts require sintering at high temperatures for device fabrication. "Quasi-solid electrolytes" (QSEs) can improve the interfacial contacts of the SEs by using soft materials such as liquid electrolytes and flexible polymers; however, Li+ transference numbers (tLi+) of such soft materials are generally lower than those of the SEs, which causes a concentration polarization of Li+ in the QSEs. We present a new concept of QSEs using single cation ionic liquids (SCILs) which are defined as ionic liquids not including organic cations but containing only single alkali metal cations such as Li+ and they show no concentration polarization of Li+ under anion blocking conditions. 1

We developed a Li-SCIL composed of lithium bis(fluorosulfonyl)amide [LiFSA, Li (FSO2)N(SO2F)] and lithium (fluorosulfonyl)(trifluoromethanesulfonyl)amide [LiFTA, Li (FSO2)N(SO2CF3)] with a composition of Li[FSA]0.35[FTA]0.65, which shows the lowest melting point (76 °C) among Li salts. 2 QSEs formed by hot pressing (90 °C) of mixed powder of lithium aluminum titanium phosphate (LATP) and 10–25wt% Li-SCIL shows higher ionic conductivity (0.5–1.2×10−4 S cm−1 at 90 °C) than Li-SCIL itself (0.4×10−4 S cm−1 at 90 °C), indicating that Li+ conduction is accelerated by LATP. DC polarization measurements (10 mV for 600 seconds) were performed using Li symmetric cells (Li/Li-SCIL/QSE/Li-SCIL/Li) at 80 °C and a ratio of steady-state current/initial current is 0.98, indicating almost no concentration polarization occurred within the cell.3 This study has shown the Li-SCIL imparts ionic conductivity to oxide-based SEs without sintering process and the QSE does not cause Li+ concentration polarization and contribute to stable battery operation.

Upscaling and Advanced Extrusion as Enablers for Efficient Solid Polymer Electrolyte Development

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FZ Jülich GmbH

The development of solid polymer electrolytes (SPEs) generally follows a linear process, where each candidate is sequentially synthesized, processed and tested. This approach is time-consuming and often inefficient, as many candidates are deemed unsuitable only after extensive experimentation. Implementing early-stage upscaling alongside advanced processing techniques enables a more efficient selection process by providing rapid feedback on processability and performance of the electrolyte materials. Integrating scalable processing at the outset of development allows for swift identification of high-performance SPEs, thereby reducing efforts on non-viable candidates and accelerating the transition from laboratory research to industrial production.

In addition to emphasizing the significance of upscaling and processing, the focus is directed towards evaluating the potential of extrusion in the development of novel polymer materials. In this study, two polycaprolactone-based electrolytes, Bt-PCL and Al2O3_PCL, are utilized to illustrate the efficacy of extrusion techniques in the efficient manufacturing of battery materials.

Fast-Charging of Solid-State Batteries Enabled by Functional Additives Infused into High-Mass-Loading NMC Cathodes

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Solid-state batteries (SSBs) are a leading candidate for next-generation electrochemical energy storage, offering enhanced safety and the potential for higher energy densities compared to conventional lithium-ion batteries.[1] However, their practical deployment is hindered by interfacial contact limitations and poor cathode processability, particularly at real-application relevant mass loadings.[2, 3, 4]

In this work, we build upon our previous research[5] and demonstrate that the incorporation of functional polymer additives with specific properties directly into the cathode slurry provides a simple yet powerful strategy to overcome these barriers. Using brush vinyl ether (BVE) polymers as catholytes, we achieve high-mass-loading NMC811 cathodes (~6.5 mg cm^{-2}) paired with fast-charging capability (1.0C) in all-solid-state polymer-based lithium metal batteries. The optimized cathodes exhibit significantly improved cycle life, reduced interfacial resistance, and enhanced lithium-ion transport compared to additive-free or conventionally treated electrodes.

Electrochemical characterization (cycling, GITT, EIS, and dQ/dV analysis) confirms that additive infusion increases interparticle and interphase contact without altering intrinsic redox processes. Morphological analysis (PFIB-SEM) further validates reduced porosity and improved conductive network stability in additive-containing cathodes. Notably, the one of BVE additives tested delivers the best overall performance, enabling ~90 % capacity retention after extended cycling at high current densities.

This additive-infusion approach is readily compatible with existing electrode manufacturing and provides a scalable pathway to high-energy, fast-charging polymer-based solid-state batteries, bringing them closer to implementation in electric vehicles and large-scale energy storage systems.

Impact of Li6PS5Cl Comminution on the Densification and Cell Performance of Solid-State Cathodes

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A well-engineered cathode microstructure is of significant importance to improve the cell performance of solid-state lithium-ion batteries. A crucial factor is the particle size of the used electrolyte, as it influences the interfacial contact area with the active material and thus, the ionic charge transfer. Therefore, a small particle size in the cathode composite is advantageous because the higher surface area provides more contact points with the active material. However, commercial electrolyte materials such as Li6PS5Cl often exhibit a wide particle size distribution with coarse particles above 100 µm impeding the formation of a well-defined electrode microstructure. To address this challenge, the solvent-based comminution of Li6PS5Cl was investigated in a planetary ball varying the rotational speed. The subsequent electrode processing was performed in an inert glovebox atmosphere with p-xylene as solvent, polyisobutylene as binder, carbon black as conductive additive, and single-crystalline LiNi0.83Co0.11Mn0.06O2 as cathode active material. Here, the applied fabrication pressure was varied to investigate the relationship with the particle size. The resulted particle size distribution of the electrolyte, the cathode coating density, as well as the cell performance was investigated systematically. By reducing the particle size, for example, it was possible to significantly improve the initial specific discharge capacity from 130 mAh/g for the cathodes with non-milled electrolyte to 184 mAh/g for cathodes with electrolyte milled at a rotational speed of 600 rpm. This study aims to give concrete recommendations for the cathode processing for solid-state batteries, as well as it emphasizes the importance of the electrolyte particle size for improving interfacial properties and cell performance.

Electrode and cell production: Cell assembly

Modelling the multi-layer electrode of solid-state battery and validation of handling process

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Politecnico di Milano

Electrode handling and fixturing are crucial steps in the current battery cell stacking process. During these stages, electrode sheets may experience deformation due to vacuum or mechanical pressure, leading to plastic deformation or surface damage. While measuring the elastic modulus and yield strength allows for predicting deformation, the electrode consists of two coating layers and one metal layer connected by specific method. Each layer deforms differently, but they are synchronized by the connections. As a result, deformation can lead to detachment between layers, or the coating layer may break while the metal layer remains intact.

Currently, research mainly focuses on influence of deformation in calendaring process, with limited attention given to the multi-layer structure of the electrode. As solid-state battery (SSB) materials are rapidly developing, studying the multi-layer structure will help improve parameter control for various SSB materials and enhance manufacturing quality.

The investigation involves model preparation, scenario validation, and material extension, initially focusing on sulfide electrodes. Key considerations include multi-layer structure, material properties, and combination methods. The 3D laminate theory helps model the electrode structure, assessing individual and combined layer properties to understand the relationships between the material-property and connection method. Handling and fixturing scenarios were developed to evaluate detachment, deformation, and surface damages. Comparing multi-layer model results with traditional methods provides insights into the impact of multi-layer structures during stacking. This research aims to improve stacking quality and, once validated for sulfur-based materials, it can be extended to other SSB materials, exploring the effects of different combination methods.

Enhanced Modulated Laser Processing Techniques for Lithium Metal Anodes

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Using state-of-the-art die-cutting technology to generate battery-grade electrodes imposes limits on soft and adhesive materials such as lithium or sodium metal. For these materials, as well as for all standard electrode materials, laser cutting—being a contact-free, fast, and reliable process—may be applied instead. Therefore, continuous wave (cw) and both short and ultrafast pulsed laser systems with wavelengths ranging from approximately 1070 nm to about 250 nm are widely used.

A lithium-coated copper foil, as a potential electrode material, presents two challenges regarding the ablation process: the lithium coating, with a thickness of about 20 µm to 100 µm, has a low melting point of 180.5 °C, while the current collector, such as a 10 µm thin copper foil, has a high melting point of 1085 °C. Additionally, certain laser wavelengths may not couple effectively with copper, which can degrade the sublimation effect.

Since recent results from various research efforts show that burr-free (<20 µm) and spill-free cutting edge morphology cannot be achieved with either cw or pulsed laser systems, influences on cell per-formance related to the cutting results can never be completely excluded. Those sources also report a heat-affected zone on the lithium side that is at least more than double the kerf width. In this work, a new method of using a modulated laser for shaping electrodes containing lithium metal is introduced. A comprehensive parameter screening, including laser power and interaction velocity, as well as the evaluation of results using REM and topography measurements, is presented. Ultimately, the goal of generating almost no heat-affected zone—resulting in very high cutting edge quality and geometric accuracy—can be achieved. The absence of melting spills larger than 10 µm guarantees excel-lent anode behavior at cell level. Furthermore, the entire electrode, including both the body and the uncoated electrode flag, can be processed in the same manner.

Electrode and cell production: Dry coating + new coating technologies

Investigating the influence of the residence time distribution in a twin-screw extruder on dry coated granules for electrode production

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To support the transition to a greener future and an effective circular economy, understanding residence times in battery processing is essential. This insight is crucial for tracking raw materials during electrode production and fine-tuning product properties. In twin-screw extrusion of dry-coated battery granules, residence time affects the mechanical, morphological, and functional properties of the granules. The residence time distribution (RTD) governs material exposure to shear and compaction forces, influencing binder fibrillation, granule structure, and electrode performance. A new method was applied to measure RTD inline during extrusion, enabling high-resolution detection of material flow under dry conditions and quantification of process dynamics with minimal disturbance.

By varying screw speed, mass flow rate, barrel temperature, and screw configuration, a broad range of RTD conditions was explored. Granules produced under these conditions were characterized regarding bulk and tap density, particle size, cohesion, wall friction, compressibility, and conductivity. Higher mean residence times increased compressibility and reduced cohesion, indicating enhanced binder fibrillation and improved powder flow. Electrodes manufactured from these granules via calendaring showed lower in-plane resistivity and better mechanical stability.

These results demonstrate a strong link between residence time, granule structure, and final electrode properties. The applied measurement method proved effective for real-time RTD detection and offers potential for integration in broader process monitoring systems. Figure 1 presents an exemplary RTD measured during continuous granule production, showing strong alignment with plug flow and tank reactor models. Controlling RTD in dry extrusion emerges as a key parameter for tailoring electrode quality and scaling solvent-free battery technologies.

Effect of LFP particle sizes on the pore structure of semi-dry processed lithium-ion battery cathodes

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Conventional lithium-ion battery electrode production involves a mixing and dispersing process with low solids content followed by die coating, which results in long drying times and high energy consumption. The granulate-based semi-dry electrode process offers a promising alternative by reducing solvent content, thereby shortening drying time and lowering energy costs, while also providing long-term storage stability with minimal sedimentation [1]. The limited use of solvent enables controlled evaporation, which promotes the formation of a desirable pore structure and enhances handling during dispersion compared to dry electrode processing.

The investigation of semi-dry processed anodes showed that their distinct pore structure and distribution reduce kinetic limitations at high C-rates compared to conventionally processed anodes using a planetary mixer. This improvement is attributed to higher stress intensity and stress number during extrusion, resulting in increased graphite surface area and a narrower pore size distribution [2].

This study investigates the semi-dry fabrication of lithium iron phosphate ($LiFePO_4$) cathodes, examining how different LFP particle sizes affect pore structure and lithium-ion diffusion. Electrodes were produced via semi-dry extrusion under various screw configurations, then coated, dried, and calendered using a four-roll calender, and compared to slurry-cast references. Electrochemical impedance spectroscopy was used to assess ionic resistance and tortuosity, while cyclic voltammetry provided insight into ion diffusion kinetics. Structural and electrochemical findings were further supported by scanning electron microscopy.

Challenges of Dry Coating: How Does Scale-Up Affect Powder and Electrode Properties?

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A new alternative process for electrode production is solvent-free, calender-based dry coating. Various methods exist to prepare powders suitable for dry coating, enabling effective processing in multi-roll calender. Continuous (extruder) or batch (intensive mixer) processes are used. After dry mixing, the powder is processed in a multi-roll calender, where the procedure can be divided into three distinct stages. First, a free-standing, continuous film is formed from a powder blend consisting of active material (e.g., graphite or lithium nickel cobalt manganese oxide (NCM)), binder (polytetrafluoroethylene, PTFE), and conductive additives (carbon black (CB)). In the second stage, this film is compacted and thinned. Finally, during lamination, the compressed film is applied to a carbon-coated current collector with a defined thickness and density.

This study investigates the differences of process-property relationships that occur during scale-up when using an intensive mixer (Zeppelin FML10) and a multi-roll calender. For this purpose, different powder mixtures were prepared by varying mixing parameters such as mixing time, mixing speed, temperature, and the timing of binder addition. During dry coating, an effective process parameter space comprising temperature, roller speed, force or gap control, and friction is selected for a desired electrode, depending on the active material. Various characterization methods were used to investigate the influence of batch mixing scale-up and the film formation parameters during multi-step calendering on PTFE fibrillation in anode powders, as well as on the properties of the resulting free-standing films and electrodes. Parameters such as particle size distribution, compaction speed, porosity and electrical resistance were analyzed. Initial results for dry mixing show that a higher filling level minimizes the time-consuming heating step and maximizes the powder quality.

Electrode and cell production: Slurry processing

Solvent-Reduced Continuous Processing of Lithium-Ion Battery Cathodes

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The high demand for lithium-ion batteries (LIBs) in various applications necessitates the development of scalable, cost- and energy-efficient electrode manufacturing processes. Therefore, a solvent-reduced process for LIB slurry was investigated by applying a continuous mixing and dispersion method, employing a co-rotating twin-screw extruder.

Extrusion has a limited dwell time and it was found that the solids content must be increased in order to achieve higher stress intensities to improve Carbon black (CB) decomposition and to create a suitable CB-binder-network similar to batch processes with higher dispersion time. Operating at a solids content of 85 wt.-% in the kneading zone ensured a good dispersion of the CB with a sufficiently high aggregate fraction and dispersion index DICB [1]. In the dilution zone, the final solids content was adjusted from 70 to 77.5 wt.-%. By increasing the final solids content, particle-particle interactions are enhanced which is evident by a two-order-of-magnitude increase in low-shear viscosity. Electrode films were then comma-bar coated and dried in a continuous, convective drying process. Microscopic evaluation of the dried electrode edges shows that at low final solids content, the low slurry viscosity and its predominantly viscous character is also reflected in the coating edge by wide, unstable edge areas. In contrast, at the highest solids content, a structurally stable film with a sharp edge is obtained.

Finally, full cells were assembled. The electrochemical performance remains similar at low C-rates but differs significantly at higher C-rates: A 5% increase in capacity was reached with the highest solids content. The corresponding particle size distribution indicates the necessity of a specific CB agglomerate fraction or size, or a certain DICB, to adjust both electric and ionic conductivity to enable higher capacities at higher C-rates. This finding aligns with the conclusions of recent studies [2].

Influence of stress mechanism on slurry mixing in stirred media mills

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The preparation of battery slurries is typically carried out as a batch process using planetary mixers. However, from an industrial perspective, continuous manufacturing processes are more attractive due to their higher production rates and lower operational costs. Consequently, continuous mixing processes are becoming increasingly relevant in both research and industrial applications. For the continuous production of battery slurries, stirred media mills (SMMs) can be employed. In these systems, particles are subjected to mechanical stress by freely moving grinding media. However, grinding of battery materials is undesirable, as it can negatively affect battery performance. Instead, the objective is to disperse carbon black (CB) agglomerates and homogenize the battery components. By adjusting the process conditions, it is possible to achieve dispersion and mixing without grinding the active materials. In initial investigations, process parameters such as stirrer tip speed, flow rate, grinding media size and filling degree were varied. Their impact on the slurry's rheological properties and resulting carbon black particle size distribution was evaluated. It was shown that, in particular, residence time, media filling degree, and stirrer speed are the most influential parameters for mixing an anode slurry with well-dispersed CB. Interestingly, it was discovered that the type of stress mechanism plays a crucial role in the processing of anode slurries. To gain deeper insights, additional experiments were conducted in which either graphite or CB was processed individually in the SMM. The stress mechanism was adjusted by varying the grinding media filling degree. At 0%, only shear stress is applied, while increasing the filling degree introduces more impact forces. It was found that, in order to preserve the structure of graphite, shear forces are more suitable, as impact stresses tend to damage the active material. Therefore, no grinding media should be used when processing graphite. In contrast, the deagglomeration of CB benefits from impact stresses, making high media filling degrees advantageous. These findings reveal that CB and graphite have different processing requirements that cannot be met simultaneously in a single SMM. As a result, we propose a two-step mixing process: First, CB is processed in an SMM with a high media filling degree. Then, the pre-dispersed CB is combined with graphite in a second mill operated without grinding media, serving solely for homogenization.

Electrode, cells and systems analytics and applications: Battery production 4.0, modelling, simulation and digital twin

Electro-chemo-mechanical modelling of cathode in sodium-nickel chloride batteries using PyBaMM

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The global demand for safe energy storage with CO2-neutral technologies to overcome the environmental challenges are thriving every day. New battery concepts, particularly with less critically limited raw materials, increased safety concepts, durability and better recycling capability [1] are in demand. Sodium-Nickel Chloride (Na-NiCl2) batteries have the technological potential due to its diverse chemistry and high safety aspects [2]. Since the cathode chemistry and the interaction of individual components plays a significant role, it is important to study its behavior to improve the overall performance of the battery. Here, using the PyBaMM framework [3], the evolution of mechanical stress due to the electro-chemical changes within the cathode during the charge and discharge phases are studied. The model considers a constant electrolyte volume in the cell, such that it allows for the computation of generated mechanical stresses due to the evolution of solid phases during cycling. Observations from the simulations using Discrete Element Method (DEM) is used as an input to the PyBaMM model for the better understanding of the micro-level characteristics. This allows for the precise calculation of the stress response due to the volumetric change, which elucidate the possible ageing properties like cracking or fragmenting.

Modeling Swelling Behavior in Nano-Silicon Coated Graphite Anodes Using Discrete Element Method: Insights into Particle-Level Interactions and Irreversible Volume Changes

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Nano-silicon-coated graphite anodes have emerged as a promising solution for enhancing the performance of lithium-ion batteries, combining the high energy storage capability of silicon nanoparticles with the structural stability of graphite. While silicon nanoparticles exhibit reduced volumetric expansion (~20–30%) compared to bulk silicon (~300%), the dynamic behavior of these anodes during cycling remains complex. This study employs the Discrete Element Method (DEM) to simulate the swelling and shrinking behavior of nano-silicon-coated graphite anodes, with the Thornton-Ning model used to solve particle interactions. A comprehensive sensitivity analysis is conducted to examine the effects of critical parameters, including the carbon binder domain (CBD), friction coefficient, Thornton-Ning yield ratio, Young's modulus, and the restitution coefficient between graphite and nano-silicon particles, to validate the experimental results.

Development tool for sustainable and repairable battery systems for electric and hybrid powertrains

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Otto-von-Guericke-University Magdeburg

The ongoing electrification of mobile applications poses significant challenges to developers in the field of battery system design. The development process must address high demands for energy density, service life, safety, and system integration within a constrained timeframe. To advance this process, the utilisation of modular development tools is recommended, as these tools enable the holistic and interdisciplinary design of battery systems for electric and hybrid powertrains. The OVGU tool utilises evolutionary algorithms to distribute battery cells within the available installation space optimally. Building on this, extensions are to be developed that use the fundamentals from simulating electrochemical processes in specific cell chemistries (e.g., PyBAMM) and thermal simulations. The incorporation of criteria is facilitated by the involvement of various disciplines, enabling an initial assessment of service life and cost for the developed battery system concepts. The combination of data-driven analysis, parametric simulation, and rule-based decision support enables a rapid evaluation of diverse cell chemistries, cooling concepts, interconnection designs, and housing variants. The objective of the simulations is to enable well-informed decision-making at the inception of the project, thereby minimising potential risks and reducing development durations. In light of the findings from preceding studies and the utilisation of demonstration vehicles, a so called OvGU tool is to be developed. This endeavour will be accompanied by extensive literature research and the existing tool. The OVGU tool will be useful in providing support to designers and developers of battery systems.

Smart Machinery & Digital Tools for Energy?Efficient, Scalable Battery Cell Manufacturing (BATMACHINE)

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Vrije Universiteit Brussel

Current battery cell manufacturing processes frequently rely on conventional machinery that lacks the flexibility, efficiency, and precision needed for sustainable production. The sector faces challenges such as high scrap rates, energy-intensive operations, and limited integration of real-time monitoring and process control. To address these issues, cell manufacturing is rapidly evolving. Modern battery machinery now features greater automation and modularity in key stages like mixing, coating, and calendaring. These innovations improve process control and product quality. However, material scrap rate remains a critical economic and environmental challenge. The adoption of smart machinery and advanced digital tools has become essential. Intelligent systems— capable of real-time process adaptation, predictive fault detection, and data-driven optimization—pave the way to reduce waste, stabilize production, and lower the environmental footprint of battery-cell manufacturing. The BATMACHINE project (www.batmachine.eu), funded under Horizon Europe, directly addresses these challenges by developing a new generation digitally enabled, high-performance manufacturing equipment. Core activities include designing modular slurry-preparation units, advanced slot-die coating and drying systems, integrated calendaring, and creating shared data spaces and digital interfaces for comprehensive process monitoring, operator support, and traceability. BATMACHINE also conducts on-site demonstrations, lifecycle assessment, and techno-economic analyses to inform sustainable process design and facilitate future battery passport architectures. Through these innovations, BATMACHINE aims to reduce scrap rates and energy use, boost throughput, and enable scalable, data-driven manufacturing solutions. The project will supply the technological and digital foundation required for European gigafactory development, strengthening the resilience and competitiveness of the battery value chain.

Sustainable and digitalized GIGAfactory for BATtery production with made-in-Europe machinery (GIGABAT)

Iker Boyano
Cidetec

Europe needs to efficiently consolidate its battery manufacturing value chain for large-scale cell production to enable a sustainable and ecological transition. To achieve this, it is essential to promote EU-based machinery and suppliers, fostering technological and industrial independence. GIGABAT project, funded under Horizon Europe, delivers targeted solutions to these challenges by upgrading sections of the processes and equipment for electrode and cell fabrication planned for installation in European Gigafactories for Li-ion battery production. GIGABAT focuses on optimizing existing machinery and developing novel innovative new equipment, alongside process engineering improvements to manufacturing processes to enhance flexibility, throughput, and energy efficiency. GIGABAT also targets logistics and recyclability improvements to reduce waste and enhance scrap recovery, while holistically addressing the digitalization of gigafactory production plants. Core machinery development activities in the project include the design of innovative gigafactory-scale post- drying machinery with IR-assisted drying; the development of advanced mixing systems to reduce time and energy consumption; novel systems such as an inline electrode burr-check vision system, an innovative electrode stacking group, and advanced formation stations for prismatic cells; as well as the manufacturing of a highly sensorized calender machine. On the digital front, key developments include advanced analytics and machine learning models to reduce scrap, as well as scalable, process-specific energy models tailored to different manufacturing steps. In addition, electrochemical cell degradation models and system-level climatic chamber models are being developed to link formation properties with energy consumption during the formation stage. GIGABAT is also evaluating direct scrap recycling at pilot scale to support the future development of industrial- scale applications and is conducting lifecycle assessments to define quantitative targets that gigafactories must meet to achieve absolute sustainability. By leveraging these advancements, GIGABAT aims to deliver the core technological and digital infrastructure to support the rollout of European gigafactories, driving a stronger and more competitive battery industry.

Electrode, cells and systems analytics and applications: Diagnostics during production- and use-phase

Ensuring the highest quality in Battery Cell Manufacturing through advanced sensors

Florian Hermann
Precitec GmbH & Co. KG

Ensuring the highest quality at every step of battery cell manufacturing is essential for producing safe batteries and reducing production waste. In this contribution, we present two representative use cases from electrode and battery cell manufacturing that demonstrate how advanced sensor technologies can improve production quality.
First, we address the safety-critical issue of cutting burrs, which can penetrate the separator and cause short circuits. Using a chromatic vision camera from Precitec, we achieved reliable inline detection of burrs smaller than 10 µm at belt speeds of 60 m/min. Second, we examine the impact of electrolyte residues remaining on the cell surface, which significantly affect the laser welding process. A photodiode-based process monitoring system was implemented for both laser cleaning and laser welding, enabling inline evaluation and control of weld seam quality.

Aging Behavior of Sodium-Ion Batteries

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Sodium-ion batteries (SIBs) are considered a promising alternative to lithium-ion batteries (LIBs), particularly in light of the growing demand for safe, sustainable, and resource-efficient energy storage technologies. Due to the broader availability and more balanced global distribution of sodium resources, SIBs offer significant advantages in terms of sustainability and supply security. Furthermore, their lower risk of thermal instability reduces safety concerns, making them especially attractive for stationary and safety-critical applications.
In this study, the electrochemical performance of prismatic SIB cells with a nominal capacity of approximately 150 Ah was investigated. Calendar and cycle aging behavior was analyzed under varying temperature and charging conditions to evaluate the mechanisms and rates of degradation. Electrochemical characterization included internal resistance measurements, capacity retention analysis, and C-rate testing. The results provide insights into the long-term stability of large-format SIB cells and highlight their potential for use in stationary energy storage systems, especially under controlled thermal and operational conditions.

Recycling & Sustainability: Circular economy, battery supply chains and factory designs

AI-Optimized Recycling of Lithium-Ion Batteries: Enhancing Sustainability and Circularity through Intelligent Process Control

Steffen Fischer
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In response to the increasing demand for sustainable, resource-independent lithium-ion batteries (LiBs), this project aims to enhance the recovery and recycling efficiency of end-of-life (EoL) batteries, especially those with nickel-rich cathodes and silicon-based anodes, which are widely used in electromobility applications. The project's primary scientific goal is to optimize the entire recycling process, from black mass recovery to synthesizing new cathode active materials and producing second-life battery cells.
This is achieved by integrating advanced artificial intelligence and machine learning frameworks to optimize and monitor the process in real time at a pilot scale recycling plant. Therefore, key process parameters, such as comminution intensity, mixing speed, temperature, and sieve size, as well as their impact on the physicochemical properties of the recovered black mass, are identified and evaluated. These parameters include particle size distribution, chemical composition, contamination levels, delamination yield, and specific energy consumption. Iterative optimization based on experimental data ensures that target specifications are met and that the subsequent hydrometallurgical and solvometallurgical steps can operate under ideal conditions. In the pilot phase, up to three 30-kg batches of black mass will be recovered from spent LIB cells and modules. The batches will vary in particle size and impurity levels and undergo thorough characterization targeting >95% delamination yield, >98% purity, a particle size distribution between 1 and 400 µm, and a 10% reduction in energy use. The optimized black mass will then be forwarded to subsequent recovery steps for reprocessing into functional battery materials.
The project emphasizes technology transfer to industrial partners to ensure practical application and scalability. This establishes a flexible and scalable foundation for next-generation battery recycling across a broad range of materials.

Metrology for Eco-Assessments of Batteries

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Physikalisch-Technische Bundesanstalt (PTB)

Battery recycling, circular economy and metrology for environment and climate comprises various fields of application. At PTB those are overseen by the Innovation Cluster Environment and Climate with interdisciplinary contributions from different scientific areas. There is also a wide range of interfaces to energy related metrology research at PTB. For accepting and utilizing batteries in electromobility or stationary storage facilities, an understanding of batteries' State of Health (SoH) and degradation under different cycling conditions is crucial, e.g. for improving lifespans and performances. As a measure of degradation, an SoH value can be assessed via Electrochemical Impedance Spectroscopy (EIS), a non-invasive tool to probe internal battery dynamics, including ion diffusion, charge transfer, and interface behavior. However, other methods with individual advantages on their sides are available as well. In this contribution we showcase examples of recent studies devoted to battery degradation behavior during first and second life but also outline other methodologies including those utilizing modern quantum technology-based instruments.

Accurate SoH determination is especially relevant for batteries facing increasingly demanding requirements in applications like in electric vehicles, renewable energy systems, and portable electronics. Unmatched or strongly varying charge and discharge processes significantly influence battery degradation, and these effects can be directly observed through EIS. Changes in EI-spectra, shifted patterns, due to increased internal resistance indicate stress from fast or irregular charging, accelerating degradation and capacity decrease. Those studies support the development of more robust battery management strategies and second-life utilization options. Thus, it helps to save the environment and facilitates new economic explorations.

LiPLANET – From EU-Project to Pan-European Innovation Network for Lithium-Ion Cell Production

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Background Europe's technological sovereignty in e-mobility and stationary storage hinges on turning laboratory breakthroughs into gigafactory reality. Yet the "pilot-to-plant" gap still adds years, cost and risk to the scale-up of advanced lithium-ion chemistries. The Horizon-2020 CSA "LiPLANET" (GA 875479, 2020-2022) addressed this bottleneck by interlinking the continent's most capable research pilot lines and by creating the legal, organisational and digital backbone for lasting collaboration. Since its transformation into the non-profit association LiPLANET e.V. in 2021, the network has evolved into Europe's first open, industry-ready innovation and production ecosystem for lithium-ion cells. Mission & Visions • Accelerate industrialisation of next-generation Li-ion technologies. • Grow Europe's talent pool through hands-on, pilot-line based training. • Exploit synergies via shared infrastructure, harmonised KPIs and data. • Offer services ranging from proof-of-concept cells to scale-up consultancy under a transparent, standardised legal framework. Key Building Blocks • Mapping & Networking: 12 pilot lines in Europe catalogued by chemistry, format, capacity and equipment; interactive map hosted on the LiPLANET Digital Platform. • Legal & Data Framework: common NDA/UA, IP-sharing rules and a secure cloud workspace enabling multi- partner projects while protecting confidential know-how. • Harmonised KPI & TRL Scheme: unified metrics for process capability, yield, cost and sustainability; verified in a five-site round-robin on NMC811 and LFP pouch cells. • Skills & Training: modular curriculum (online + hands-on): targeted for certifying engineers and researchers • Strategic Roadmap 2030: priority actions on dry-room-free coating, AI-driven digital twins, solvent recycling and battery-passport compliance, endorsed by the Batt4EU Partnership. Early Impact In addition to already reported technical developments of Li-ion battery cells, LiPLANET will extend its scope to solid-state, Na-ion and high-voltage LFP-tandem chemistries, roll out AI-based inline quality control and pilot a "Virtual Gigafactory Sandbox" for rapid techno-economic studies. Collaboration with the European Raw Materials Alliance and Battery Passport Consortium will secure full value-chain traceability and circularity. Take-Home Message From an EU project to a permanent, member-driven network, LiPLANET offers an open yet secure playground where Europe's battery innovations can be matured rapidly and cost-efficiently up to industrial scale. IBPC participants are invited to join the poster sessions, share challenges, express interest in access to the pilot-line infrastructure and co-shape Europe's battery future.

Recycling & Sustainability: Synthesis, (direct) recycling, second use and resynthesis

Joint-adapted separation processes for the automated disassembly of battery systems

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Driven by efforts to reduce emissions from climate-damaging fuel combustion, the share of electric vehicles is rising rapidly. Automakers' research and development therefore focuses on maximizing battery energy density while keeping production costs low. How-ever, a crucial factor-dismantlability- is often neglected during this phase, leading to wi-despread use of non-detachable joints. Since battery systems and modules usually cannot be taken apart easily, they are shredded and their constituent materials are then separa-ted in elaborate downstream sorting processes. This both prevents the reuse of compo-nents and demands complex treatment steps. An alternative approach entails sequential-ly disassembling battery systems and modules, thereby reducing the mixing of lower-value materials with sought-after raw materials. To reduce the sorting effort, cutting techniques are being introduced to achieve the purest possible material separation, thereby streamlining subsequent sorting and preparation. The foundation for an automa-ted, variant-flexible disassembly process is a thorough characterization of these cutting methods so that the optimal technique can be chosen for each specific application.

In this work, separation processes are presented with regard to their possible applications for the automated dismantling of battery systems and modules. In addition, challenges and limitations for the individual separation processes are identified. The results show that a combination of different separation techniques, depending on the type and posi-tion of the joints, is necessary to effectively dismantle a battery system. While mechanical separation processes have a high application potential for point-shaped joints, laser-based cutting processes are particularly suitable for linear joints.

Reviving Production Scrap and End-of-Life Anodes

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Fraunhofer Institute for Silicate Research ISC

Conventional recycling approaches, such as pyrometallurgy and hydrometallurgy, have proven effective in recovering valuable metals from lithium-ion batteries and are well-suited for specific battery chemistries. However, these methods are often associated with high energy consumption or the use of acids and solvents, making the recovery of lower-value components, such as graphite, economically less attractive. To address this gap, direct recycling offers a more resource-efficient alternative by enabling the preservation and reintegration of functional materials. In this context, the present work explores an aqueous delamination strategy for recovering graphite from both end-of-life (EoL) and production scrap cells, with a focus on how the process affects material properties and electrochemical performance.[1]

This work focuses on the direct recycling of graphite anodes from both end-of-life (EoL) and production scraps using an aqueous delamination approach. The process utilizes the solubility of the carboxymethyl cellulose (CMC) binder to separate the graphite from the current collector, eliminating the need for harsh chemicals. Recovered graphite is systematically analyzed to assess how the aqueous treatment affects its structural, morphological, and surface chemical properties. Particular attention is given to potential differences between EoL and production scrap material, including aging-related degradation or manufacturing-related residues. The impact of the delamination process on the electrochemical performance of the recycled graphite is evaluated through full-cell testing, with an emphasis on capacity retention, rate capability, and impedance characteristics. Furthermore, it will be shown how dissolved binder can be reused in new electrode slurries. This study aims to clarify how the delamination process influences the material characteristics of graphite and how these, in turn, affect its electrochemical behavior in newly assembled lithium-ion cells.

Recycling of NMC: How Synthesis Methods Influence the Effect of Impurities

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The transition to renewable energy and the proliferation of electric vehicles have led to an exponential increase in the use of lithium-ion batteries (LIBs), rendering their end-of-life management increasingly critical. The high-value metals are predominantly found in the cathode active material (CAM) typically consisting of lithium nickel-manganese-cobalt oxide (NMC), and therefore recycling of the cathode is especially desired. Nevertheless, one of the most significant challenges in the cathode recycling process pertains to the presence and management of impurities. These contaminants present in the synthesis educts – originating from the recycling processes and thus being distinct from usual impurities of the original educts derived from natural resources – can significantly degrade the electrochemical performance and safety of resynthesized cathode materials, thereby negatively impacting the value and applicability of recycled products.
In this work, we methodically examine the impact of impurities on the quality of NMC cathode materials, with a particular focus on the modulation of these effects by different synthesis routes. In order to achieve this objective, NMC materials were prepared via three representative synthesis techniques: hydrothermal synthesis, sol-gel synthesis, and co-precipitation. Each method was applied to precursor solutions intentionally mixed with typical impurities commonly encountered during battery recycling, including iron, copper and aluminum. A comparative analysis of the resulting NMC materials was performed using a combination of structural (X-ray diffraction, scanning electron microscopy) and electrochemical characterization methods.

Recovery of LIB electrolyte from blackmass by solvent-extraction

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Driven by the growing demand for electric vehicles and energy storage systems, the volume of end-of-life (EoL) lithium-ion batteries (LIBs) is rapidly increasing. In response, the European Union has set ambitious targets, requiring a minimum recycling efficiency of 70% for LIB materials by 2030. Achieving this goal demands advanced recycling processes that go beyond metal recovery and also address electrolyte components, which are often lost during thermal treatment.
This study investigates a solvent-based extraction process for the selective recovery of electrolyte components, aiming to improve black mass processing and overall recycling efficiency. Residual electrolytes, such as lithium hexafluorophosphate ($LiPF_6$) and ethylene carbonate (EC), can hinder further blackmass treatment due to their reactivity and safety risks. Their removal stabilizes downstream processes and enables recovery and potential reuse.
The solvent-based approach presented here relies on commercially available solvents and standard equipment, making it a cost effective and scalable solution suitable for industrial application. It offers a practical alternative to more complex recovery methods and can be readily integrated into existing recycling processes.
Laboratory-scale experiments systematically evaluated the selective extraction of EC and $LiPF_6$ from crushed LIB material, focusing on key parameters such as solvent choice, extraction temperature, and process configuration.
The results demonstrate high selectivity and recovery efficiency under mild conditions. Future work will focus on developing methods for the separation and purification of the extracted electrolyte components to enable their reuse in new battery systems.

Balancing Efficiency and Composition in the Recovery of Black Mass from Lithium-Ion Battery Recycling

Marcelo Oliveira
CeNTI

The unprecedented demand for lithium-ion batteries, which inevitably reach the end of their lifecycle, is driving the growth of the battery recycling industry. Recycling these batteries is crucial not only for environmental sustainability but also for their significant economic potential: lithium-ion batteries contain critical raw materials, such as lithium, cobalt, nickel, and manganese, in concentrations often higher than those found in natural resources. Recycling typically begins with shredding, followed by sieving to recover the "black mass," a fine powder rich in valuable metals, depending on the specific battery chemistry. One of the main challenges in reintroducing black mass into the battery production cycle is achieving high purity with minimal contaminants, which is essential for its further refinement into high-purity individual components via hydrometallurgical processes. As in many industrial separation processes, there is often a trade-off between recovery efficiency and product quality. Thus, careful optimization is necessary to balance material recovery with purity, ensuring both economic viability and environmental sustainability. This study systematically examined sieved fractions of black mass by ICP-OES, focusing on optimizing sieve mesh sizes to enhance the recovery of active material. The results demonstrate that selecting appropriate sieve mesh sizes significantly improves active material recovery while reducing contaminant levels. A detailed chemical analysis of the refined black mass confirms its improved purity, reinforcing the effectiveness of this optimization approach.


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