


# INTERNATIONAL BATTERY PRODUCTION CONFERENCE

4 to 5 November 2026

## CONFERENCE BROCHURE

# WELCOME





Dear IBPC 2026 participants,

Batteries are a key enabling technology for the global energy transition of mobility and industry. As demand for energy storage grows, establishing a competitive, sustainable and resilient European battery ecosystem is becoming increasingly important. Secure supply chains, access to critical raw materials and competitive production technologies and gigafabs are essential to Europe's technological sovereignty amid geopolitical challenges. At the same time, reducing energy use, raw material demand and the carbon footprint across the battery value chain remains a priority. Circular economy principles, including the recycling of production scrap and end-of-life batteries, are crucial to conserving valuable materials and reducing dependencies. Next-generation battery technologies offer new opportunities to improve performance, safety and sustainability. Translating these innovations into industrial-scale circular production requires close collaboration across the battery value chain and skilled professionals educated at universities and research centres.

Building on the success of previous editions of the International Battery Production Conference (IBPC), each attracting around 260 participants and featuring approximately 50 presentations, we are delighted to welcome you to IBPC 2026. The conference provides a platform for industry and academia to exchange knowledge, discuss current challenges and explore innovative solutions for battery manufacturing. This year's programme places particular emphasis on the European battery ecosystem, its circular production capabilities and its supply chains, addressing the challenges of establishing a resilient and competitive European battery value chain. Next-generation battery technologies remain another central focus, reflecting the need to advance innovative materials, cell concepts and production processes while ensuring their industrial viability. The presentations and poster sessions cover topics ranging from electrode and cell production, cell design and safety, performance and diagnostics, formation and ageing to sustainable manufacturing, battery factory design, circular economy and recycling. For the first time at IBPC a hands-on seminar at the BLB EducationLab and an additional networking day with LiPLANET are offering practical insights into battery production and the collaboration between research and industry within the European battery ecosystem.

Our sincere thanks go to all contributors and partners for their valuable support, and especially to our gold sponsors BioLogic Science Instruments GmbH, Maschinenfabrik Gus¬tav Eirich GmbH & Co KG, NETZSCH-Gerätebau GmbH, Werner Mathis AG, Zeppelin Systems GmbH, Nara Machinery Co., GranuTools SRL and our silver sponsors No Canary GmbH, Nexopart GmbH & Co. KG, El-Cell GmbH, IKA Werke GmbH & Co. KG, MDPI AG and TSE Troller AG. 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

BLB+ Braunschweig Labfactories for Batteries and more

The Braunschweig Labfactories for Batteries and more (BLB+) is a regional network of research institutions in the Braunschweig area, uniting expertise of three research centers – the Battery LabFactory Braunschweig (BLB), the Center for Circular Production of Next-Batteries and Fuel Cells (CPC) and the Fraunhofer Center for Energy Storage and Systems ZESS – and affiliated institutions that bundle their expertise with industry. It serves as a collaborative platform to coordinate battery research, enhance visibility, and drive innovation in energy storage technologies.

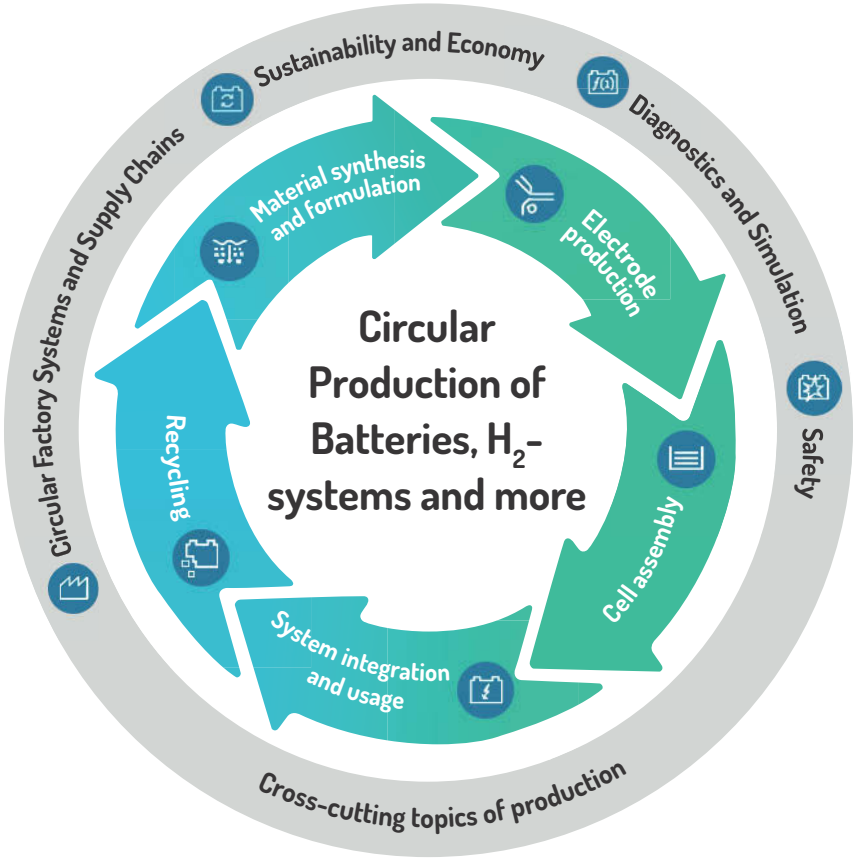
Focus is the circular development and production of innovative batteries, H2-systems and future technologies („next generation“) and its entire value chain- from material development and cell production to characterisation and recycling with active material resynthesis from recycled raw materials. In addition to lithium-ion, sodium-ion and lithium-sulfur batteries, solid-state batteries and fuel cells are being investigated.

The aim is the research for knowledge-driven development and production of sustainable and circular technologies and processes along the circular value chain as well as the transfer of research results to teaching, industry and society.

With nearly two decades of research experience, the BLB combines over 1.500 m² for cell production in their labs spanning laboratory to pilot plant scales. The shared infrastructures of the centers stands for a model of interdisciplinary cooperation around circular battery production that is unique in Europe.

With more than €100M invested in cutting-edge infrastructure across the BLB+ network, including the just recently opened Fraunhofer ZESS and the CPC (to be inaugurated in 2028), the exploration will be further extending its research and lab infrastructure to advanced lithium-ion and solid-state batteries, fuel cells, and energy converters

BLB+ partners collectively offer infrastructure to develop and characterize large-sized batteries, modules, and packs. This supports both fundamental and application-oriented research.




**Object of research**

- Lithium & Sodium-ion batteries
- Lithium-sulfur batteries
- Solid-state batteries
- Metal-oxygen batteries
- PEM fuel cells
- Redox-flow batteries

**Fields of application**

- Electric cars
- Electric trucks
- Aerospace
- Stationary storage systems
- Powertools
- etc.

# CONTENT

PARTNERS ..... 6
PROGRAMME ..... 14
PRESENTATION ABSTRACTS ..... 22
POSTER SESSION ..... 50
POSTER ABSTRACTS ..... 56
IMPRINT ..... 91

# PARTNERS

BioLogic designs, manufactures and supplies high-precision measurement instruments and dedicated control and analysis software for battery research, development and testing.

With a comprehensive portfolio of potentiostat-galvanostats, battery cyclers and impedance analyzers, BioLogic provides a solution for each step of battery development — from fundamental electrochemical research and material characterization to cell development, performance testing, ageing studies and quality control.

Our instruments and software are developed in close collaboration with scientists, battery researchers and industrial R&D laboratories worldwide. This application-driven approach combines measurement accuracy, flexibility and ease of use, helping our customers generate reliable data and make confident decisions throughout the battery development process.

Beyond batteries, BioLogic solutions are also widely used in fuel cells, photovoltaics, corrosion, biosensors and other advanced electrochemical applications.

www.biologic.net

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

EL-CELL develops advanced electrochemical test equipment for battery research, material characterization, and cell development. With our expertise in electrochemistry and mechanical engineering, we provide researchers and battery developers with reliable and reproducible tools for evaluating new electrode materials, cell chemistries, and electrochemical processes.

At the core of our portfolio is the modular PAT (PArallel Testing) system, designed for efficient and reproducible two- and three-electrode measurements. The platform enables precise electrochemical characterization and supports the systematic evaluation of materials and cell components during battery development.

Our portfolio also includes a wide range of in-situ test cells for investigating processes such as electrode expansion, gas evolution, pressure development, and other changes occurring during battery operation.

Together with our dedicated potentiostats and laboratory tools for battery component preparation, EL-CELL provides an integrated test environment supporting battery research from material characterization to cell development and validation.

www.el-cell.com

Granutools offers comprehensive powder characterization instruments and services tailored to address the unique challenges faced by battery manufacturing industries and research centers. Our cutting-edge instruments, including GranuPack (and GranuPack High Temperature), GranuDrum, GranuCharge, GranuFlow, and GranuHeap, are specifically designed for accuracy, repeatability, and operator independence.

With strict initialization protocols and high levels of automation ensuring reliable and precise results, each Granutools instrument addresses specific challenges such as tapped density, packing dynamics, cohesive index, dynamic properties, electrostatic charge measurement, vertical flow rates, angle of repose, and static cohesion.

In battery manufacturing, where various materials contribute to electrode composition, powder flow characterization plays a pivotal role in optimizing the manufacturing process. By gaining better control and understanding of powder properties, manufacturers can achieve safer and more powerful batteries.

www.granutools.com

IKA is a global technology leader in laboratory and process engineering, providing innovative equipment and solutions for research, development, and industrial manufacturing.

We cover the entire spectrum, from small laboratory instruments to large-scale process plants, and possess extensive expertise in developing, optimizing, and scaling up manufacturing processes.

Our portfolio includes high-speed mixing systems for low-viscosity products, kneading technologies for highly viscous materials, as well as equipment and complete systems for dry processing applications.

In the field of battery production technology, IKA focuses on fully continuous and scalable processes designed for efficient, high-volume manufacturing of wet and dry battery elec.

www.ika.com

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

# PARTNERS

A pioneer in open access publishing, MDPI has supported academic communities since 1996. Based in Basel, Switzerland, its mission is to foster open scientific exchange across all disciplines. MDPI publishes 547 open access journals, including 538 peer-reviewed and 9 conference journals, supported by over 295,000 academic experts. All content is distributed under a CC BY license, ensuring research is freely available worldwide. Its portfolio includes at least 330 journals with impact factors, 70% ranked in the top two quartiles of their fields. With offices in Beijing, Wuhan, Tianjin, Nanjing, Philadelphia, Barcelona, Belgrade, Novi Sad, Manchester, Tokyo, Cluj, Bucharest, Toronto, Kraków, Singapore, Bangkok, and Seoul, MDPI has published work by over 4.6 million authors, with about 1.9 billion article-level requests yearly

www.mdpi.com

Nara Machinery Co., Ltd. is a Japanese powder processing equipment manufacturer with over 100 years of history since its founding in 1924. Over the century, we have built extensive expertise and a strong track record in powder handling across various industries. Rather than simply supplying equipment, we work closely with customers as a collaborative partner to address process improvement needs and co-develop optimal solutions.

In the battery materials sector, we have an extensive track record not only with our Hybridization System (NHS) exhibited here, but also with industrial drying equipment.

In this time, we express our sincere gratitude to Technische Universität Braunschweig (TUB) for their inquiry regarding the NHS and for granting us this opportunity to exhibit at IBPC 2026.

www.nara-m.co.jp/en

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.analyzing-testing.netzsch.com

NEXOPART
simplicity for your lab

With its innovative solutions, NEXOPART sets new standards for laboratory efficiency and thus represents the “next generation of particle analysis”.

Nexopart is a successful german manufacturer of products and measuring equipment for determining particle size/shape. The company evolved from its two renowned parent companies, Hosokawa Alpine AG and Haver & Boecker oHG.

In the new brand, the two parent companies, each with a 50 percent stake, are pooling their decades of experience in the manufacture and sale of products and measuring equipment in particle analysis to determine particle size and shape in the premium segment.

NEXOPART GmbH & Co. KG has its legal headquarters in Oelde, Westphalia and operates a branch office in Gersthofen near Augsburg.

As an independent company, NEXOPART offers optimal alignment and focus of all processes and activities to meet the needs of the analytical, biotechnology and laboratory technology markets and their customers.

www.nexopart.com

NO CANARY

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

# PARTNERS

TSE TROLLER
COATING SECRET

More than 60 years of know-how in the development and production of premetered coating dies have allowed TSE Troller to be a world leading specialist in the applied coating technology sector. TSE has developed advanced coating solutions, which have paved the way for the future.

TSE Troller uses the most precise equipment for producing and measuring the die plates in order to guarantee the highest possible quality of the equipment.

Beside precision and surface quality, it is the design of the cavities that plays a crucial role in achieving a superb performance of the die. TSE has wide know how in modelling different liquids. Target of the dual cavity distribution system is a uniform cross profile of the coated film over a wide range of different products without any adjustments.

www.tse-coating.ch/en

VDMA
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.eu/en/

ZEPPELIN®
WE CREATE SOLUTIONS

Zeppelin Systems specializes in the design, construction, and technological upgrading of industrial plants for storing, conveying, mixing, dosing, and weighing high-quality bulk materials and raw materials. With around 1,900 employees worldwide, Zeppelin Systems provides daily solutions for customers in the plastics, chemicals, rubber, and tire industries. Customers in the food industry also value Zeppelin Systems' many years of technological know-how and experience in delivering turnkey solutions. From plant planning and project implementation to after-sales service including process optimization – Zeppelin Systems is an integrated solutions provider, delivering complete solutions from a single source. As an international plant engineering specialist, Zeppelin understands the specific requirements of battery mass production, regardless of whether it is a wet or dry process. With the FM high-intensity mixer a precise and efficient battery mass production is guaranteed. The mixer ensures reliable raw material handling, precise premixing, and optimal active material distribution for superior battery mass quality. We Create Solutions for our customers every day.

www.zeppelin.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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TSE TROLLER

COATING SECRET

SWISS PRECISION

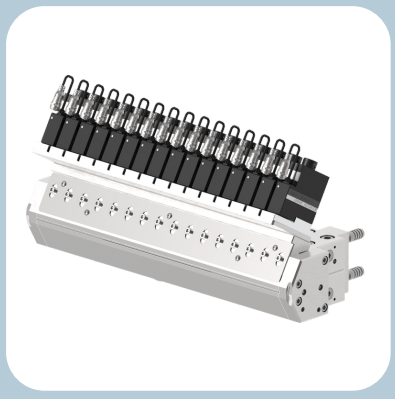
# Shaping the future of coating technologie

## Innovation starts where precision meets experience.

Behind every TSE coating die stands more than 60 years of experience, engineering passion and a commitment to perfection. From research to production, we help our customers turn coating challenges into competitive advantages.



R&D Slot die



Slot die with flex lip



Cleaning station for Slot die

## From R&D to production.
## Your partner for coating innovation.

tse-coating.ch

NEXOPART

simplicity for your lab

# Particle analysis of dry bulk material

A **Haver & Boecker** and
**Hosokawa Alpine** company




www.nexopart.com

# PROGRAMME

## CONFERENCE DAY 1 | Nov. 4th

8:00 I Registration

9:00 I Welcome Speech by Prof. Dr.-Ing. Arno Kwade and Prof. Dr.-Ing. Christoph Herrmann

9:20 I Morning Address by Dr. Alexandra-Gwyn Paetz, Federal Ministry of Research, Technology and Space (BMFTR)

9:40 I Keynote by Dr. Christoph Hartnig, Director R&D and Business Development at AMG Lithium
"Solid electrolytes: from mine to global markets"

10:10 I Short Poster Presentation Round 1 (Presentations by Alice Hoffmann, Jannik Born, Florian Mückan)

10:35 I **Parallel Sessions**

### Next Generation Battery Systems

**Room Maschinenhalle I Chair: René Wilhelm**

High cyclability, zero-expansion sulfide ASSBs enabled by Si nanotextile anodes
*Sahin Cangaz, Fraunhofer IWS*

The scale up path of dry processing of polymer based solid-state battery components
*Katharina Platen, Fraunhofer IFAM*

Additives for Zinc-Based Batteries: Tailoring carboxylates as surfactant for dendrite-free zinc electrodeposition
*Joachim Hering, TU Braunschweig I InES*

### Process Analytics & Quality Assurance

**Room Nimes I Chair: Georg Garnweitner**

Beyond Viscosity: Rheology as Jack-of-all-trades Characterization
*Hannes Bauer, Fraunhofer ISC*

Quantification and Investigation of the fibrillation degree of PTFE in continuous produced dry coated lithium ion battery anodes.
*Julius Gerk & Finn Reinkensmeyer, TU Braunschweig I iPAT*

In-Line Quality Assurance for Solid-State Battery Slurries: Spatially Resolved Measurement of Electronic and Ionic Conductivity
*Constantin Rueß, TU München*

11:35 I Poster Session and Coffee Break

12:05 I **Parallel Sessions**

### Dry Electrode Coating

**Room Maschinenhalle I Chair: Rüdiger Daub**

Advances in DRYtraec® Dry Electrode Processing for LIB and Next-Generation Battery Technologies
*Benjamin Schumm, Fraunhofer IWS*

PFAS-Free Dry Electrode Processing: Innovative Binder Systems and Coating Routes for High-Performance Electrodes
*Oliver Fitz, Fraunhofer ISE*

Dry coating of Gen 4 LFP to high press density while maintaining competitive mechanical and electrochemical performance
*Sam Burrow, Anaphite Ltd*

### Battery Circularity

**Room Nimes I Chair: Thomas Spengler**

Statistical error in the experimental determination of the element specific recycling ratio of Lithium-Ion Batteries (LIB)
*Simon Bendl, TU Bergakademie Freiberg*

Are existing recycling processes for lithium-ion batteries ready for solid-state batteries?
*Kirstin Schneider, TU Clausthal*

Life Cycle Engineering of rechargeable alkaline batteries for stationary energy applications
*Siavash Aghaei, TU Braunschweig I IWF*

13:05 I Lunch Break

14:10 I Keynote by Prof. Dr. Louis Piper, Head of Battery Materials & Cells, WMG, University of Warwick
"From Particles to Performance: The Manufacturing Challenge of Next-Generation Battery Materials"

14:40 I Keynote by Dr. Stefan Permien, UniverCell
"Solvent Free Dry Coating - Efficient Production Processes for Next-Generation Batteries"

15:10 I Break

15:25 I **Parallel Sessions**

Innovative Recycling Techniques

**Room Maschinenhalle I Chair: Odne Burheim**

Front-End Lithium-Ion Battery Upgrading Using Coupled Contact Electrostatic Charging and Electrostatic Free-Fall Separation
*Benjamin Hotte, University of Ottawa*

Pilot-Scale Battery Recycling: Bridging Research and Industrial Deployment Through Process Optimisation and Material Characterisation
*Marcelo Oliveira, CeNTI*

Dual-Functional Conductive Magnetic Supraparticles: Battery Identifiers for Direct Recycling with Enhanced Conductivity
*Andreas Wolf, Fraunhofer ISC*

Investigation of (Post) Drying Techniques

**Room Nimes I Chair: Sabrina Zellmer**

Battery Drying Conditions and Rate Capacity
*Ronan Njøs Dunne, NTNU*

Laser Drying of Battery Electrodes: Enabling Energy Efficient Battery Cell Manufacturing
*Sebastian Wolf, Laserline GmbH*

Experimental and Simulative Investigation of the Mass Transport Mechanisms during Jelly Roll Post-Drying
*Maximilian Brand, KIT*

16:25 I Poster Session and Coffee Break

16:55 I **Parallel Sessions**

Manufacturing of Sodium-Ion Batteries

**Room Maschinenhalle I Chair: Sebastian Thiede**

Sodium-Ion Batteries: Drop-in Ability and Comparison of Various Cathode Active Materials
*Kriss-Kevin Daniel Kasten, TU Braunschweig I iPAT*

Scaling Up Sodium-Ion Cathodes: Translating LFP Production Insights into Scalable Thermal Processes for the Emerging European Market
*Katja Kretschmer, IBU-tec*

Cost-Competitive Sodium-Ion Cells: Areal Capacity as the Dominant Lever between Cell Cost, Processability and Electrochemical Performance
*Luca Sophie Brinkmann, TU München*

Circular Cathode Production

**Room Nimes I Chair: Simon Lux**

From Lab to Pilot: Scaling Ni-Rich NMC and LFMP
*Peter Axmann, ZSW Ulm*

BASF Battery Recycling – Starting up a Black Mass Production
*Thomas Mütze, BASF*

Influence of Process Parameters on the Delamination Efficiency of Production Cathode Scrap vs. End-of-Life Lithium-Ion Batteries
*Steffen Fischer, TU Braunschweig I iPAT*

17:55 I Break

18:10 I Conversion for Dinner

Industry Session I

**Room Nimes I Chair: Klaus Dilger**

Particle Design Technology- Key to Improving Rechargeable Battery Performance via NHS
*Daisuke Murase, Nara Machinery Co., Ltd.*

*From Pump to Coater: Measuring What the Slurry Really Is – Inline Viscosity in Battery Electrode Production*
*Thomas Böhme, Dr. Thomas Haenel, Onur Özgül, Netzsch*

De-Risking Dry Electrode Scale-Up: Testing the Process Chain from Powder Handling to Mixing and Calender Feeding
*Hans Schneider, Zeppelin*

18:55 I Break

19:45 I Gala Dinner

# PROGRAMME

## CONFERENCE DAY 2 | Nov. 5th

8:30 I Keynote by Dr.-Ing. Arno Kwade, Chairman of LiPLANET e.V., Head of the BLB & CPC and Dr. Payam Hashemi, CEO of LiPLANET e.V.
"Accelerating European Battery Industrialization Through Open-Access Pilot Lines and Ecosystem Continuity"

9:00 I Keynote by Dr. Stefan Gerl, Eirich and Dr. Olga Isakin, BYK
"Synergizing Machinery and Chemistry: Advancing Sustainable Wet and Dry Electrode Manufacturing via Innovative Mixing and Tailored Additives"

9:30 I Short Poster Presentation Round 2 (Presentations by Ross Sloan, Julia Hövels, Matthias Kammermeyer)

9:40 I Poster Session and Coffee Break

10:10 I **Parallel Sessions**

### Lithium Sulfur Battery Production

**Room Maschinenhalle I Chair: Holger Althues**

Solid-State Lithium-Sulfur Battery Concepts for Aviation Applications
*Georg Garnweitner, TU Braunschweig I iPAT*

High Energy Si/S Batteries via One Pot Production of Porous Semiconductor Polymer Electrodes
*Jonathan Florez Montaño, CSMB HU Berlin*

Practical binder and conductive additive systems for sulfurized polyacrylonitrile cathodes enabling long cycle life and enhanced rate capability in lithium sulfur batteries
*Ralf Müller, Fraunhofer IWS*

### (Simulation of) Slurry-based Processing

**Room Nimes I Chair: Thomas Koller**

Optimized slot dies with flex lips and closed control loop for precise thickness adjustment
*Remo Andreas Ziörjen, TSE Troller AG*

Modelling and Optimisation of Battery Electrode Slurry Preparation Process by Extrusion
*Sarah Bhutta, Warwick Manufacturing Group*

A Hybrid Experimental, CFD, and Machine-Learning Framework for Viscoelastic Battery Slurry Slot-Die Coating
*Sung Hin Lam, School of Mechanical Engineering (University of Leeds)*

11:10 I Break

11:25 I **Parallel Sessions**

### Modelling & AI-Assisted Battery Production

**Room Maschinenhalle I Chair: Thomas Vietor**

From degradation diagnosis to physics-based lifetime prediction of NMC/graphite battery cells
*Connie Chen, Forschungszentrum Jülich GmbH*

Optimizing Slot-Die Coating of High-Viscous Slurries in Battery Electrode Production
*Vladimir Popok, FOM Technologies*

Overcoming Data Scarcity in AI-Based Quality Assessment of Lithium-Ion Cells
*Tessa Krause, Precitec GmbH & Co. KG*

### Advanced Characterization Methods

**Room Nimes I Chair: Michael Kurrat**

Non-Invasive LIB Quality Assessment by Spatial Magnetic Operando and Relaxation Analysis
*Paul-Martin Luc, CDO2 Germany UG*

High-Throughput, Non-Invasive SOH Estimation for End-of-Life Batteries Using Impedance-Based Techniques
*Simeon Kremzow-Tennie, Keysight Technologies*

Robot-Assisted X-Ray Computed Tomography for Non-Destructive Quality Inspection of Battery Packs
*Steven Oeckl, Fraunhofer IIS*

12:25 I Lunch Break

13:25 I Panel Discussion "European Battery Supply Chain"

14:10 I Poster prizes

14:30 I **Parallel Sessions**

Sustainable Electrode Fabrication

**Room Maschinenhalle I Chair: Rachel Smith**

Dry manufacturing process for the gelled SOLGAIN™ electrodes
*Jeremie Salomon, CEA Tech*

Effect of Mechanical Stress Conditions During Extrusion on Semi-Dry Anode Microstructure and Performance
*Niclas Hornischer, TU Braunschweig I iPAT*

Semi-dry coating by direct extrusion as flexible manufacturing strategy for battery electrodes
*David Werner, Fraunhofer IKTS*

European Battery Ecosystem

**Room Nimes I Chair: Peter Axmann**

Mixing and Processing of Gen 5 LFP: From Slurry Formulation to cell formation
*Iñigo Raposo, CIDETEC Energy Storage*

NoVOC- Advancing Sustainable Lithium-Ion Battery Manufacturing through Aqueous and Dry Electrode Processing
*Stina Starborg, RISE Research Institutes of Sweden*

Battery Production Digitalization: Challenges and Learnings from BATMACHINE project
*Sylvain Gouttebroze, SINTEF*

15:30 I Poster Session and Coffee Break

16:05 I **Parallel Sessions**

Innovative Battery Production

**Room Maschinenhalle I Chair: Carsten Schilde**

High-rate solid-state lithium batteries achieved by infiltrating a single-layer LLZO scaffold
*Muhammad Zubair, MLU Halle-Wittenberg*

Waste to battery materials: building a circular and resilient onshore supply chain for high purity alumina
*Isaac Sousa Martins, Queensland University of Technology*

Development and Performance Validation of High-Voltage Pouch Cells: From Conventional to Fully Gellified Architectures
*Jon Rodriguez Romero, CIC energiGUNE*

Industry Session II

**Room Nimes I Chair: Daniel Schröder**

Accelerating Dry Electrode Development through Simultaneous Powder Conductivity and Densification Analysis
*Roozbeh Valadian, Granutools*

Holistic Moisture Management in Battery Production Lines
*Fabienne Huttner, PowerCo SE*

DRYOON® MiniEnvironments – Moisture Diffusion and its impact on Dryroom Design
*Michael Schmauß, Exentec Germany GmbH*

17:05 I Goodbye Speech by Prof. Dr.-Ing Arno Kwade and Prof. Dr.-Ing- Christoph Herrmann

17:30 I Tour through the BLB ProductionLab or CircularLab

# IKA

designed to work perfectly

# Fully scalable mixing solutions
# WET & DRY electrode processing






## DRY PROCESS

### Continuous electrode processing

> Seamless scale-up
> Suitable for anode & cathode
> Slow speed - minimized wear
> Continuous inline process

## WET PROCESS

### Efficient slurry processing

> Smallest footprint
> Improved cell conductivity
> Minimized OPEX
> Batch-or Conti-Inline processing

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## SETTING A NEW STANDARD FOR ELECTRODE PROCESSING

> Customized process solutions
> Advanced battery materials
> Lab-to-industrial scale-up
> From single machine to turnkey solution
> Global subsidiaries for local support
> 100+ years of family-owned reliability



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## DRY or WET.
## From LAB to PRODUCTION.

IKA powers battery innovation

20261008_WET_DRY Coating Flyer_94000811

ZEPPELIN®
WE CREATE SOLUTIONS

HIGH-PERFORMANCE MIXING, DOSING AND CONVEYING SOLUTIONS FOR BATTERY PRODUCTION

# ADVANCED MIXING & MATERIAL HANDLING

- Maximum dispersion and shear
- Multiple cooling zones
- Durable, low-maintenance design
- Adjustable shear intensity for every process
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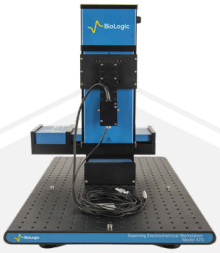




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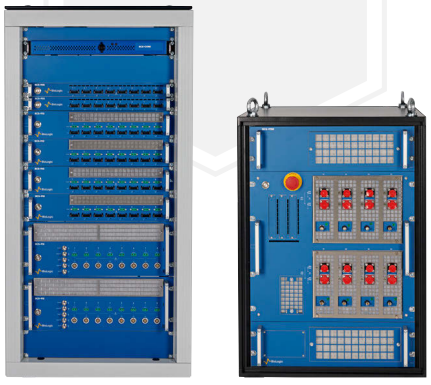
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# PRESENTATION ABSTRACTS

## Next Generation Battery Systems

### High cyclability, zero-expansion sulfide ASSBs enabled by Si nanotextile anodes

*Sahin Cangaz*
*Fraunhofer Institute for Material and Beam Technology IWS*

While sulfide solid electrolytes (SE) provide outstanding properties including high ionic conductivity exceeding 3 mS/cm, there is still a need for innovations in processing and design of electrodes and cells for the development of high energy all-solid-state batteries (SSBs). A growing type of SSB cell concepts which can demonstrate the potential of solid electrolytes are those based on 100 % Si anodes. Recently, with this type of SSB cell concept a promising high energy density and high cycle life could be shown. Silicon represents a highly abundant anode material with high specific capacity and ideally suited for SSBs; however, this requires achieving the appropriate microstructure to meet cell requirement, and the use of chemical engineering processes scalable to the kilo ton per annum (ktpa). Here, this work reports on the use of 100 % silicon anodes produced through thermocatalytic decomposition of silane using a scalable gas-phase process. The anodes are entirely made of silicon nanowires (SiNWs), and are formed floating in a gas stream as macroscopic sheets to form anodes of high areal capacity up to 10 mAh/cm2 which are later calendered to the current collector with sufficient porosity to accommodate volume expansion upon lithium uptake.
In this work, SiNW anodes were used as anodes in pouch cells with NMC / LPSCl composite cathodes and LPSCl SE membranes. The cycling performance was evaluated at different temperature and external pressure. The results show a good combination of electrochemical properties: high rate capability (e.g. 3 C discharge), high cycle life above 1.000 cycles (retention above 80%) and negligible cell expansion (< 5%). Cells were successfully tested at reduced external pressure below 5 MPa. These results confirm that Si nanotextile anodes can readily enable high performance solid-state batteries. Work is in progress to test multi-layer pouch cells under extended conditions that meet entry specifications by cell producers.

### The scale up path of dry processing of polymer-based solid-state battery components

*Katharina Platen*
*Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM*

All-solid-state batteries (ASSBs) are considered a promising next-generation alternative to conventional lithium-ion batteries due to their higher energy density and improved safety enabled by replacing flammable liquid electrolytes with ion-conducting solids. However, scaling up the production of solid electrolytes (SEs) and composite cathodes (CCs) remains a key challenge. Because polymeric SE materials are already available on larger scale, research can focus on scalable manufacturing. Here, we investigate solvent-free dry process for polymer-based ASSB components using hot-melt extrusion. This approach enables kilo-scale production and reduces process costs by eliminating premixing and drying steps. To improve cathode-SE interfacial contact, CCs containing conventional cathode materials and SE are processed via continuous twin-screw extrusion. The twin-screw extrusion process enables separate feeding and homogeneous mixing of both composite cathode and SE components.
This work addresses the scale-up of dry processing of PEO-based electrolytes from laboratory scale (50 mL) to pilot scale (kg scale). A laboratory kneader is used to evaluate the influence of process parameters and additives and to define the processing window for the extrusion process. In the extrusion process, the effects of dosing type, feeding position, and screw geometry on the mixing behavior of PEO-based SEs and CCs are investigated. Process monitoring includes screw speed, torque, pressure, and temperature and is used to evaluate the process quality. Besides electrochemical characterization as quality control, temperature- and frequency-dependent DMA is used to assess mechanical properties (storage module G', loss module G'' and loss factor tan(δ)) of the single components and SE/CC-laminate.

### Additives for Zinc-Based Batteries: Tailoring carboxylates as surfactant for dendrite-free zinc electrodeposition

*Joachim Hering*
*TU Braunschweig I Institute of Energy and Process Systems Engineering (InES)*

The growing need for efficient and sustainable battery technologies highlights the importance of understanding metal electrodeposition. Batteries using zinc metal as anode, especially Zinc Ion Batteries, are safe and cost-effective but require control of zinc plating to prevent dendrite formation and enhance cycle life.
We propose an effective electrolyte-engineering strategy that hinders interfacial charge-transfer kinetics, promoting uniform zinc growth at practical current densities.
We create a dynamic adsorption layer at the zinc-electrolyte interface by using polyethylene glycol and a carboxylate chelating agent in mildly acidic media. This approach enhances kinetic control over the process. The surfactant slows electron transfer, while the carboxylate stabilizes $Zn^{2+}$. Consequently, zinc deposition transitions from diffusion-limited to kinetics-regulated.
A comprehensive experimental study, including overpotential analysis and in situ Raman spectroscopy, reveals that the rate-determining step shifts from $Zn^{2+}$ transport to interfacial electron transfer, while bulk ion transport remains unchanged. Studies with chelate agent/surfactant systems show that (1) the surfactant's kinetic barrier effect is independent of molecular structure, and (2) non-sequestering carboxylate groups are essential for effective kinetic regulation. DFT calculations support a model where electrolyte components enhance $Zn^{2+}$ transfer to the electrode surface.
The kinetically regulated interface prevents localized current hotspots and dendrite growth, while maintaining surface activity. The self-regulating adsorption layer improves cycle life from 43 to 2600 cycles in tests with coin cells (Hering et al., DOI: 10.1002/celc.202400668). Our research shows that stable metal electrodeposition is possible using a surfactant-based kinetic barrier and non-chelating anionic moieties, providing a scalable route for safer, longer-lasting rechargeable metal batteries.

## Process Analytics & Quality Assurance

### Beyond Viscosity: Rheology as Jack-of-all-trades Characterization

*Hannes Bauer*
*Fraunhofer Institute for Silicate Research ISC*

Characterizing the rheological properties of an electrode slurry through its flow behavior is a fundamental step in ensuring high-quality manufacturing. Validating viscosity as a function of applied shear not only streamlines the process but also prevents potential issues that could compromise the final product.Each additional piece of information desired typically demands another analytical method. Fortunately, rheological analysis can provide much more information than flow curves alone.
This work introduces rheological insights into LFP CMC/SBR electrode slurries, revealing that the interaction between the particle network and the binder system is primarily governed by the ratio of particle size to binder length. It is shown that the viscosity of a given composition and LFP particle size can be mainly defined by adjusting the binder polymer length; e.g., a particle with a d50 of 1 µm exhibits lower viscosity with shorter CMC polymers than with longer ones. These results could be particularly useful for process optimization, as they allow reducing the use of solvents and binders without compromising the slurry's flow properties by simply adjusting the d50-to-polymer chain length ratio, thereby increasing energy density, for example. This can also be valuable for recycled material, as the particle sizes differ, especially from those of pristine material, and finding a suitable binder polymer can still enable straightforward processability.
Furthermore, the electronic percolation network is assessed using rheo-impedance measurements, inspired by the approach of Takeno et al.[1], enabling a comprehensive evaluation of the slurry's electronic properties. The development of internal resistances before and during shearing further indicates the stability of the electronic network and its expression during the coating process.

[1] M. Takeno, Chem. Lett. 2017, 46, 892.

## Quantification and Investigation of the fibrillation degree of PTFE in continuous produced dry coated lithium-ion battery anodes.

*Julius Gerk & Finn Reinkensmeyer*
*TU Braunschweig I Institute for Particle Technology (iPAT)*

Dry coating enables sustainable, cost-effective lithium-ion battery electrode manufacturing by eliminating solvent handling and drying. This study investigates polytetrafluoroethylene (PTFE) binder fibrillation in dry-processed graphite anodes as a critical quality parameter linking process conditions to microstructure. Granules were produced via twin-screw extrusion under systematically varied temperature and screw-intensity conditions, then calendered into anode films. Both granules and films were characterized by scanning electron microscopy (SEM) and differential scanning calorimetry (DSC). SEM revealed increased PTFE fibrillation with higher extrusion temperatures and more aggressive screw configurations. DSC measurements showed decreasing specific melting enthalpy with increasing specific energy input, indicating reduced crystallinity and higher fibrillation degree. Calendering induced additional, process-dependent fibrillation, further lowering melting enthalpy in final films. Across all process steps, specific melting enthalpy correlated strongly and approximately linearly with specific energy input. This demonstrates DSC can quantitatively assess PTFE fibrillation in dry-coated graphite electrodes, while specific energy input during mixing serves as a soft sensor for optimal process conditions. These results establish that PTFE fibrillation can be effectively monitored through combined process energy input, SEM, and DSC analysis, providing a foundation for process understanding, quality control, and soft-sensor development in sustainable dry electrode manufacturing.

## In-Line Quality Assurance for Solid-State Battery Slurries: Spatially Resolved Measurement of Electronic and Ionic Conductivity

*Constantin Rueß*
*TU München*

The shift from lithium-ion to solid-state batteries promises a higher energy density and improved safety, yet it entails a more complex and cost-intensive process chain. Electrode quality is set early in the process chain. During mixing, the homogeneity of the slurry defines the percolation networks that govern later electrode performance. Today, slurry quality can only be judged indirectly through properties such as rheological characteristics or particle size, and it cannot be finally evaluated independently of the downstream steps. As a result, the mixing process cannot be optimized in isolation.

This work introduces an in-line process analytics approach that characterizes composite cathode slurries for solid-state batteries directly through their electronic and ionic conductivity. In contrast to conventional lithium-ion battery slurries, the solid electrolyte in solid-state slurries make both conductivity components measurable already during mixing. A multilayer impedance spectroscopy setup with sequentially addressed electrode pairs across several measurement planes resolves conductivity in space and time inside a cylindrical mixing vessel. The setup was calibrated throughout the electrodes with reference solutions and applied to a polymer-based composite cathode slurry.

It reliably distinguished resistance differences across the measurement planes from which electronic and ionic conductivity were derived. A three-dimensional reconstruction localized macroscopic inhomogeneities qualitatively.

By establishing conductivity as a direct, in-line quality criterion, the work shows a promising building block toward a framework that decouples the mixing process and enables property-oriented, process-chain-independent control of slurry production for solid-state batteries.

# Dry Electrode Coating

## Advances in DRYtraec® Dry Electrode Processing for LIB and Next-Generation Battery Technologies

*Benjamin Schumm*
*Fraunhofer Institute for Material and Beam Technology IWS*

The shear-force-induced dry coating process DRYtraec® is increasingly establishing itself in both academia and industry as one of the leading dry coating technologies for manufacturing battery electrodes. Alongside ongoing efforts in technology scale-up, current research is placing greater emphasis on understanding the interdependencies between individual process steps. Furthermore, the future viability of the technology is being actively discussed, particularly with regard to emerg-ing cell chemistries and alternative binder systems.

This presentation will first highlight key process-technical relationships between material mixing, dry blend properties, and the coating of LFP electrodes. The roll of particle size distribution and energy input during mixing will be discussed. In addition, the versatility of the DRYtraec process will be demonstrated using the examples of hard carbon and NFPP electrodes for sodium-ion batteries.

Finally, the use of alternative binders within the DRYtraec process will be addressed. In addition to conventional engineering polymers such as polyethylene, the applicability of biopolymers will be discussed.

Overall, the presentation provides an overview of the current state of DRYtraec technology and outlines several important trends in its ongoing development.

## PFAS-Free Dry Electrode Processing: Innovative Binder Systems and Coating Routes for High-Performance Electrodes

*Oliver Fitz*
*Fraunhofer Institute for Solar Energy Systems ISE*

The growing demand for advanced battery electrode manufacturing that eliminates solvent-intensive drying and PFAS-based binders is driving the development of alternative routes, particularly for lithium-ion and sodium-ion batteries. Process optimization offers substantial economic and environmental benefits compared with state-of-the-art wet coating, for example by transitioning to low-solvent or solvent-free processes, using PFAS-free binders, and enabling direct lamination onto metallic current collectors without primer coatings.

At Fraunhofer ISE, we demonstrate that PFAS-free binders can deliver electrochemical performance comparable to or better than PFAS-containing reference electrodes by using two innovative process routes: dry and semi-dry electrode processing techniques. The resulting electrodes exhibit tunable morphology, including controlled porosity, adjustable layer thicknesses from the micrometer to millimeter range, and high mechanical robustness. These properties are achieved through advanced material treatment technologies such as pelletization and high-shear kneading.

Our PFAS-free binder systems enable direct lamination of the electrode film onto metal current collectors, eliminating the need for carbon primer layers and thereby reducing material and process costs. The developed (semi-)dry coating routes also significantly lower the environmental impact associated with fluorinated materials and solvent handling.

Overall, this work highlights the suitability of PFAS-free binders and dry/semi-dry processing as viable, scalable solutions for efficient and sustainable electrode production, while maintaining electrode integrity and high battery performance.

### Dry coating of Gen 4 LFP to high press density while maintaining competitive mechanical and electrochemical performance

*Sam Burrow*
*Anaphite Ltd*

Dry-coating requires a system-level approach to understand and integrate a wide variety of elements, in order to successfully produce desirable electrode product at high speed and yield.
Anaphite is a company dedicated to solving dry coating manufacturing challenges using its Dry Coating Precursor (DCP®) platform for dry coating powder formulation & production.
Typically, LFP dry coating has been extremely challenging due to the high surface area and small particle size leading to difficulties mixing powders to form flexible films. Solving this dry coating challenge could enable dry coating to reach its full potential. Indeed, moving from NMP coating to dry coating with LFP could save up to 4.5 kWh(energy) / kWh (cells). This is compared to about 1.5 kWh(energy) / kWh (cells) for the equivalent transition with NMC.
In this presentation, we will present a case study of how i) materials selection & formulation, ii) powder structure, and iii) coating conditions can be optimised to produce dry-coated LFP electrodes that are competitive with the best electrodes produced by state-of-the-art NMP coating processes.
We find that dry-coated LFP electrodes produced by optimising these parameters meet all essential requirements for a competitive LFP electrodes. For example, high press densities of 2.6 g/cm3 and high LFP active content (>97%) is achieved.
To characterise these LFP electrodes, we will present: coating performance, electrode defects, mechanical properties, and electrochemical properties in comparison with state-of-the-art NMP coated electrodes.

## Battery Circularity

### Statistical error in the experimental determination of the element specific recycling ratio of Lithium-Ion Batteries (LIB)

*Simon Bendl*
*TU Bergakademie Freiberg*

EU Regulation 2023/1542 establishes mandatory recycling ratios for LIB [2]. But, how precise can the recycling ratio be determined?
With the obligatory increase in the recycling ratio for materials like Co, Cu and Ni up to 95 % by end of the year 2031, the determination of the recycling ratio is becoming increasingly important being the central building block in the legal framework. The delegated regulation 2025/606 of the European Commission explains and specifies the regulation of 2023/1542. Three methods are described to determine the chemical composition of the input stream. These three methods are 1) battery passport (if available), 2) sampling and analyzing the feed flow e.g. with dismantling studies, 3) analysis of all output fractions and recalculating the feed.
Each of these methods hosts challenges, e.g. the battery passport will not be available for end of live (EoL) batteries in the upcoming years- For the analysis of output fractions like casing and foil concentrates, industrial standards for analysis still need to be developed. Last not least, dismantling studies are quite expensive and subjected to analytical error.
The EU regulation does not specify statistical accuracy. Regulation 2023/1542 requires a quality report along to the data and the delegated regulation 2025/606 specifies that the authority is allowed to check the accuracy of the information by requesting support documents such as contracts, shipping documents, or contact information. This suggests that statistical error has not been taken into account until now.
This presentation will provide an error analysis for the mechanical battery recycling compared to Wuschke based on gaussian error propagation. The analysis includes a dismantling study as well errors from sampling and analysis of black mass (BM) via ICP-OES.

## Are existing recycling processes for lithium-ion batteries ready for solid-state batteries?

*Kirstin Schneider*
*Clausthal University of Technology*

Current industrial recycling processes and legislation focus on production scrap and end-of-life lithium-ion batteries (LIBs) with liquid electrolytes. As solid-state batteries (SSBs) emerge, their solid electrolytes and novel cell concepts pose significant challenges to existing recycling infrastructure. Assessing the adaptability of LIB recycling routes for SSBs is therefore essential to ensure a circular battery economy and align emerging technologies with future infrastructure.
This study conducts a techno-environmental assessment of three industrial LIB recycling routes and three SSB chemistries (oxide, polymer, and sulfide), and derives tailored SSB recycling concepts based on the findings. The technological assessment shows that adapting LIB routes for SSBs requires chemistry-specific process modifications and stringent safety measures. While most adapted routes meet the European Battery Regulation's recovery rate targets, the efficient recovery of cobalt, lithium, and nickel remains challenging. The environmental assessment applies material and energy flow analysis to evaluate the global warming potential of a selected recycling route. Results show that on the one hand SSB recycling often involves greater process efforts but on the other hand achieves higher recovery credits than the corresponding process route for LIB with liquid electrolyte. To address the limited direct transferability of LIB recycling routes, SSB-specific recycling concepts are proposed to overcome key technological constraints.
The findings highlight the importance of integrating design-for-recycling principles into battery development and implementing flexible recycling processes. The methodological framework is transferable to other next-generation battery technologies, offering decision support for industry and policy in a rapidly evolving battery landscape.

## Life Cycle Engineering of rechargeable alkaline batteries for stationary energy applications

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

Rechargeable alkaline Zn-MnO2 batteries are one of the emerging battery technologies under research for application in the stationary energy storage sector. Because of their resemblance to the primary alkaline batteries, these batteries benefit from existing material processing, production, and recycling infrastructure and know-how about their chemistry and performance. Furthermore, Zn-MNO2 batteries avoid using materials such as lithium, copper, and cobalt which are associated with concerns regarding their availability to supply the growing battery demands. However, comparatively lower energy density in comparison to lithium-ion batteries currently limit suitable application of Zn-MNO2 batteries to stationary storage units. While rechargeable alkaline batteries are under further development, their environmental sustainability is one major aspect to be considered. To this end, this presentation discusses the life cycle assessment results of producing Zn-MnO2 batteries. Based on the results, anion exchange membrane containing polybenzimidazole is the main environmental hotspot in the production of these batteries. Rechargeable alkaline batteries production on pilot scale leads to approximately 0.2 kg CO2-eq climate change impact per Wh of capacity, which is about double the 0.09 kg CO2-eq. for reference industrial lithium iron-phosphate cells. Based on the performed research, cylindrical cell structure allows decreasing the amount of anion exchange membrane considerably, while maintaining cell functioning. As a result, this structure is considered as an engineering mitigation option for the environmental impacts, as well as dry coating process and material-related strategies such as reducing the amount of bismuth in the cell.

# Innovative Recycling Techniques

## Front-End Lithium-Ion Battery Upgrading Using Coupled Contact Electrostatic Charging and Electrostatic Free-Fall Separation

*Benjamin Hotte*
*University of Ottawa, Department of Chemical and Biological Engineering*

The selective separation of graphite from metal-bearing battery materials is of increasing interest in lithium-ion battery recycling. This work investigates a novel dry front-end upgrading strategy based on coupled contact electrostatic charging and free-fall electrostatic separation to exploit differences in the charging behavior of graphite and cathode-derived materials in black mass. The objective is to produce an upgraded metal-bearing feed stream and a graphite-rich product stream prior to downstream processing techniques such as hydrometallurgy and pyrometallurgy. The upgrading strategy consists of electrostatic charging of black mass through pneumatic conveying in a stainless-steel tube and into a free-fall electrostatic separator, where particles of various compounds are separated according to their acquired charge polarity and magnitude. As a proof of concept, contact charging and electrostatic separation were first evaluated using a synthetic powder mixture consisting of graphite, nickel oxide, and lithium oxide. The synthetic mixtures exhibited distinct charging responses that enabled selective separation of graphite from the metal oxides, achieving product purities of 40, 75, and 85 wt.% for lithium oxide, nickel oxide, and graphite, respectively. The methodology was subsequently applied to three lithium-ion battery-derived materials: as-received black mass, pyrolyzed black mass, and pyrolyzed-crushed black mass. For the pyrolyzed and crushed black mass, a single-pass, single-stage separation reduced graphite content by approximately 50 wt.%. These results demonstrate that coupled contact charging and free-fall electrostatic separation can effectively exploit intrinsic differences in particle electrical charging properties to achieve front-end upgrading of lithium-ion battery recycling streams. The findings establish the technical feasibility of an entirely dry beneficiation approach and highlight its potential to complement existing recycling flowsheets.

## Pilot-Scale Battery Recycling: Bridging Research and Industrial Deployment Through Process Optimisation and Material Characterisation

*Marcelo Oliveira*
*CeNTI*

The unprecedented demand for lithium-ion batteries, which inevitably reach the end of their lifecycle, is driving the rapid growth of the battery recycling industry. Meeting the targets set by the EU Batteries Regulation (2023/1542), including minimum recycled content thresholds and material recovery efficiencies, requires not only mature industrial processes but also continuous innovation at every stage of the recycling chain. Pilot-scale infrastructure occupies a critical position in this landscape: bridging the gap between laboratory research and industrial deployment, it enables systematic process optimisation under realistic operational conditions while maintaining the flexibility necessary for experimental investigation.

This work illustrates the role of pilot-scale mechanical recycling in advancing two complementary objectives: the optimisation of black mass recovery and the characterisation and valorisation of the electrolyte fraction. Through systematic variation of sieve mesh sizes and ICP-OES analysis of the resulting fractions, the trade-off between active material recovery efficiency and contaminant reduction was quantitatively mapped, yielding actionable parameters for process design. Concurrently, the electrolyte recovered by drying and condensation was characterised by GC-MS and FTIR-ATR, establishing a compositional baseline for recovered organic carbonates across different cell types and shredding conditions. Together, these results demonstrate how pilot-line experimentation generates the process knowledge and material quality data required to de-risk scale-up and inform regulatory compliance.

### Dual-Functional Conductive Magnetic Supraparticles: Battery Identifiers for Direct Recycling with Enhanced Conductivity

*Andreas Wolf*
*Fraunhofer Institute for Silicate Research ISC*

Direct recycling of lithium iron phosphate (LFP) cathodes represents an energy-efficient and economically attractive route for valorizing battery waste, yet it relies on well-sorted and chemically uniform feed streams. Reliable identification and sorting of cells prior to recovery is therefore essential. External labels are susceptible to abrasion and falsification, whereas magnetic supraparticles (MSPs) incorporated directly into the cathode serve as tamper-proof, cathode-level identifiers that can be read out non-destructively within seconds by magnetic particle spectroscopy (MPS).
This contribution traces the evolution of MSPs from a marker particle designed purely for identification purposes into a dual-functional electrode additive. Supraparticle architectures combining magnetic signal carriers with conductive carbon were realized as both intermixed and core–shell configurations in order to enhance electronic conductivity. The MSP design was optimized to deliver the maximum conductivity benefit to the electrode while minimizing the required amount of carbon black. These robust MSPs were integrated into aqueous LFP slurries, where their distinct magnetic signatures enable individual electrode batches to be identified. Following aqueous delamination, the cathode composite and MSPs were recovered and separated by magnetic separation, achieving 91.7% separation efficiency and 97% purity; the magnetic signature remained intact, allowing direct marker reuse. The influence of particle architecture on electrode microstructure, electronic transport, and electrochemical performance is evaluated, focusing on rate capability and preservation of magnetic readout and recoverability. The results demonstrate that tailored magnetic supraparticles can simultaneously provide traceable material fractions for sorting-based direct recycling and improve cell performance, thereby transforming identification technology into added value for the electrode itself.

## Investigation of (Post) Drying Techniques

### Battery Drying Conditions and Rate Capacity

*Ronan Njøs Dunne*
*Norwegian University of Science and Technology*

This work aims to bridge the knowledge gap between electrode drying and battery performance by developing a deeper understanding of electrode drying kinetics and their influence on electrode microstructure and electrochemical performance. Reducing the energy consumption associated with electrode drying is essential for improving the energy and cost efficiency of lithium-ion battery (LIB) manufacturing, as electrode drying and solvent recovery account for approximately 30–50% of the total energy consumption depending on the drying method and battery chemistry.
A key focus of this work is understanding electrode drying behaviour through the development of drying curves and evaluation of drying rates under different processing conditions. Establishing how parameters such as temperature, air velocity, and electrode thickness influence solvent removal provides important takeaways for optimising drying processes and scaling towards industrial production. Understanding the relationship between drying kinetics and electrode microstructure evolution is critical for achieving energy-efficient drying strategies while maintaining electrode quality and battery performance.
This work evaluates conventional heated compressed air drying and near-infrared (NIR) drying using a custom-built drying rig designed to replicate industrially relevant conditions. The effects of drying temperature, air velocity, and electrode thickness on drying behaviour and electrode properties are investigated. Electrode thickness has been shown to influence battery performance, with increased thickness often associated with improved capacity retention, although limitations in mass transport can affect rate performance at higher cycling rates. A hyperspectral camera was used as an in-line characterisation tool to monitor electrode drying in real time, while focused ion beam (FIB) and scanning electron microscopy (SEM) were used to examine microstructural changes after drying.

## Laser Drying of Battery Electrodes: Enabling Energy-Efficient Battery Cell Manufacturing

*Sebastian Wolf*
*Laserline GmbH*

Electrode drying is one of the most energy-intensive process steps in lithium-ion battery manufacturing, accounting for a significant share of production costs and factory footprint. Conventional convective drying requires long drying units and substantial energy input for solvent evaporation, creating a major bottleneck for the sustainable scale-up of battery production.
Laser drying has emerged as an alternative that enables rapid and highly efficient solvent removal through direct energy deposition into the electrode coating. Recent research has demonstrated the potential of laser-based and hybrid laser-convection drying processes to significantly reduce energy consumption and equipment footprint while maintaining electrode quality and electrochemical performance.
This presentation provides an overview of the fundamentals of laser drying, key process-product relationships and recent advances in the drying of lithium-ion battery electrodes. Experimental results illustrate the influence of laser drying on process performance and electrode quality characteristics. Furthermore, recent progress in process scale-up and equipment development demonstrates the successful transfer of laser drying from research environments into industrial production. The presented results showcase how laser-based drying solutions combine high throughput, reduced energy consumption and compact system design, establishing laser drying as a key technology for economically and ecologically sustainable scale-up of battery cell manufacturing.

## Experimental and Simulative Investigation of the Mass Transport Mechanisms during Jelly Roll Post-Drying

*Maximilian Brand*
*Karlsruhe Institute of Technology (KIT)*

Residual moisture is a critical quality parameter in lithium-ion battery manufacturing because residual water reduces cell performance, safety and lifetime. Therefore, humidity management throughout battery cell production is essential, yet associated with high energy demand. Vacuum post-drying of assembled wound combinations of anode, cathode and separator, known as jelly rolls, is an established industrial process to reduce residual moisture before electrolyte filling.
This study investigates mass transport during post-drying of jelly rolls by combining material characterization, drying experiments and a simulation model. Sorption behaviour and structural transport parameters of electrodes and separators were characterized and implemented as simulation inputs. Wound samples were prepared with defined web tension and dried in a magnetic suspension balance under controlled pressure and temperature conditions.
A PE separator and a ceramic separator are compared, differing in pore structure and sorption behaviour. The results show that separator type influences significantly the post-drying kinetics of jelly rolls. Complementary simulations resolve mass transport and local water activity within wound jelly roll layers. The simulations identify the key transport limitations: binder diffusion in the anode is negligible for the investigated geometry, whereas sorption behaviour and gas-phase transport through porous structures are decisive. These simulations allow an estimation of mass transfer through the separator, which correlates with the experimentally observed influence of the separators on drying time.
Overall, this study provides insights into the mass transport mechanisms during post-drying of jelly rolls. This enables targeted optimization of vacuum post-drying, with the potential to reduce drying time and energy demand in industrial lithium-ion battery production.

# Manufacturing of Sodium-Ion Batteries

## Sodium-Ion Batteries: Drop-in Ability and Comparison of Various Cathode Active Materials

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

The industrialization of battery manufacturing for electric vehicles or aerospace applications has intensified demands on production-integrated quality assurance. Fully assembled battery packs present a fundamental inspection challenge: structural defects such as bonding voids, porosity in insulating foam, and insufficient thermal interface connections are not detectable by conventional electrical testing. Current practice relies on destructive sampling, sacrificing complete assemblies for visual assessment—a method that is economically and ecologically unsustainable at production scale.
This contribution presents a robot-assisted 3D X-ray computed tomography system (RoboCT) developed at Fraunhofer IIS. Two cooperating robotic arms independently position X-ray source and detector, enabling flexible, application-specific scan trajectories around large and geometrically complex battery packs—without size, weight, or disassembly constraints. Patented software algorithms compensate for the inherently lower positioning accuracy of robot kinematics, eliminating costly precision hardware. In a first step, radiographic overview scans identify anomalies such as cell displacement, structural damage, or bonding defects across the full assembly. Regions of interest are subsequently analyzed in three dimensions using CT or laminography at resolutions of up to 30 µm, enabling targeted, high-resolution defect characterization.
Experimental validation on representative large-format battery packs—including crash-tested modules—demonstrated reliable detection and localization of safety-relevant defects across the full assembly volume. The results confirm that robot-assisted CT enables efficient quality control, failure analysis, and damage assessment of complete battery systems in a production-relevant context.

## Scaling Up Sodium-Ion Cathodes: Translating LFP Production Insights into Scalable Thermal Processes for the Emerging European Market

*Katja Kretschmer*
*IBU-tec advanced materials AG*

As the sodium-ion battery (SIB) market gains rapid commercial momentum in China, Europe is increasingly looking to SIBs as a strategic imperative to diversify energy storage supply chains and mitigate lithium price volatility. However, scaling up relies heavily on establishing localized, cost-effective, and highly scalable cathode manufacturing. Drawing on operational insights from mature lithium iron phosphate (LFP) production lines, this work presents an industrially viable, two-step thermal synthesis method for polyanion (e.g., NFPP) and sodium manganese-based layered oxide cathodes. We utilize a scalable thermal spray synthesis/drying technique followed by continuous calcination in a rotary kiln to achieve highly crystalline, electrochemically active structures. By utilizing low-cost, globally abundant precursors entirely free of critical minerals like cobalt and nickel, this process offers a direct blueprint for rapid factory deployment using existing thermal processing infrastructure. The tunable nature of this two-step procedure allows precise customization of product morphology and composition. Ultimately, this approach bridges the gap between lab-scale synthesis and localized giga-scale production, offering a sustainable, economically resilient pathway to accelerate the European sodium-ion ecosystem.

## Cost-Competitive Sodium-Ion Cells: Areal Capacity as the Dominant Lever between Cell Cost, Processability and Electrochemical Performance

*Luca Sophie Brinkmann*
*TU München*

Sodium-ion batteries (SIBs) are widely regarded as a resource-abundant, low-cost alternative to lithium-ion cells. The cathode material $Na_4Fe_3(PO_4)_2P_2O_7$ (NFPP) paired with a hard carbon anode constitutes the polyanionic sodium analogue of the lithium iron phosphate (LFP)/graphite cell. Process-based cost models place NFPP cells close to cost parity with LFP. However, key SIB-

specific parameters such as areal loading, active-material fraction, or the admissible dry-room specification enter these models as fixed inputs rather than being examined systematically as cost-driving variables.
This work addresses the gap through a sensitivity analysis along the coupled manufacturing chain. The analysis builds on an established, process-step-resolved cost model of cell production, into which SIB-specific cascade effects are incorporated. A cascade effect is defined as a causal chain in which the variation of a single material-side parameter propagates through several coupled process steps and translates into a change in total cell cost. Cost levers are thereby captured not as isolated material properties but as effects propagating along the manufacturing chain. They are ranked according to their influence on the total cell cost (€/kWh), which, for the dominant levers, is resolved across the individual process steps.
The novelty of this work lies in coupling this process-step-resolved cascade analysis with cost parity against LFP as an explicit evaluation benchmark. The analysis identifies not only the cost-driving material and process parameters but also the parameter ranges within which NFPP cells compete with LFP. Consequently, it derives in which steps along the manufacturing chain production-process development promises the greatest cost benefit, and which parameters qualify as prioritized candidates for subsequent experimental validation. The contribution links techno-economic modeling directly to a manufacturing-oriented research agenda for cost-competitive SIBs.

# Circular Cathode Production

## From Lab to Pilot: Scaling Ni-Rich NMC and LFMP

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

Global demand for lithium-ion batteries continues to grow, driven by electrification in transportation, stationary energy storage, and industrial applications. This development increases pressure for scalable and economically competitive manufacturing processes across the battery value chain. Cathode active materials account for a major share of cell costs and therefore represent a key lever for reducing battery costs while maintaining performance, sustainability, and supply resilience.
Beyond composition, optimization of cathode material morphology has become increasingly important for enabling high-performance and manufacturable battery materials. Particle size distribution, architecture, porosity, and compositional homogeneity strongly influence electrochemical performance, electrode processing, and production robustness. However, transferring morphology-controlled synthesis concepts from laboratory environments into industrially relevant scales remains a major challenge. This contribution presents recent work from the synthesis pilot plant Powder-Up! addressing the scale-up of advanced cathode active materials and supporting the transition from laboratory development to industrial implementation.
The activities focus on nickel-rich NMC and lithium iron manganese phosphate (LFMP), representing two principal concepts of morphology control. For nickel-rich NMC, morphology is established through controlled crystallization requiring precise particle formation and growth in precursor synthesis. In contrast, LFMP relies on spray drying as the central shaping step to achieve defined particle structures and processability. Together, both material classes enable investigation of complementary scale-up strategies for different morphology-forming mechanisms.
The presentation reports on pre-development and scale-up approaches for both material classes and discusses process considerations during the transition from laboratory synthesis to pilot-scale production.

## BASF Battery Recycling – Starting up a Black Mass Production

*Thomas Mütze*
*BASF Battery Materials and Recycling Schwarzheide GmbH*

Global demand for battery-powered applications – including small appliances, power tools, stationary energy storage systems, and electric vehicles – continues to grow strongly. This development is accompanied by increasing volumes of both production scrap and end-of-life batteries.

Lithium-ion batteries are highly complex composite materials and pose significant technological challenges in recycling due to their variability and associated hazard potentials. A typical recycling value chain therefore includes collection, ADR-compliant transport, dismantling and discharging where required, followed by me-chanical processing, material liberation and separation, and metallurgical refining.

At the BASF site in Schwarzheide, key elements for closing the European battery val-ue chain are being established, including Europe's first fully automated large-scale production plant for cathode active materials (CAM), a black mass production facility, and a plant for hydrometallurgical refining.

The presentation focuses on the start-up and ramp-up of the black mass production plant. In addition to the overall plant concept, particular emphasis is placed on opera-tional aspects during commissioning, the implemented hygiene concept with black-and-white separation, and the resulting quality of black mass and secondary material streams.

The contribution provides practical insights into the challenges encountered during scale-up and highlights key factors for stable and safe operation of industrial battery recycling processes.

### Influence of Process Parameters on the Delamination Efficiency of Production Cathode Scrap vs. End-of-Life Lithium-Ion Batteries

*Steffen Fischer*
*TU Braunschweig I Institute for Particle Technology (iPAT)*

The rapid expansion of lithium-ion battery (LIB) production and adoption has generated two major waste streams: industrial manufacturing scrap and end-of-life (EOL) electric vehicle batteries. Mechanical pretreatment is essential for liberating valuable electrode active materials (black mass) from current collector foils prior to hydrometallurgical or direct recycling. This study compares the performance of a high-speed impact mill when processing production cathode scrap versus EOL battery sieve fractions containing anode and cathode materials. The influence of operating parameters, including rotor speed and feed rate, on delamination efficiency, particle size distribution, and product purity was assessed by systematically varying these parameters. The copper particles in the EoL fraction are further agglomerated and spheroidized due to the stress they undergo during crushing and mixing, which makes decoating more challenging. Additional screening can significantly reduce impurities in both the end-of-life and scrap fractions. These findings provide critical design constraints for scaling up adaptive mechanical recycling facilities capable of processing heterogeneous LIB waste streams.

## Industry Session I

### Particle Design Technology – Key to Improving Rechargeable Battery Performance via NHS

*Daisuke Murase*
*Nara Machinery*

In the pursuit of higher capacity, superior output, and enhanced safety for lithium-ion and all-solid-state batteries, 'Particle Design' of electrode materials and solid electrolytes plays a pivotal role. This presentation highlights particle design technology using the Hybridization System (NHS)—a dry impact powder processing method in high-speed air flow—along with applications in rechargeable battery manufacturing.

While natural graphite offers low cost and high crystallinity, its flakey shape inherently suffers from low packing density. By applying the NHS, graphite can be spheroidized with high yield and compact installation space compared to conventional multi-stage crushing and classification lines.

In all-solid-state battery fabrication, achieving uniform interface contact between the solid electrolyte and electrode active materials via powder handling is paramount. The NHS successfully accomplishes uniform coating and surface compositing of fine sulfide-based solid electrolyte particles onto core cathode active materials (e.g., NCM).

At IBPC 2026, the real lab machine 'NHS-0'—ideal for R&D and feasibility testing—will be physically exhibited. We warmly invite attendees to visit our booth to inspect the machine and discuss particle design solutions for battery performance breakthrough.

## From Pump to Coater: Measuring What the Slurry Really Is – Inline Viscosity in Battery Electrode Production

*Thomas Böhme, Dr. Thomas Haenel, Onur Özgül*
*Netzsch*

Slurry viscosity is one of the key parameters that decides whether an electrode coating runs stable or produces scrap. In most production lines it is still monitored by taking samples and measuring them offline in the lab. This approach has structural limits. Between sampling and measurement the material changes: it rests, rebuilds structure, loses solvent or changes temperature. Results also depend on the operator, the sampling point, the waiting time and the measurement protocol. And a few samples per shift give only snapshots of a process that changes continuously.

Inline rheometry measures the slurry where it matters, under the real flow, shear history and temperature of the process, without sample handling. Continuous, low-pulsation pumping is the prerequisite, as only a steady flow creates the defined shear conditions in which pressure drop reliably reflects viscosity. The result is a continuous data stream instead of isolated points, which reveals drifts and disturbances as they develop and makes the measurement independent of the individual operator.

The benefit is economic as much as technical. Earlier detection of deviations reduces scrap and rework, shortens ramp-up and product changeovers, lowers the effort for sampling and lab work, and creates the data basis for closed-loop process control.

In this joint contribution, NETZSCH Analyzing & Testing and NETZSCH Pumps & Systems present field experience from a pilot line, discuss the differences between lab and inline results, how pump and loop design influence the measurement, and how inline rheometers can be verified reliably.

## De-Risking Dry Electrode Scale-Up: Testing the Process Chain from Powder Handling to Mixing and Calender Feeding

*Hans Schneider*
*Zeppelin Systems GmbH*

Dry electrode production introduces specific challenges in processing active materials, conductive additives, binders and their dry mixtures with significantly different bulk solid properties, flow behavior and bulk densities. Reliable scale-up therefore requires a detailed understanding of the complete powder-processing chain.

This presentation focuses on testing and optimizing powder handling, gravimetric dosing, conveying, mixing and controlled feeding to the calender. Key challenges include dosing stability, segregation, cohesive powder behavior, additive dispersion, mixture homogeneity and stable mass flow.

An integrated testing approach enables the interaction between individual unit operations to be evaluated under representative process conditions. Critical process parameters can be identified and equipment configurations systematically optimized before transfer to production scale.

The presentation demonstrates how engineering and testing of the complete powder pathway can reduce scale-up risks and support the transition from dry electrode process development to continuous industrial production.

# Lithium Sulfur Battery Production

## Solid-State Lithium-Sulfur Battery Concepts for Aviation Applications

*Georg Garnweitner*
*TU Braunschweig I Institute for Particle Technology (iPAT)*

Solid-state lithium-sulfur batteries (SSLSBs) are considered one of the most promising next-generation battery technologies to meet the requirements of specific applications such as all-electric aviation, due to their high specific energy and improved safety characteristics. Whilst good progress was achieved in lithium-sulfur systems in the last years, further optimization on the materials level, on cell design and improvement of cycling stability are still needed, as well as an enhanced understanding of operation and degradation mechanisms – particularly the polysulfide shuttle effect, which causes rapid performance degradation over repeated cycles.

In this contribution, several innovative concepts for SSLSBs with improved performance established within the Cluster of Excellence SE²A - Sustainable and Energy-Efficient Aviation are presented. Our work thereby focused on the materials and cell design as well as fabrication of polymer-based SSLSBs capable of room-temperature operation. The performance of SSLSBs was enhanced through comprehensive investigation and improvement of each cell component, with the goal of achieving tailored components for stable operation.

Polymer-based solid electrolytes (PSEs) promise good processability and low interfacial resistance, but typically show low ionic conductivity at room temperature. We have designed a novel co-polymer system based on crosslinked PETEA-TEG, which was further enhanced by different fillers such as metal oxide particles as well as aramids, achieving a significant increase in ionic conductivity up to 2.1·10–3 S cm-1 at 20 °C, which is fully sufficient for room-temperature battery operation.

In parallel, the performance of sulfur-carbon composite cathodes was enhanced by incorporating the copolymer-hybrid-based solid electrolyte as binder (catholyte). On the other hand, high-surface-area conductive carbon materials that can inhibit the polysulfide shuttling and thus improve cycling stability, ...

## High Energy Si/S Batteries via One Pot Production of Porous Semiconductor Polymer Electrodes

*Jonathan Florez Montaño*
*Center for the Science of Materials Berlin*

The production of next-generation batteries requires active materials with high specific capacity, mechanical robustness, and processes compatible with industrial-scale manufacturing. This work presents a unified electrode design platform based on porous semiconducting polymers that enables one-pot fabrication of silicon anodes and sulfur cathodes directly on current collectors, eliminating conventional additives such as binders and carbon black.

For silicon anodes, a graphdiyne-type triazine polymer grows in situ on copper, encapsulating silicon nanoparticles through covalent bonding. The resulting porous network functions simultaneously as an electronic conductor, mechanical binder, and semipermeable membrane. This architecture achieves capacities approaching the theoretical limit of silicon (~3500 mAh $g^{-1}$), with strong retention after extended cycling and excellent structural stability under bending and thermal stress.

For sulfur cathodes, a microporous imine polymer is polymerized directly around KB/S particles on aluminum, forming a conjugated network that traps polysulfides, enhances electron transport, and removes the need for PVDF or conductive additives. The resulting Li–S cells deliver high capacities (1200 mAh $g^{-1}$ at 0.2C), strong rate capability (807 mAh $g^{-1}$ at 3C), and minimal degradation over 500 cycles.

Both electrode types can be processed using standard coating methods such as doctor-blade coating and are compatible with pouch-cell production lines, supporting straightforward industrial scaling.

These results demonstrate that porous semiconducting polymers can fully replace traditional multicomponent electrode formulations, simplifying manufacturing, increasing active-material content, and enabling flexible, stable, high-energy electrodes. This strategy provides a clear pathway toward sustainable, scalable, and critical-material-free energy-storage technologies aligned with European goals for advanced battery production.

### Practical binder and conductive additive systems for sulfurized polyacrylonitrile cathodes enabling long cycle life and enhanced rate capability in lithium sulfur batteries

*Ralf Müller*
*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[1,2]. Consequently, this battery type is notably suitable for lightweight applications such as aviation[3]. 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[4,5].
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 conducted as well as electrochemical tests such as electrochemical impedance spectroscopy and galvanostatic cycling using coin cells and multi-layered pouch cells with capacities up to 5 Ah. Recent electrodes achieved discharge capacities up to 1400 mAh/g(S) and high rate capabilities up to 3 C with good capacity retentions of approximately 75 %, even after a densification of 50 %, demonstrating the potential for usage in aviation applications.

## (Simulation of) Slurry-based Processing

### Optimized slot dies with flex lips and closed control loop for precise thickness adjustment

*Remo Andreas Ziörjen*
*TSE Troller AG*

Premetered slot-die coating is a key enabling technology for applying single- and multilayer structures onto continuously moving substrates in battery electrode manufacturing. It offers excellent thickness control, high material utilization and scalability for high-throughput production. However, increasingly complex battery slurries place high demands on die design, manufacturing accuracy and process control.
An optimized internal slot-die geometry is essential to ensure stable flow conditions and uniform cross-direction (CD) coating profiles for a wide range of slurry rheologies and solid contents. Inside the slot die two distribution cavities followed by two metering slots are designed to uniformly distribute the slurries coming from circular pipe geometry to the desired coating width either in single or multiple lane pattern. Properly designed internal distribution cavities and metering slots minimize pressure variations, avoid particle sedimentation and support homogeneous slurry delivery across the full coating width.
High-precision fixed-lip slot dies achieve excellent CD uniformity through precisely manufactured die plates, very flat exit slot surfaces and optimized internal distribution. They can reach steady-state operation after only a few metres of coated material, which reduces start-up losses. In applications with larger batch-to-batch variations in slurry properties, flex-lip slot dies combined with automated closed-loop control provide additional flexibility. Real-time CD thickness measurement identifies profile deviations and enables direct adjustment of the flexible lip during start-up and production.
By combining optimized internal slot-die design, automated flex-lip control and integrated CD measurement, battery manufacturers can improve coating uniformity, shorten start-up and changeover times, reduce material waste and increase overall coating performance in high-volume electrode production.

## Modelling and Optimisation of Battery Electrode Slurry Preparation Process by Extrusion

*Sarah Bhutta*
*University of Warwick*

Lithium-ion batteries are central to modern energy storage technologies, powering applications ranging from electric vehicles to portable electronics. A critical step in their manufacturing is the preparation of electrode slurry, where active materials, conductive additives, and binders are dispersed in a solvent to form a homogeneous mixture. Conventional batch mixing processes often struggle to maintain consistent slurry quality due to limited control over mixing dynamics, resulting in uneven particle dispersion, high energy consumption, and challenges in scaling production. These limitations can adversely affect electrode microstructure, electrochemical performance, and overall manufacturing efficiency.

This work presents a predictive modelling framework for lithium-ion battery slurry preparation using twin-screw extrusion (TSE) as a continuous mixing approach. The proposed framework aims to improve understanding and control of slurry mixing behaviour while enabling scalable and more energy-efficient manufacturing processes.

A multi-scale methodology is employed, integrating Computational Fluid Dynamics (CFD) simulations with experimental validation using lab-scale extrusion trials. The modelling framework captures slurry flow behaviour and mixing characteristics within the extruder while systematically investigating key parameters such as screw speed, torque, pressure, specific energy input (SEI) and power.

The study provides insights into the relationship between extrusion processing conditions and slurry homogeneity, highlighting how process parameters influence flow behaviour and energy consumption during extrusion. The developed modelling framework offers a generalisable tool to support process optimisation, improve manufacturing consistency, and accelerate the adoption of continuous processing technologies for lithium-ion battery electrode production.

## A Hybrid Experimental, CFD, and Machine-Learning Framework for Viscoelastic Battery Slurry Slot-Die Coating

*Sung Hin Lam*
*School of Mechanical Engineering, University of Leeds*

Increasing electrode thickness and active material loading is essential for improving the energy density of next-generation lithium-ion batteries. However, complex slurry rheology, including shear-thinning and viscoelastic behaviour, strongly affects slot-die coating stability, uniformity, and operating window. To reduce trial-and-error development, this study develops a predictive framework linking experimental rheology, transient multiphase Computational Fluid Dynamics (CFD), and machine-learning surrogate modelling.

Experimental rheological data, including steady shear viscosity, storage modulus, and loss modulus, are used to fit a multi-mode Giesekus constitutive model. The fitted parameters provide physically meaningful inputs for a transient multiphase CFD slot-die coating model. A key novelty of this work is the implementation and application of the experimentally fitted multi-mode Giesekus model in OpenFOAM, enabling analysis of viscoelastic stress evolution, free-surface dynamics, and coating bead stability. A database of 300 CFD cases is generated on a high-performance computing system by varying operating and rheological properties. Preliminary analysis indicates that rheological parameters have the strongest influence on coating response among the investigated variables. Supervised machine-learning models, including Gaussian Process Regression and tree-based ensemble methods, are trained using the CFD database and selected experimental coating data. These models act as fast surrogates for predicting coating thickness uniformity, pressure response, and stabilisation behaviour.

Selected slot-die coating experiments are used to validate predictions through laser-based coating thickness measurements and observation of meniscus shape and position, and coating uniformity. The framework supports rapid screening of material and process parameters, construction of data-driven operating windows, and optimisation of scalable battery electrode manufacturing.

# Modelling & AI-Assisted Battery Production

## From degradation diagnosis to physics-based lifetime prediction of NMC/graphite battery cells

*Connie Chen*
*Forschungszentrum Jülich GmbH*

Accurate battery lifetime prediction requires models that are both physically interpretable and computationally efficient. This work combines differential temperature–voltage (DTV) analysis with an electro-thermal-aging coupled pseudo-two-dimensional (P2D) model to identify and predict the dominant degradation mechanisms of commercial NMC622/graphite pouch cells.
An 18-month aging campaign was conducted on 6.5 Ah cells under 56 combinations of temperature and C-rate, with repeated cells for each condition. Surface temperature and voltage were continuously measured, and reference performance tests were used to track degradation. By extending conventional incremental-capacity/differential-voltage analysis to DTV, thermodynamic information related to entropy and electrode phase transitions was extracted from cycling data. Characteristic DTV peak evolution indicated lithium inventory loss and graphite degradation associated with SEI growth on the anode side, while broadening of the high-voltage NMC622 transition reflected cathode phase-transition degradation.
These mechanisms were implemented in a coupled P2D framework. SEI growth was modeled as a combined time- and cycle-dependent process, while cathode degradation was represented by a shrinking-core model linking degraded-shell growth to lithium loss and loss of active cathode material. A thermal submodel calculated reversible and irreversible heat generation and introduced temperature-dependent kinetics through Arrhenius corrections.
The model reproduced voltage, temperature, and capacity evolution across multiple C-rates and temperatures, with capacity prediction errors below 5% at 30 °C over 1200 cycles and below 6% at 60 °C over 800 cycles. The results show that DTV fingerprints can bridge experimental diagnosis and physics-based modeling, enabling electrode-level interpretation and reliable temperature-accelerated lifetime prediction.

## Optimizing Slot-Die Coating of High-Viscous Slurries in Battery Electrode Production

*Vladimir Popok*
*FOM Technologies*

Slot-die has established itself as a key deposition technique for thin and uniform functional coatings. Use of it for battery electrodes at industrial scale (wide width of coating) presents significant challenges in flow distribution and coating homogeneity due to high-viscous slurries.
In this work, we present recent developments on the optimization of slot-die head (SD) for high-viscous slurries carried out at FOM Technologies. By employing computational fluid dynamics (CFD) simulations, we systematically iterated through manifold designs to minimize internal flow resistance and improve homogeneity of the slurry distribution inside the SD. A key objective was to achieve a wide coating width of 30 cm while minimizing the velocity differences across the SD width. It was found that variation of the ink velocity can be significantly reduced if the SD has three inlets instead of one. However, such configuration would complicate manufacturing and following operation of SD with the pump during the coating. Therefore, we kept one inlet but rather changed volume and shape of manifold inside the SD that, according to the CFD, allowed to reduce the ink velocity relative deviation across the width to 1.5%.
Experimental validation of the newly optimized SD in application to typical carbon-containing slurries used in coating of battery electrodes (viscosity of up to 20 Pa.s) showed an order of magnitude improvement in homogeneity of the films compared to a standard head. In the presentation, we will show both CFD simulation results and experimental coating data highlighting the critical role of application-specific slot-die head design in achieving high-performance coatings.

### Overcoming Data Scarcity in AI-Based Quality Assessment of Lithium-Ion Cells

*Tessa Krause*
*Precitec GmbH & Co KG*

Lithium-ion batteries are increasingly deployed in safety-critical applications, making reliable end-of-line quality assurance an essential part of the manufacturing process. Additionally, improved quality assurance protocols shorten production ramp-up times following changes in materials or processes while reducing waste. AI-based anomaly detection offers the opportunity to identify subtle deviations in cell behaviour that may indicate defects. However, generating representative cycling data across large numbers of cells is both time-consuming and costly. This limits the availability of training data during algorithm development and presents a significant barrier to robust machine learning models.

This work presents a physics-informed framework for synthetic data generation and unsupervised anomaly detection for lithium-ion battery quality assessment. A hybrid modelling approach generates realistic synthetic cycling data by combining physics-based battery models with data-driven residual correction. The synthetic dataset is used to pre-train an autoencoder, which is then adapted to a limited set of real production measurements through transfer learning. By combining conventional electrical measurements with non-contact volume expansion sensing, the proposed approach improves sensitivity to subtle variations in cell behaviour while substantially reducing the dependence on large quantities of real training data.

Preliminary results demonstrate that cells with normal electrochemical signatures can exhibit abnormal mechanical behaviour, enabling the detection of anomalies that conventional methods may miss. Rather than replacing conventional quality assurance methods, the anomaly score provides a complementary, data-driven means of prioritising samples for further characterisation. The methodology provides a practical pathway towards data-efficient AI and reliable end-of-line quality assurance.

## Advanced Characterization Methods

### Non-Invasive LIB Quality Assessment by Spatial Magnetic Operando and Relaxation Analysis

*Paul-Martin Luc*
*CDO2 Germany UG*

As battery production scales toward higher throughput and larger-format cells, manufacturers need non-invasive quality assurance methods that detect internal electrochemical inhomogeneities before they cause performance loss, safety risks or costly late-stage rejection. However, standard end-of-line tests mainly capture global cell responses and may miss local imbalance and redistribution processes despite apparently normal voltage behaviour.

To evaluate whether such states can be detected non-invasively, pristine, aged and locally impaired commercial pouch cells were used as model systems with different degrees of electrochemical heterogeneity. We present spatially resolved magnetometry as a diagnostic approach for detecting internal redistribution processes in LIB cells. LFP and NMC cells were investigated during cycling and open-circuit relaxation. After current interruption, persistent and spatially structured magnetic fields were observed, indicating that redistribution currents remain active even under open-circuit conditions. Their signatures depended strongly on cell chemistry, state of charge, cell condition and local defects.

Compared with conventional voltage relaxation after formation, magnetic relaxation measurements add spatial information on equilibration processes within the cell and increase the diagnostic depth of quality assurance. In LFP cells, similar voltage behaviour was associated with clearly different magnetic signatures, indicating imbalance not distinguishable from voltage data alone. In NMC cells with local pressure-induced degradation, spatial magnetic maps revealed defect-related heterogeneity and modified current pathways.

These results demonstrate that spatial magnetometry can complement established end-of-line diagnostics for commercial LIB cells by providing access to internal redistribution processes and cell-specific inhomogeneities that remain largely hidden in global electrical signals.

## High-Throughput, Non-Invasive SOH Estimation for End-of-Life Batteries Using Impedance-Based Techniques

*Simeon Kremzow-Tennie*
*Keysight Technologies Deutschland GmbH*

The scalable repurposing of end-of-first-life battery systems requires fast and reliable state-of-health assessment integrated directly into disassembly and sorting processes. Because conventional capacity testing is too time-intensive for industrial throughput, rapid non-invasive diagnostic approaches are required.

This contribution presents a modular demonstrator developed within the Re-Use project (EFRE-20800137) for rapid electrical characterization of battery modules under workshop conditions. The platform combines open-circuit voltage, direct current internal resistance, alternating current internal resistance, and electrochemical impedance spectroscopy, enabling a systematic comparison of diagnostic value and test duration. Capacity testing is retained as a reference method. Owing to its modular design, the demonstrator supports measurements from 0 to 500 V and thus provides a technical basis not only for module-level assessment but also for future testing at pack level.

Presented results demonstrate the successful integration of these methods into high-throughput battery testing workflows and highlight the trade-off between measurement time and information content. In addition, investigations on individual and serially interconnected modules show that key findings from single-module measurements can be transferred to interconnected assemblies. These results represent an important step toward extending validated SOH assessment from isolated modules to higher integration levels, including pack-level applications.

The presented approach establishes a technically validated pathway toward fast, non-invasive, and scalable SOH diagnostics for second-life battery assessment in industrial workflows.

## Robot-Assisted X-Ray Computed Tomography for Non-Destructive Quality Inspection of Battery Packs

*Steven Oeckl*
*Fraunhofer Institute for Integrated Circuits IIS*

The industrialization of battery manufacturing for electric vehicles or aerospace applications has intensified demands on production-integrated quality assurance. Fully assembled battery packs present a fundamental inspection challenge: structural defects such as bonding voids, porosity in insulating foam, and insufficient thermal interface connections are not detectable by conventional electrical testing. Current practice relies on destructive sampling, sacrificing complete assemblies for visual assessment—a method that is economically and ecologically unsustainable at production scale.

This contribution presents a robot-assisted 3D X-ray computed tomography system (RoboCT) developed at Fraunhofer IIS. Two cooperating robotic arms independently position X-ray source and detector, enabling flexible, application-specific scan trajectories around large and geometrically complex battery packs—without size, weight, or disassembly constraints. Patented software algorithms compensate for the inherently lower positioning accuracy of robot kinematics, eliminating costly precision hardware. In a first step, radiographic overview scans identify anomalies such as cell displacement, structural damage, or bonding defects across the full assembly. Regions of interest are subsequently analyzed in three dimensions using CT or laminography at resolutions of up to 30 µm, enabling targeted, high-resolution defect characterization.

Experimental validation on representative large-format battery packs—including crash-tested modules—demonstrated reliable detection and localization of safety-relevant defects across the full assembly volume. The results confirm that robot-assisted CT enables efficient quality control, failure analysis, and damage assessment of complete battery systems in a production-relevant context.

# Sustainable Electrode Fabrication

## Dry manufacturing process for the gelled SOLGAIN™ electrodes

*Jeremie Salomon*
*CEA*

SOLGAIN™ technology has been developed by CEA-Liten and Syensqo (ex Solvay) with the aim at improving the performances of conventional Li-ion battery (LIB) with reducing the safety issues due to the use of volatile and flammable electrolyte. SOLGAIN™ technology is based on hybrid polymer lithium battery, where the electrolyte is confined in a hybrid polymer membrane as well as in gelled electrodes from their manufacturing.
The gelled electrodes can be produced according to conventional electrode manufacturing process (i.e using mixing, coating and calendaring machines) at pilot line scale in anhydrous atmosphere using Syensqo proprietary functionalized PVdF as binder, which allows trapping the LiPF6 containing organic electrolyte within the electrode microstructure.
However, today as there is growing demand for environmentally-friendly manufacturing processes on an industrial scale, (e.g. solventless or dry process commonly used as terminology), new process has been developed in order to manufacture the gelled electrodes without any solvent other than the electrolyte that will be confined within the electrodes. This way allows simplifying considerably the cell manufacturing process, increasing the safety and reducing the cost as well as the carbon footprint because no solvent is evaporated and recovered, as is the case for conventional LIBs.

## Effect of Mechanical Stress Conditions During Extrusion on Semi-Dry Anode Microstructure and Performance

*Niclas Hornischer*
*TU Braunschweig I Institute for Particle Technology (iPAT)*

The increasing demand for LIBs for electric vehicles and energy storage requires more sustainable and cost-efficient electrode manufacturing processes. Semi-dry electrode processing has emerged as a promising alternative, enabling significantly higher solids contents, reduced drying requirements, and continuous extrusion-based manufacturing. In addition, the compact process design, integrating coating, drying, and calendering within a single multi-roll calender system, reduces both energy consumption and production footprint, offering substantial potential for cost-efficient battery manufacturing. This work investigates the influence of different mechanical stress conditions, such as the stress intensity (SI) and number of stress events (SN) during extrusion on the microstructure and electrochemical performance of semi-dry processed graphite anodes. The effects of the applied stress conditions on the microstructure were analyzed by carbon black deagglomeration using laser diffraction and pore structure characterization via mercury porosimetry. Furthermore, the electrodes were evaluated regarding ionic and electronic conductivity, adhesive strength, and electrochemical performance in full cells against state-of-the-art NMC622 cathodes. The results show that increasing the stress number during extrusion improves carbon black deagglomeration and electronic conductivity. However, a high SN simultaneously causes a strong deterioration in coating quality and adhesive strength, indicating binder failure and/or graphite delamination and fracture. Electrochemical characterization further indicates that an elevated SN leads to structural damage within the electrode resulting in increased capacity fading. In contrast, higher stress intensities at comparatively low SN improve dispersion and electrode homogeneity without inducing severe structural degradation. Overall, balancing SN and SI is essential for optimized semi-dry anode manufacturing..

## Semi dry coating by direct extrusion as flexible manufacturing strategy for battery electrodes

*David Werner*
*Fraunhofer Institute for Ceramic Technologies and Systems IKTS*

The increasing demand for cost-efficient, sustainable, and scalable battery electrode manufacturing drives the development of alternative coating processes beyond conventional slurry-based approaches. Semi-dry coating via direct extrusion enables a solvent reduction of up to 50% compared to standard wet coating, while integrating continuous mixing and coating into a

single process step [1]. The approach supports PFAS-free electrode fabrication and remains compatible with established binder systems such as PVDF/NMP and CMC/SBR. Its versatility across lithium-ion batteries (LIB), sodium-ion batteries (SIB), and all-solid-state batteries (ASSB) positions direct extrusion as a flexible manufacturing platform.
In this contribution, we present results from multiple research activities demonstrating this broad applicability. For NMC-based cathodes processed with PVDF/NMP (85% solid content), the influence of key process parameters on coating quality and electrochemical performance of thick electrodes is discussed, with emphasis on mixing conditions and rheological behavior. Water-based LFP electrodes using CMC/SBR binder systems were successfully produced with up to 70% solids, highlighting process scalability and the advantages and challenges of an aqueous production route. For ASSB applications, composite cathodes combining NMC with the sulfide solid electrolyte LPSCl were fabricated with 84% solids, focusing on binder optimization and the impact on processing and electrochemical performance. Finally, first activities to extend direct extrusion to sodium-ion battery electrode manufacturing will be presented.
Collectively, the results demonstrate that semi-dry coating by direct extrusion is a highly adaptable and scalable manufacturing strategy with strong potential to advance the industrialization of both conventional and next-generation battery technologies.

[1] Seeba, J. (2020). Chemical Engineering Journal (402).

# European Battery Ecosystem

## Mixing and Processing of Gen 5 LFP: From Slurry Formulation to cell formation

*Iñigo Raposo*
*CIDETEC Energy Storage*

Reducing the particle size of LiFePO4 (LFP) active material is a promising strategy to boost the intrinsically limited electronic conductivity and rate capability of this cathode chemistry. However, moving from a conventional 10 um LFP to a 1 um grade introduces severe processing challenges at the slurry level, driven by the much higher specific surface area of the fine powder. This work presents the successful development, at pilot plant scale, of a stable, processable 1 um LFP slurry, overcoming the main obstacles found during formulation: poor colloidal stability, premature gelation, and particle agglomeration. A tailored two-step mixing protocol, together with adjusted solid content, enabled a homogeneous, coatable ink from the fine-particle material.
Electrodes from the 1 um LFP slurry were benchmarked against a standard 10 um reference across peel adhesion, particle size distribution, rheology, rate capability, electronic conductivity, and coating density. The 1 um formulation showed a marked improvement in electronic conductivity, with interface, surface, and volumetric conductivity roughly one order of magnitude above the 10 um baseline, together with higher achievable densification and improved capacity at increasing C-rates. These gains came with a trade-off in collector adhesion, addressed through binder and mixing optimization.
These results show that the processing barriers of fine-particle LFP can be overcome, unlocking its electrochemical potential for high-power electrode manufacturing.

## NoVOC - Advancing Sustainable Lithium-Ion Battery Manufacturing through Aqueous and Dry Electrode Processing

*Stina Starborg*
*RISE Research Institutes of Sweden*

The expansion of battery production requires manufacturing technologies with lower environmental impact, reduced energy consumption, and decreased reliance on hazardous chemicals. Conventional lithium-ion battery manufacturing relies on N-methyl-2-pyrrolidone (NMP), resulting in significant energy use and volatile organic compound (VOC) emissions. The Horizon Europe project NoVOC (Eliminating VOC from Battery Manufacturing through Dry or Wet Processing), coordinated by RISE

Research Institutes of Sweden, develops sustainable electrode manufacturing routes based on aqueous and dry processing technologies.

Aqueous processing is the most industrially mature pathway for eliminating VOC emissions. However, high-nickel and high-voltage cathodes remain challenging due to material reactivity in water. Lithium leaching increases slurry pH, causing residual lithium accumulation, transition-metal dissolution, slurry instability, and aluminium current collector corrosion. Within NoVOC, these challenges are addressed through interfacial engineering, including surface passivation and pH management, enabling stable aqueous processing with water-borne, PFAS-free binders. The developed processes have been scaled to pilot roll-to-roll coating, demonstrating industrially relevant manufacturing and competitive electrochemical performance.

In parallel, dry electrode processing is being developed as a solvent-free alternative that eliminates drying and solvent recovery steps. Optimized powder mixing, fibrillation, calendaring, and lamination have enabled promising electrode performance while reducing manufacturing complexity, energy demand, and environmental footprint.

Digital process optimization, life-cycle assessment, and techno-economic evaluation support industrial implementation. The results demonstrate that aqueous and dry processing provide complementary pathways toward sustainable battery manufacturing, strengthening Europe's competitiveness in battery production..

### Battery production digitalization: challenges and learnings from BATMACHINE project

*Sylvain Gouttebroze*

*SINTEF*

Digitalisation can accelerate battery-factory ramp-up, improve process control, and reduce material losses and energy use. In practice, production data remain fragmented across heterogeneous machines, proprietary signal names, laboratory instruments, and isolated software systems. Connectivity alone is therefore insufficient: process data also needs consistent meaning, material provenance, and experimental context.

This presentation reports challenges and lessons from BATMACHINE, a Horizon Europe project developing energy-efficient equipment and intelligent control for electrode production, including slurry mixing, roll-to-roll coating and drying, and calendaring. SINTEF has developed a semantic dataspace combining OPC UA acquisition of machine signals, time-series and object storage, a knowledge graph, visualisation, and interfaces for process optimisation. Configurable “equipment wrappers” describe each machine, acquire relevant channels, and map vendor-specific tags to shared ontology concepts. The approach has been applied from slurry mixing to calendaring and extended to connect pilot-line trials with recipes, material batches, and offline measurements.

Several practical learnings emerge. Semantic models and interfaces must be co-developed with equipment suppliers, process experts, and end users; ontologies evolve when confronted with real machinery; and a limited set of well-contextualised signals is often more valuable than collecting all available data. The architecture must accommodate online and offline equipment, line reconfiguration, cybersecurity constraints, and on-premises deployment. Traceability across material, process, and quality data is essential for reproducibility and AI-based optimisation.

The presentation discusses the architecture and demonstrators, together with steps towards closed-loop control, interoperable digital twins, and faster transfer of production knowledge from laboratory and pilot scale to industrial battery manufacturing.

## Innovative Battery Production

### High-rate solid-state lithium batteries achieved by infiltrating a single-layer LLZO scaffold

*Muhammad Zubair*

*Martin-Luther University Halle-Wittenberg*

We designed flat, thin (~200 µm) Li6.45Al0.05La3Zr1.6Ta0.4O12 single-layer 3D porous scaffolds by the tape-casting technique. Leveraging a meticulously engineered single-layer scaffold, lithium metal is uniformly infiltrated to an average thickness of 35 µm, ensuring seamless interfacial contact. Concurrently, a solid polymer electrolyte is integrated, facilitating the formation of a

robust composite solid polymer-garnet separator with a precise thickness of 165 µm, all within a unified structural framework. The integrated single-framework not only reinforces structural and interfacial stability of the metallic anode but also facilitates rapid $Li^+$ transport, markedly enhancing ionic conductivity. This synergistic effect enables exceptionally high-rate performance, paving the way for more efficient and reliable electrochemical applications. Full cells with lithium iron phosphate cathode and the Li-infiltrated single-layer ceramic/polymer electrolyte cycled at record current rates of 2C and 5C at room temperature and achieved 100% capacity retention for 30 cycles at 0.1C. The discharge specific capacities at 2C and 5C are record high 106.4 and 76.7 mAh g-1, respectively. This innovative single-layer framework is designed to enable high-current density, room-temperature solid-state lithium-metal batteries while eliminating the need for stacking pressure.

References:
1. Zubair, M.; Ye, R.; Liu, X.; Touidjine, K.; Soundaraj, P. V.; Finsterbusch, M.; Tietz, F.; Fattakhova-Rohlfing, D.; Guillon, O. J. Power Sources 2026, 666, 239065.

## Waste to battery materials: building a circular and resilient onshore supply chain for high purity alumina

*Isaac Sousa Martins*
*Queensland University of Technology*

High purity alumina (HPA) is a critical enabling material for lithium-ion batteries, where it is used as a ceramic coating on polymer separators to improve their thermal stability, safety, and performance. However, conventional HPA production is typically dependent on high-purity primary feedstocks and internationally concentrated supply chains. In collaboration with industry partner Lava Blue, this research is developing a circular and feedstock-flexible pathway for producing battery-grade HPA from diverse waste resources, ranging from domestic aluminium foil waste to mine waste rocks and tailings. A hydrochloric acid (HCl)-based processing pathway has demonstrated a high degree of robustness across these compositionally diverse feedstocks. Scale-up at Lava Blue's demonstration plant has repeatedly produced 10 kg batches exceeding 99.995% $Al_2O_3$ purity, demonstrating the potential to manufacture battery-grade HPA from secondary resources at commercially relevant scales. Importantly, residual trace-element profiles provide a characteristic impurity “fingerprint” associated with different feedstocks, offering opportunities to understand and potentially trace the provenance of HPA products. HPA produced from waste-derived feedstocks is being applied as a coating to polymer separators prior to lithium-ion cell assembly and electrochemical testing. Ionic conductivity, coulombic efficiency, and 3C capacity retention were significantly improved for the Lava Blue HPA-coated Celgard separator compared with uncoated Celgard, while 50-cycle capacity retention remained comparable (Table 1). These results demonstrate a pathway for converting diverse waste streams into high-value battery materials without compromising product quality or performance. By integrating circular feedstocks, flexible processing, rigorous quality assurance, scale-up and end-use validation, this work provides a framework for establishing a secure and sustainable Australian HPA supply chain.

## Development and Performance Validation of High-Voltage Pouch Cells: From Conventional to Fully Gellified Architectures

*Jon Rodriguez Romero*
*CIC energiGUNE*

Solid-state and quasi-solid-state lithium-ion batteries have emerged as leading candidates for next-generation energy storage, offering safety improvements and compatibility with high-voltage chemistries. However, translating these systems into pouch cell format introduces mechanical, interfacial, and procedural complexities that remain insufficiently characterized.
This work directly compares a conventional porous electrode system with a fully gel-based architecture developed within the NextCell EU project, evaluating both in coin cell and single-layer pouch cell format. The gel-based system, comprising dry-processed gel cathode, gel anode, and gel membrane, requires distinct processing adjustments. Both systems use an identical active material set, with a high-voltage LMNO cathode and a silicon-carbon (Si/C) anode paired with a shared electrolyte, enabling direct comparison.

Assembly parameters, holder types, and foam interlayers are systematically optimized. Post-formation degassing protocols are evaluated for their impact on gas removal and long-term performance. SEI quality is assessed via EDX and coupled with PEIS data, establishing impedance spectroscopy as a predictive tool for formation quality. Integrated load cells and LVDTs monitor thickness and force during cycling, defining operating pressure to manage stack swelling from Si/C anode expansion.
Understanding these coupled mechanical and electrochemical phenomena bridges laboratory innovation and scalable cell-level applications.

# Industry Session II

## Accelerating Dry Electrode Development through Simultaneous Powder Conductivity and Densification Analysis

*Roozbeh Valadian*
*Granutools*

As dry battery electrode (DBE) manufacturing gains momentum, the industry faces a critical challenge: identifying powder formulations that deliver optimal electrical performance throughout densification and electrode processing. Granutools introduces a novel characterization approach that combines powder electrical conductivity and tapped density measurements within a single automated workflow using the GranuPack Conductivity instrument. By monitoring conductivity as a function of packing fraction, the method provides direct insight into the formation and efficiency of conductive pathways, a key parameter governing electrode performance and manufacturing robustness. Results demonstrating clear differences in conductive network development, depending on powder formulation, level of fibrillation, and other characteristics, will be presented to highlight the importance of such characterization.
By linking electrical performance to powder packing behavior, this innovative methodology enables battery manufacturers and material developers to rapidly screen formulations, compare conductive additive strategies, and better predict electrode performance before pilot-scale processing. The approach offers a unique opportunity to accelerate the development of dry electrode technologies, reduce trial-and-error experimentation, and support the transition toward more efficient and sustainable battery production.

## Holistic Moisture Management in Battery Production Lines

*Fabienne Huttner*
*PowerCo SE*

Moisture is a critical factor in lithium-ion battery production, affecting electrochemical performance, safety, manufacturing costs, and process stability. Its control is particularly challenging because the moisture content of cell components depends on their material properties, process history, storage and transport conditions, factory environment, and operator-related moisture ingress.
This talk presents a holistic approach to moisture management across the entire battery production chain. It highlights the complex sorption behavior of battery materials, including hysteresis effects, material-specific characteristics, and changes caused by manufacturing processes such as calendering. Particular attention is given to three key optimization levers: improved dry and conditioning room concepts, chemistry-specific moisture specifications and dew-point requirements, and advanced post-drying strategies supported by inline moisture measurement. These approaches can help reduce energy demand and moisture-related manufacturing costs while maintaining product quality and safety.

## DRYOON® MiniEnvironments – Moisture Diffusion and its impact on Dryroom Design

*Michael Schmauß*
*Exentec Germany GmbH*

Dryrooms are one of the largest energy consumers in lithium-ion battery cell production, accounting for approximately 25–35% of total energy demand in gigafactories. Conventional room-based concepts require conditioning large air volumes and continuously compensating for moisture introduced by human activity and material flow, resulting in significant operational expenditure and limited process efficiency.

This presentation introduces modular Mini Environments as a fundamentally different design approach, shifting from centralized dryrooms to localized mini environment concepts. By consistently separating people from the process and providing ultra-dry conditions directly at the point of use, DRYOON® systems achieve dew points below -65 °C while significantly reducing the volume of treated air and the total energy consumption. This approach enables a targeted “dry cocoon” around critical process steps, minimizing external influences and improving process stability.

A key element of the DRYOON® concept is the integration of optimized airlock systems. As the interface between controlled and uncontrolled environments, airlocks play a decisive role in moisture management. It is demonstrated that minimizing dead volumes and controlling air exchange during transfer processes significantly reduces moisture ingress, shortens recovery times, and stabilizes operating conditions.

In addition, the interaction between MiniEnvironments, transport boxes, and automated material flow is analyzed. Controlled transfer solutions reduce moisture carry-over during handling and enable efficient, scalable, and automation-ready production layouts.

The combined DRYOON® approach- MiniEnvironment, optimized airlock design, and controlled material flow- provides a practical pathway to reduce OPEX, lower $CO_2$ footprint, and enable highly automated, next-generation battery manufacturing with minimized human impact.




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# 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.

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**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



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**PROCESS TEMPERATURE**

Binders that look identical at ambient can diverge once heated. Tested from room temperature up to 200 °C, as on the line.

## PTFE

**FIBRILLATION & CONDUCTIVITY**

On an LFP, carbon black and PTFE blend, conductivity rises with fibrillation, then falls. Packing dynamics pinpoint that optimum on the powder.

## COHESION

**SULFUR BLENDS AT LINE SPEED**

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# POSTER SESSION I Day 1

## Modeling & AI-Assisted Battery Production: Machine Learning & Data Analysis (MLDA)

MLDA_1.1 Data-Efficient Calibration of Particle Fracture and Scale-Aware Mechanical Response in Lithium-Ion Battery Electrode Calendering

*Jiashen Chen, University of Leeds*

MLDA_1.2 Data-Driven Causal Relationship Analysis in Battery Cell Manufacturing Lines

*Manuel Wanisch, BMW Group*

## Modeling & AI-Assisted Battery Production: Simulation Methods (DEM, CFD, FEM & beyond) (SIM)

SIM_1.1 Investigation of the Dynamics of a Web Guiding Model in the Battery Cell Stacking Process

*Yann Rutschke, KIT*

SIM_1.2 Capturing Cross-Web Behaviour: Hybrid 1D-2D Web-Handling Simulation in Battery Production

*Stefan Gartzke, KIT*

SIM_1.3 Influence of Single-Sine and Multi-Sine Electrochemical Impedance Spectroscopy on Battery Model Parameterization under Constant-Current Conditions

*Marvin Nebelsiek, TU Braunschweig I elenia*

## Next-Generation Battery Systems: Lithium-Free Battery Systems (e.g., Na-ion, Zn-air) (LFB)

LFB_1.1 Interfacial Engineering of Alkaline Zinc Batteries using Low-Concentration Polysorbate Additives

*Jana Mrowetz, TU Braunschweig I InES*

LFB_1.2 Operando Pseudo-Potentiostatic EIS for the Evaluation of Formation Protocols in Sodium-Ion Batteries with Hard Carbon and Prussian White

*Cedric Jackmann, TU Braunschweig I elenia*

LFB_1.3 Sustainable NFPP/C cathode manufacturing for cycling-stable sodium ion batteries

*Florian Mückan, Fraunhofer IWS*

LFB_1.4 Cadmium Ferrite-Based Nanocomposite Electrodes for Next-Generation Electrochemical Energy Storage: PANI/CdFe2O4 and Biogenic CaCO3/CdFe2O4 Systems

*Samia Firdous, University Hildesheim*

LFB_1.5 Reliable Nanomechanical Characterization of Zn Foils for Quality Assurance of Next-Generation Aqueous Battery Anodes

*Zhi Li, PTB*

## Next-Generation Battery Systems: Solid-State Batteries (SSB)

SSB_1.1 Crystallization-Induced Confinement Enables Decoupled Li+ Transport in Ionogel Electrolytes

*He Jia, Hipole*

SSB_1.2 Ceramic and Molecular Solid Electrolytes for Next-Generation All-Solid-State Batteries

*Zouina Karkar, National Research Council Canada*

## Process Optimization for Lithium-Ion Battery Production: Hybrid Production and New Cell Finishing Concepts (HPCF)

HPCF_1.1 Multilayer Cathodes with Graded Inactive Materials: Impact on Adhesion and Electronic Conductivity in Lithium-Ion Battery Electrodes

*Fatjon Maxharraj, Fraunhofer IKTS*

HPCF_1.2 Assessing Packaging Applications for Prismatic Battery Cells under Safety & Flexibility Considerations

*Thomas Fey, RWTH Aachen*

## Process Optimization for Lithium-Ion Battery Production: Process Analytics & Quality Assurance (PAQA)

PAQA_1.1 High-precision measurement of surface tension of electrolytes in batteries using droplet shape analysis

*Anna-Lina Wolf, TU Braunschweig I IfT*

PAQA_1.2 Evaluation of the Impact of Electrode Calendering on the Coating Adhesion on the Substrate

*David Kraus, KIT*

PAQA_1.3 Slurry Electrochemical Impedance Spectroscopy for assessing mixing-induced network structure in battery electrode slurries

*Panch Poologalingam, University of Birmingham*

PAQA_1.4 Systematic Evaluation and Selection Methodology for Inline Measurement Technologies in Scalable Lithium-Ion Battery Cell Assembly Processes

*Do Minh Nguyen, TU Braunschweig I IWF*

PAQA_1.5 Bulk material handling and storage in gigafactories

*Merle Schröder, TU Braunschweig I iPAT*

PAQA_1.6 Methodological Investigation of Degassing Timing During the Formation Process of Lithium-Ion Batteries

*Merit Holdorf, TU Braunschweig I elenia*

PAQA_1.7 Formation of an artificial SEI layer to improve the performance of lithium-ion batteries

*Nina Philipp, TU Braunschweig I iPAT*

PAQA_1.8 Continuous Processing and Inline Characterization of Electrode Slurries Using Twin-Screw Extrusion

*Kevin Raczka, KIT*

PAQA_1.9 Synthesis of nickel-rich cathode active materials in automated precipitation systems

*Elisabeth Glatt, TU Braunschweig I iPAT*

PAQA_1.10 Accelerated Infrared Drying of NMP-Based Cathodes: Scaling Production for Efficient Battery Life Cycles

*Payam Hashemi, TU Braunschweig I iPAT*

PAQA_1.11 Material-to-Process: Design of Multilayer Anodes for Scalable Battery Production

*Tobit Eckey, RWTH Aachen*

# POSTER SESSION I Day 1

## Recycling & Sustainability: Direct Recycling & (Re-)Synthesis (DRS)

DRS_1.1 Transferability of Mechanical Brush Delamination for Direct Recycling of Sodium-Ion Battery Anode Electrodes

*Florian Kaltwasser, KIT*

DRS_1.2 Manufacturing and Validation of Resynthesized NMC Cathodes

*Mattes Renner, KIT*

## Recycling & Sustainability: Material Supply Chains & Circular Economy (MSCE)

MSCE_1.1 Separation of LIPF6 and EC via solvent extraction from shredded LIBs on a pilot scale

*Jannik Born, TU Braunschweig I iPAT*

MSCE_1.2 Gas Analysis as a Key for Safety, Quality, and Sustainability throughout the Lifecycle of Batteries

*Olav Werhahn, PTB*

MSCE_1.3 Comparative Analysis of Trace Sodium, Cobalt and Copper Contamination Effects in Lithium-Ion Batteries for High-Power Applications

*Slaheddine Jabri, TU Braunschweig I IAP*

## Sustainable Battery Production: Dry & Semi-Dry Electrode Coating Processes (DSEC)

DSEC_1.1 Retrofit of Twin-Screw Extruder for Continuous Mixing in Battery Cell Production – Transition from Wet to Semi-Dry and Dry Electrode Manufacturing

*Maximilian Hofmann, KIT*

DSEC_1.2 Conductive graphite additive as solid lubricant to improve processability of dry coated NMC811 cathodes

*Svenja Schreiber, TU Braunschweig I iPAT*

DSEC_1.3 Extrusion and Lamination of Double-Sided NMC Electrodes for Polymer-Based Lithium Batteries: From Electrode Manufacturing to Cell Integration

*Chazelle Sophie, CEA*

## Sustainable Battery Production: Innovative Fluorine-Free Binder Materials (FFB)

FFB_1.1 Influence of different polymeric binders and densities on the capacity retention and expansion of silicon-dominant composite anodes for lithium-ion batteries

*Sebastian Scherer, University Ulm*

# POSTER SESSION I Day 2

## Modeling & AI-Assisted Battery Production: Machine Learning & Data Analysis (MLDA)

MLDA_2.1 Calendering-Aware Thermal Conductivity Modeling for AI-Assisted Battery Production

*Julius Störk, TU Braunschweig & VARTA MB*

## Modeling & AI-Assisted Battery Production: Simulation Methods (DEM, CFD, FEM & beyond) (SIM)

SIM_2.1 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*

SIM_2.2 A stress-based multi-contact elasto-plastic model for solid-electrolyte separator and cathode densification: DEM Simulation

*Cerun Alex Varkey, Fraunhofer IST*

SIM_2.3 Unlocking Dispersion Mechanisms in High-Speed Dissolvers Using SPH Simulations

*Felix Möhlen, TU Braunschweig I iPAT*

## Next-Generation Battery Systems: Lithium-Sulfur Batteries (LSB)

LSB_2.1 Multifunctional Chitosan–based Aqueous Composite Binder for Enhanced Electrochemical Performances of Lithium-sulfur Batteries

*Liqiang Lu, Helmholtz-Zentrum Berlin for materials and energy*

## Next-Generation Battery Systems: Solid-State Batteries (SSB)

SSB_2.1 Thermal Management of Vehicles with Solid-State Battery Systems

*Jan Friedrich Hellmuth, TU Braunschweig I IfT*

SSB_2.2 Advanced Multilayer Coating and Drying for Lithium-Ion Battery Electrodes

*Mika Stricker, Fraunhofer KIT*

SSB_2.3 Synthesis and Characterization of Novel Cathode Materials for All-Solid-State Batteries

*Fadila EL KOUIHEN, UM6P*

SSB_2.4 From Powder to Performance: How Sulfide Electrolyte Particle Size Governs Dry Processing and Electrochemical Performance of Solid-State Cathodes

*Philipp Haase, TU Braunschweig I iPAT*

## Process Optimization for Lithium-Ion Battery Production: Advanced Assembling Technologies (AAT)

AAT_2.1 Quantifying Stacking Quality in Automated Battery Cell Assembly: Development and Validation of a KPI-Based Evaluation Framework

*Nils Topp, KIT*

# POSTER SESSION I Day 2

## Process Optimization for Lithium-Ion Battery Production: Hybrid Production and New Cell Finishing Concepts (HPCF)

HPCF_2.1 Microenvironments as Modular Dry Zones for Existing Battery Production Lines

*Jan-Niklas Sturm, KIT*

HPCF_2.2 Numerical Analysis of Mixing Behavior in Dry Extrusion of Cathode Materials Using DEM

*Lena Fuhrmann, KIT*

## Process Optimization for Lithium-Ion Battery Production: Process Analytics & Quality Assurance (PAQA)

PAQA_2.1 The Coupled Effects of Calendering Degree and Electrolyte Formulation on LFP Cathode Performance

*Ross Sloan, CIC energiGUNE*

PAQA_2.2 Accelerating battery cell characterization through data analytics of cell formation data

*Raphael Friedrich, RWTH Aachen*

PAQA_2.3 A Dimensionless Quantity Approach to Predicting Process Instabilities During Cell Chemistry Variations in Slot Die Coating

*Justus Benteler, Fraunhofer FFB*

PAQA_2.4 From Carbon Material to Cell Output: Rapid Electrochemical Evaluation of Negative Electrode Powders for Lithium-Ion Batteries

*Anna Rollin, TU Braunschweig I elenia*

PAQA_2.5 Influence of Structure Calendering on the Electrochemical Performance of High-Loading Graphite Anodes

*Markus Driller, Technical University of Munich*

PAQA_2.6 Combined Ultrasonic and Eddy-Current Technique for Inline Slurry Quality Monitoring

*Fabian Kux, Fraunhofer FFB*

PAQA_2.7 Mapping Industrial Needs for Inline Process Control in Battery Slurry Mixing: Towards a Contactless Eddy Current Sensor Specification

*Tim Jaspert, RWTH Aachen*

PAQA_2.8 From Lab to Production: Scaling Sustainable Battery Manufacturing in Europe

*Luca Schneider, Leclanché GmbH*

PAQA_2.9 Storage Stability of a $LiNi_{0.6}Mn_{0.2}Co_{0.2}O_2$ Positive Electrode Slurry Produced by an Innovative High-Shear Rotor–Stator Mixing Process: Time-Dependent Rheo logical and Physical Characterization

*Julia Hövels, Fraunhofer FFB*

## Recycling & Sustainability: Direct Recycling & (Re-)Synthesis (DRS)

DRS_2.1 Direct Recycling of Commercial NFPP Cathodes: Comparison with Pristine and Production Scrap Feedstocks

*Gemma Maskell, University of Birmingham*

DRS_2.2 Scaling up direct recycling of lithium-ion battery cathode scrap: A comparative study of dry-mechanical processing on a pilot scale

*Dennis Beusen, TU Braunschweig I iPAT*

## Recycling & Sustainability: Material Supply Chains & Circular Economy (MSCE)

MSCE_2.1 From Biomass Waste to Supercapacitors: A Circular Economy Approach to Sustainable Energy Storage for Grid Applications

*Pietro Agola, Novac s.r.l.*

MSCE_2.2 Debonding of Adhesive Joints in Battery Systems Using CO2 Lasers

*Hakon Gruhn, TU Braunschweig I ifs*

MSCE_2.3 Challenges and future concepts for automated contacting, characterization and demand-driven discharge of used Li-Ion Battery Systems

*Matthias Kammermeyer, Fraunhofer IPA*

## Sustainable Battery Production: Alternative sustainable solvents and drying processes (ASSD)

ASSD_2.1 Production of Sustainable Lithium-Ion Cells With Water-Based LMFP Electrodes

*Alice Hoffmann, ZSW*

ASSD_2.2 Scalable Roll-to-Roll Coating of NFPP Cathodes: Overcoming Slurry Gelling via Surface Stabilisation

*David Burnett, University of Birmingham*

## Sustainable Battery Production: Dry & Semi-Dry Electrode Coating Processes (DSEC)

DSEC_2.1 Insights into dry coating of LiFePO4-based positive electrodes on a pilot scale calender

*Volker Lewandowski, Fraunhofer FFB*

DSEC_2.2 PFAS-free Dry Processed Thick Electrodes for High-Energy Lithium- and Sodium-Ion Batteries

*Lea Eisele, Fraunhofer ISE*

## Sustainable Battery Production: Innovative Fluorine-Free Binder Materials (FFB)

FFB_2.1 A needle in a haystack – how to make fluorine-free battery binders visible

*Maja Kandula, TU Braunschweig I ifs*

# POSTER ABSTRACTS I Day 1

## Modeling & AI-Assisted Battery Production: Machine Learning & Data Analysis (MLDA)

### Data-Efficient Calibration of Particle Fracture and Scale-Aware Mechanical Response in Lithium-Ion Battery Electrode Calendering

*Jiashen Chen*
*University of Leeds*

Electrode calendering involves a complex coupling between irregular particle-scale fracture and reproducible macroscopic densification. This work develops a neural-informatics framework that integrates image-informed fracture calibration with Discrete Element Method (DEM)-based electrode compression into a rapid predictive workflow for lithium-ion battery cathode manufacturing. Rather than relying on repeated manual calibration of breakage parameters, a Multi-Layer Perceptron (MLP) surrogate is trained to learn the statistical relationship between particle fracture descriptors and the resulting stress-strain response, enabling efficient exploration of the calendering parameter space.

The model demonstrates high agreement with experimental compression data across independent repeats, with an average coefficient of determination ($R^2$) of 0.9985±0.0003 and a mean absolute percentage error (MAPE) of 8.05±0.08%. More importantly, the framework reveals that apparently random particle breakage can still generate a stable statistical mechanical response when evaluated at the ensemble level. Deviations in the learned fracture landscape remain confined within narrow stress and particle-size centroids, indicating that the surrogate captures the deterministic center of an otherwise stochastic micro-fracture process.

The same informatics strategy has also been extended to examine model-scale transferability in electrode calendering. By aligning representative and full-strip DEM domains through local material state rather than global process time, the analysis distinguishes responses that can be accurately described by reduced models from kinematic and spatially heterogeneous features that require full-geometry simulation. This combined workflow links particle fracture statistics, macroscopic stress prediction, and scale-aware model selection, providing a practical basis for efficient simulation, calibration, and optimization of high-performance battery electrodes.

### Data-Driven Causal Relationship Analysis in Battery Cell Manufacturing Lines

*Manuel Wanisch*
*BMW Group*

Battery cell manufacturing is essential for scalable electrification, but achieving industrial production with high yield, low scrap and consistent quality remains challenging due to complex interactions between material, process, product and environment parameters. These dependencies are distributed across heterogeneous machines, coexisting batch and continuous process steps, and fragmented data structures, limiting cross-process transparency, root cause analysis, and systematic optimization. This work presents a cyber-physical system methodology that transforms production data into actionable knowledge for battery cell manufacturing. The methodology links the physical production world, data acquisition, cyber-world analytics, and feedback-based decision support into one integrated system. First, OPC UA-based data acquisition structures machine data from heterogeneous equipment and establishes a consistent, quality-assured foundation for further analysis. Second, cross-process tracking and tracing connects process and product parameters from electrode manufacturing to cell assembly, enabling electrode-to-cell transparency and the investigation of parameter propagation effects. Third, unsupervised clustering is used to analyze production variance and support representative cell selection for resource-limited test fields. Fourth, machine learning methods identify cross-process causal relationships between material, process, intermediate product parameters, and final cell quality. Together, these elements convert production data into interpretable digital models for targeted testing, process optimization, quality improvement, and industrial scale-up. The methodology thereby contributes to intelligent, transparent, and decision-oriented battery cell manufacturing by closing the loop between physical production, data-driven analysis, and feedback for process and product optimization.

# Modeling & AI-Assisted Battery Production: Simulation Methods (DEM, CFD, FEM & beyond) (SIM)

## Investigation of the Dynamics of a Web Guiding Model in the Battery Cell Stacking Process

*Yann Rutschke*
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Achieving climate neutrality in the transportation sector requires a substantial increase in battery demand and, consequently, in production capacity. Battery manufacturing is characterized by high scrap rates during the ramp-up phase, mainly due to insufficient understanding of complex material-process interactions. These uncertainties limit process stability, reduce yield, and increase production costs. Model-based approaches enable systematic, resource-efficient investigation of these interactions and provide a basis for improved process design, enhanced process control, and reduced scrap rates during ramp-up. A key process parameter is the web edge position during electrode separation in the cell assembly process. Deviations in web edge position directly affect product quality, stacking alignment accuracy and overall process robustness. Precise control can be achieved using a web-edge control system with a pivoting frame as an actuator. Therefore, accurate modeling of the system dynamics, including speed-dependent effects, is essential for robust and reliable process control. This paper investigates the dynamic behavior of a pivoting frame model at varying web speeds. The model is validated using experimental data obtained from a representative test setup. In addition, a frequency response analysis is performed to characterize system dynamics and identify dominant dynamic effects and limitations. The results indicate a high-pass behavior of the system and an increasing model accuracy with rising web speed. The presented approach provides a foundation for model-based optimization and control of web edge guiding processes in battery manufacturing.

## Capturing Cross-Web Behaviour: Hybrid 1D-2D Web-Handling Simulation in Battery Production

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Web handling in battery production transports thin foils and coated webs through coating, drying, calendering, and either winding (roll-to-roll) or singulation (roll-to-sheet). Across these steps, web tension governs product quality. Uneven or excessive tension may cause wrinkling, cracks, or web-edge inaccuracies that lead, for example, to imprecise stacking. Full-line simulation is therefore key to process design, virtual commissioning, and control.

Existing low-order, control-oriented models capture the global machine-direction tension efficiently, but their idealisation cannot resolve local cross-web stress, contact and slip, or wrinkle onset. High-fidelity FEM resolves these phenomena, yet its many degrees of freedom and nonlinear contact iterations make it prohibitive for a full line. Intermediate models for lateral dynamics, wrinkling, or single-roller contact typically remain isolated rather than integrated into a fast full-line model. An integrated framework that embeds component-level FEM into a fast full-line multiphysics backbone is lacking, particularly for battery electrode production.

This work proposes a hybrid approach. A low-dimensional multiphysics model computes the global tension state along the full web path at low cost, accounting for drive dynamics, roller friction, material behaviour, and other machine-component effects. Local FEM submodels are activated only where critical stress states arise, namely at components such as rollers or web-guiding equipment. These submodels can resolve cross-web stress, contact, slip, and wrinkle onset. Co-simulation links the subdomains via tension and displacement boundary conditions.

The contribution lies in this selective coupling, placing high fidelity only where it is physically required. The result enables parameter studies, controller design, and a scalable digital-twin basis for battery production.

### Influence of Single-Sine and Multi-Sine Electrochemical Impedance Spectroscopy on Battery Model Parameterization under Constant-Current Conditions

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Electrochemical impedance spectroscopy (EIS) is a well-established technique for the parameterization of battery equivalent circuit models. These models form the basis of numerous battery management system algorithms for state estimations and diagnostic applications. Due to the sequential excitation of individual frequencies, single-sine EIS requires comparatively long measurement times. Under operating conditions with a constant charging or discharging current, the battery state may change during the measurement, causing the recorded impedance spectrum to no longer represent a well-defined operating point.
Multi-sine EIS enables the simultaneous excitation of multiple frequencies, thereby significantly reducing the measurement time. This offers the potential to acquire impedance spectra under nearly constant operating conditions. However, it remains unclear whether the reduced measurement time, despite the more complex excitation signal, enables an equivalent or even more robust parameterization of battery models compared to the single-sine approach.
The objective of this work is to experimentally investigate the influence of the excitation method- single-sine and multi-sine EIS - on the parameterization of battery models under constant-current operating conditions. For this purpose, impedance spectra are acquired during different charging and discharging profiles using both excitation methods. Based on the measured impedance data, identical equivalent circuit models are parameterized, and the resulting model parameters as well as the overall model quality are compared. Furthermore, the study evaluates whether the reduced acquisition time of multi-sine EIS leads to a more robust parameterization by minimizing changes in the electrochemical operating point during the measurement. The results of this work are expected to contribute to the assessment of single-sine and multi-sine EIS for the model-based characterization of batteries under load.

## Next-Generation Battery Systems: Lithium-Free Battery Systems (e.g., Na-ion, Zn-air) (LFB)

### Interfacial Engineering of Alkaline Zinc Batteries using Low-Concentration Polysorbate Additives

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Rechargeable alkaline zinc-manganese dioxide (Zn-$MnO_2$) batteries are promising candidates for sustainable stationary energy storage due to their low cost, high safety, and the widespread availability of raw materials. However, their practical implementation is still limited by degradation phenomena such as non-uniform zinc deposition, dendrite formation, electrode passivation, and parasitic hydrogen evolution, all of which contribute to rapid capacity fading and limited cycle life.
Electrolyte engineering represents a scalable strategy to address these challenges. In this work, low concentrations of the non-ionic surfactant Polysorbate 20 are investigated as electrolyte additives for alkaline Zn-$MnO_2$ batteries. While higher surfactant concentrations have been reported in related zinc-based battery systems, their application in highly alkaline electrolytes is accompanied by phase separation effects, which are undesirable for practical battery operation. Therefore, this study specifically focuses on concentrations close to the critical micelle concentration to maintain electrolyte homogeneity while exploiting beneficial interfacial effects.
A systematic investigation is conducted from model electrode experiments towards symmetric cells and full-cell configurations. The influence of additive concentration and current density on zinc deposition behavior, overpotentials, corrosion tendencies, and long-term cycling stability is evaluated using electrochemical and microscopic characterization methods.
Our findings provide critical insights into the interplay between additive chemistry and electrolyte composition, highlighting tailored surfactant formulations as a strategy to enhance the durability of Zn-$MnO_2$ batteries for stationary energy storage and other sustainable applications.

## Operando Pseudo-Potentiostatic EIS for the Evaluation of Formation Protocols in Sodium-Ion Batteries with Hard Carbon and Prussian White

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The formation process is a critical step in the manufacturing of sodium-ion batteries, as it strongly influences interfacial layer development, cell impedance, and long-term electrochemical performance. Conventional evaluation of formation protocols is typically based on capacity and resistance measurements, providing only limited insight into the underlying electrochemical processes.

In this work, the formation of three-electrode sodium-ion cells employing Hard Carbon anodes and Prussian White cathodes is investigated under varying temperatures and formation C-rates. In addition to conventional performance metrics such as capacity and internal resistance, operando pseudo-potentiostatic electrochemical impedance spectroscopy (PPEIS) is applied throughout the formation process. By superimposing EIS measurements during cycling, the evolution of impedance characteristics can be monitored continuously without interrupting formation.

The study demonstrates how operando PPEIS can serve as an advanced diagnostic tool for the assessment of formation protocols, enabling a more detailed understanding of electrode and interfacial processes than conventional methods alone. Furthermore, the influence of temperature and formation rate on the electrochemical behavior of sodium-ion batteries is examined. The presented approach provides both a methodology for enhanced formation evaluation and new insights into the formation mechanisms of sodium-ion cells based on the Hard Carbon||Prussian White chemistry.

## Sustainable NFPP/C cathode manufacturing for cycling-stable sodium ion batteries

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With the fast rising global demand for advanced energy storage solutions in station-ary and mobile application areas, Na ion batteries (SIBs) gained increasing attention. Owing to the higher elemental abundance of sodium over lithium, SIBs offer geographically independent and cost efficient battery manufacturing.

Sodium ferric phosphate pyrophosphate (NFPP), as a representative of the polyan-ionic cathode materials class, consists of only inexpensive, non-toxic elements. Its robust crystal structure further allows for highly reversible Na storage, enabling high rate and cycling stability.

In this study, cathodes, consisting of 94 % commercial NFPP/C active material with a capacity of approx. 2 mAh/cm2, were manufactured by both conventional NMP-based as well as sustainable water based upscalable slurry processing. While in for-mer medium, PVDF was used as binder, low cost fluorine free CMC/SBR was uti-lized in the aqueous approach. To ensure a non-corrosive slurry pH, poly(acrylic) acid (PAA) was added.

Electrochemical performance was investigated in coin half as well as full cell configu-ration vs. hard carbon anode, respectively. In half-cell, the initial discharge capacity at C/20 was determined to be approx. 109 mAh/g for both, NMP- and H2O based cathodes. At 5C charge/discharge rate, aqueous processed cathodes still exhibit a high reversible capacity of >96 mAh/g. In full-cell configuration, both cathode sys-tems allow for a respectable initial Coulombic efficiency of >87 % (C/20). After 400 cycles at 5 C discharge rate, a high capacity retention of 88.2 % reveals the H2O based cathode systems superior cycling stability. This finding was validated in multilayer pouch cells.

As an promising alternative to aqueous, dry NFPP cathode manufacturing utilizing Fraunhofer IWS patented DRYtraec® process can enable to overcome the existing limitations of active material loadings exceeding 20 mg/cm² as well as increased electrode densification.

## Cadmium Ferrite-Based Nanocomposite Electrodes for Next-Generation Electrochemical Energy Storage: PANI/CdFe2O4 and Biogenic CaCO3/CdFe2O4 Systems

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The development of scalable, low-cost electrode materials is essential for next-generation electrochemical energy storage. Cadmium ferrite (CdFe2O4), a spinel-type metal oxide, is attractive owing to its redox activity, mixed-valence character, and ability to form hybrid composites. This work presents two complementary CdFe2O4-based systems: polyaniline/cadmium ferrite (PANI/CdFe2O4) and biogenic calcium carbonate/cadmium ferrite (CaCO3/CdFe2O4).

The PANI/CdFe2O4 composites were synthesised by DBSA-doped inverse emulsion polymerisation with pre-formed CdFe2O4 nanoparticles. A series of compositions with increasing ferrite content was characterised by XRD, FTIR, UV–Vis, CV, GCD, and EIS. Progressive band shifts confirmed polymer–ferrite interaction. The optimum composition delivered a GCD specific capacitance of 296 F $g^{-}1$ at 0.1 A $g^{-}1$, with the charge-transfer resistance decreasing from 390 mΩ to approximately 84 mΩ as ferrite content increased.

The CaCO3/CdFe2O4 composites combined co-precipitated CdFe2O4 with calcium carbonate recovered from waste eggshells. Characterisation by UV–Vis, XRD, FTIR, SEM, EDX, CV, EIS, and GCD confirmed coexisting calcite and spinel phases, with fine ferrite particles dispersed within a porous carbonate matrix. The best-performing composition gave a GCD specific capacitance of approximately 135 F $g^{-}1$.

Together, these results show that CdFe2O4 can be integrated into distinct composite architectures to enhance charge storage, supporting the development of composite electrodes for post-lithium and hybrid energy-storage systems.

## Reliable Nanomechanical Characterization of Zn Foils for Quality Assurance of Next-Generation Aqueous Battery Anodes

*Zhi Li*
*Physikalisch-Technische Bundesanstalt*

Zinc foils are promising anode materials for aqueous battery technologies owing to their low cost, intrinsic safety, and high theoretical capacity. Their mechanical properties influence stress evolution, electrode deformation, dendrite formation, and cycling stability. However, reliable determination of these properties remains challenging because the pronounced surface roughness of commercial Zn foils introduces significant uncertainty into conventional nanoindentation measurements.

In this work, we present a practical approach for quantitative nanomechanical characterization of Zn foils by combining traceable nanoindentation with high-resolution surface topography analysis. Confocal laser scanning microscopy (CLSM) and atomic force microscopy (AFM) reveal localized surface defects and roughness variations that strongly affect indentation results. To improve measurement reliability, a data-selection strategy based on the local areal roughness surrounding each indentation site is introduced, retaining only measurements below a defined roughness threshold.

The proposed methodology significantly reduces data scatter and increases the measured elastic modulus from approximately 67 GPa obtained by conventional analysis to about 77 GPa. The results are validated by nanoindentation on mechanically polished Zn foils, yielding an elastic modulus of approximately 82 GPa, and by independent traceable bending measurements, resulting in approximately 88 GPa. The good agreement between these methods demonstrates that incorporating local surface topography into nanoindentation analysis enables reliable mechanical characterization of commercial Zn foils.

The proposed approach provides a robust characterization methodology for metallic battery foils and supports quality assurance in battery manufacturing by delivering reliable mechanical parameters for material evaluation and electro-chemo-mechanical modelling of next-generation aqueous zinc batteries.

# Next-Generation Battery Systems: Solid-State Batteries (SSB)

## Crystallization-Induced Confinement Enables Decoupled Li+ Transport in Ionogel Electrolytes

*He Jia*
*Hipole*

Simultaneously achieving good mechanical properties, efficient Li+ transport and interfacial stability remains a central challenge in ionogel electrolytes for lithium metal batteries. Here, we report a hierarchical polyimide-supported ionogel electrolyte in which crystallization of dimethyl sulfone induces secondary volumetric confinement inside the primary confined structures provided by polyimide pores, leading to a reorganization of the Li+ coordination environment. This confinement-driven restructuring weakens the dynamic association between Li+ and ionic liquid (IL) species, resulting in partially decoupled Li+ transport and markedly enhanced Li+ diffusivity. Concurrently, the constrained IL dynamics suppress parasitic interfacial reactions and promote the formation of a stable solid electrolyte interphase. As a result, the stability of the ionogel electrolyte toward the lithium anode is significantly enhanced, and the assembled lithium metal battery exhibits substantially improved cycling stability. This work establishes crystallization-induced confinement as an effective strategy to regulate ion coordination and transport dynamics, offering a new method for decoupling Li+ transport from matrix dynamics in ionogel electrolytes.

## Ceramic and Molecular Solid Electrolytes for Next-Generation All-Solid-State Batteries

*Zouina Karkar*
*National Research Council Canada*

Voici une version où le paragraphe sur les MOSSE est fortement réduit et intégré au deuxième paragraphe :
Humanity faces major challenges related to environmental degradation, greenhouse gas emissions, and fossil fuel depletion, making the transition to renewable energy and electric transportation essential. In this context, the development of advanced battery technologies is critical to meet the growing demand for portable electronics and electric vehicles. However, conventional Li-ion batteries are approaching their limits in terms of energy density, safety, and cycle life, motivating the search for new materials and battery architectures.
This work investigates the integration of ceramic-based electrolytes into all-solid-state batteries (ASSBs) to enhance energy density and safety. Particular emphasis is placed on hybrid interlayers and engineered inorganic interfaces designed to mitigate chemical and mechanical degradation while improving interfacial stability and cycling performance. Our studies demonstrate that the microstructure of key cell components, including the cathode, separator, and anode, strongly influences electrochemical performance. Chemo-mechanical characterization is therefore essential to understand how processing parameters, such as particle size, electrode composition, and applied pressure, affect structural integrity and battery behaviour. In addition, recent work on molecular organic solid-state electrolytes (MOSSEs) highlights the potential of molecularly engineered solid electrolytes for solid-state batteries, providing new insights into the relationships between molecular structure, ionic transport, and electrochemical performance.

# Process Optimization for Lithium-Ion Battery Production: Hybrid Production and New Cell Finishing Concepts (HPCF)

## Multilayer Cathodes with Graded Inactive Materials: Impact on Adhesion and Electronic Conductivity in Lithium-Ion Battery Electrodes

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Thick electrodes with areal capacities exceeding 4 mAh $cm^{-2}$ are essential for high energy density lithium-ion batteries, yet they suffer from mechanical instability and degraded transport kinetics. This study evaluates multilayer cathode designs utilizing functionally graded binder or carbon black (CB) to address these limitations. Each graded design features two layers with

complementary inactive material contents (1 and 5 wt.%), yielding an average composition of 3 wt.%. For comparison, uniform single-layer electrodes were processed. Three areal loadings (4, 7, and 10 mAh $cm^{-2}$) were systematically investigated. Binder grading shifts the failure mode from adhesive to cohesive, significantly increasing pull-off strength and structural integrity at high loadings. Conversely, carbon black grading alters electronic and ionic transport pathways. While the uniform reference provides the lowest electronic resistance, it suffers catastrophic, short-circuit failure at 10 mAh $cm^{-2}$. In contrast, graded CB electrodes prevent soft short circuits and maintain electrochemical stability, successfully preserving cell integrity and retaining over 50% capacity under high-current stress. However, steep gradients can introduce electronic bottlenecks and alter pore distributions, which increases specific resistance and compromises rate capability. These performance limitations are partly attributed to the wet-on-dry fabrication route, which introduces contact resistance at the interlayer boundary. These findings demonstrate that targeted composition grading effectively prevents catastrophic failure in thick electrodes, though the exact outcome depends heavily on the grading strategy. Optimized multilayer architectures thus represent a highly promising pathway toward mechanically robust, high-loading cathodes for next-generation lithium-ion batteries.

### Assessing Packaging Applications for Prismatic Battery Cells under Safety & Flexibility Considerations

*Thomas Fey*
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European battery production is experiencing dynamic growth, driven by the growing demand for energy storage systems for electric mobility and stationary applications. Alongside topics such as innovative cell chemistries, ensuring industrial safety throughout the entire value chain is becoming an increasingly important focus for establishing large scale production. While large-format lithium-ion batteries are particularly important for the energy transition, they also pose significant fire and safety risks during production, storage and transportation.
Damage to activated battery cells after electrolyte filling and formation can lead to substantial economic losses due to safety hazards. During production planning, continuous evolution of cell designs require adaptions of interfaces between the packaging unit and the cell design with regard to safety considerations. In this context, standards and regulations must be considered as minimum requirement to ensure safety during storage and transport.
Against this background, state-of-the-art reference examples are researched and analysed. Using the example of large-scale prismatic cell production, potential packaging concepts are identified that take applicable standards and guidelines into account. Key extended requirements for these concepts include high flexibility and automation, enabling felxible packaging solutions to different cell designs while ensuring reproducible processes. Such an approach for the packaging is extendable to further machine components to significantly increase the efficiency of production development and subsequent manufacturing ramp-up.

## Process Optimization for Lithium-Ion Battery Production: Process Analytics & Quality Assurance (PAQA)

### High-precision measurement of surface tension of electrolytes in batteries using droplet shape analysis

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The electrolyte filling process remains a major challenge in the production of liquid-based batteries and can require several hours in industrial manufacturing. Reducing filling time without adapting the process parameters can impair wetting within the cell. Since wetting behavior is closely related to cell performance, the reduction of filling time requires a holistic assessment of both materials and operating conditions. In this context, reliable material property data are needed to understand how environmental parameters affect electrolyte behavior during filling. Here, the surface tension between the liquid electrolyte and the surrounding gas phase is a key macroscopic property. Measuring of the surface tension of electrolyte systems is challenging due to its high sensitivity to already small amounts of surface-active substances or contaminations. Furthermore, measurements at conditions close to thermodynamic equilibrium are often not achieved in previous studies.

This contribution introduces a high-precision experimental technique for determining surface tension under process-relevant conditions in thermodynamic equilibrium. For this, the established pendant-drop method as droplet contour analysis technique is further developed for extended measurements under different and at varying pressures and temperatures in a closed measurement cell. The latter also provides means to integrate the sessile drop method for future wetting experiments. Adjustable parameters include pressures from around 0.1 to 100 bar, temperatures from 20°C up to 200 °C, and different gas atmospheres, including vacuum, dry air, argon, and gases with contaminants. Surface tension experiments are being conducted with selected liquid and semi-solid electrolytes to investigate the influence of different operating strategies on the filling process. Based on the experimental results, first recommendations for operating strategies in electrolyte filling are derived.

## Evaluation of the Impact of Electrode Calendering on the Coating Adhesion on the Substrate

*David Kraus*
*Karlsruhe Institute of Technology (KIT)*

Calendering is a key manufacturing step in lithium-ion battery electrode production, improving electrode density and electrochemical performance. However, the mechanical compression applied during calendering also influences the adhesion between the active material coating and the current collector, which is critical for electrode integrity and long-term cell reliability. This work systematically investigates the effect of calendering parameters on the adhesion of NMC622 cathode coatings to the aluminum current collector. Adhesion is quantified using 90° peel tests, in which the coating is separated from the substrate and the peel force is measured as an indicator of interfacial strength. The influence of key process parameters, including compression level, web tension, roller temperature, line speed, and the direction of sample extraction relative to the calendering direction as well as the position of the probe on the electrode web, is evaluated. The results provide insight into how individual calendering parameters affect coating adhesion and reveal potential trade-offs between electrode densification and mechanical integrity. The findings contribute to a better understanding of the mechanical effects of calendering and support the optimization of battery electrode manufacturing processes for improved performance and reliability.

## Slurry Electrochemical Impedance Spectroscopy for assessing mixing-induced network structure in battery electrode slurries

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Electrode slurries are complex suspensions of active material, conductive additives, binder and solvent, in which mixing controls particle dispersion, agglomerate breakdown, binder–particle interactions and conductive network formation. These wet-state structures influence coating behaviour, porosity, tortuosity and the microstructure retained in the dried electrode, with subsequent effects on electrochemical performance. However, direct assessment of slurry network structure before coating and drying remains challenging. In many cases, the influence of processing is only evaluated after drying, calendaring, assembling into a cell, performing formation and electrochemical testing. Rheological measurements can provide valuable in-situ information, but their interpretation in relation to conductive network formation and electrode structure is not always straightforward. This work investigates slurry electrochemical impedance spectroscopy (EIS) as a method for studying mixing-induced network structure in battery electrode slurries. Slurries are prepared under varied mixing and formulation conditions to alter conductive additive distribution, agglomerate size and particle–polymer interactions. The resulting impedance response is compared with rheology and conventional slurry assessment methods to relate wet-state behaviour to the development of electrode microstructure. Particular attention is given to the frequency-dependent impedance response under different material and processing conditions, including changes in bulk conductivity, interfacial polarisation and capacitive behaviour. These features are evaluated as potential indicators of changes in ionic pathways, conductive network formation and structural rearrangement.
This work aims to develop a process-relevant diagnostic for understanding how mixing history affects electrode slurry structure before full electrode manufacture by combining slurry EIS with complementary wet-state characterisation techniques.

## Systematic Evaluation and Selection Methodology for Inline Measurement Technologies in Scalable Lithium-Ion Battery Cell Assembly Processes

*Do Minh Nguyen*
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Automotive Lithium-ion battery (LIBs) gigafactories are driven by the demand for high production volumes. Key factors are high energy and material inputs as well as desired minimal scrap rates. Hence, inline measurement technologies are crucial for the real-time detection and minimization of deviations. The selected material formulations and production processes are affected by varying customer and market demands as well as adaptations to production processes or cell formats. A selection of suitable manufacturing technologies with matching sensor systems is therefore essential for achieving a high accuracy and flexibility. Especially during production ramp-up, changes to measurement principles add complexity and risk undesirably high scrap rates. In this paper, a systematic method for evaluating and selecting inline measurement technologies for scalable LIB production is presented. By integrating a wide variety of working principles with specifications, weighted evaluation criteria for technical, hardware along with software interface aspects, and expert knowledge on innate process limitations, the developed method enhances the selection of suitable inline measurement system options for the individual production processes for an objective decision-making. While usable on the entire battery production process chain, the method is demonstrated for a single sheet stacking process and showcases different applicable options depending on predefined use scenarios. The presented method is designed to support in the planning and scale-up of LIB production lines, paving the way towards lowered scrap rates in battery gigafactories while allowing for the adaption to production lines of other industries and inline measurement purposes.

## Bulk material handling and storage in gigafactories

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Battery cell production starts with electrode mixing processes. Nevertheless, there are a number of material handling steps that must be completed before cell production. All raw materials and components such as housing, electrode and separator foils, liquid electrolytes, solvents, and powdered electrode materials must be stored and transported in a gigafactory. This can be especially challenging for powders, as each powder may demonstrate unique flow behaviour and therefore determine the required equipment for each handling step. For dusty materials, safety precautions must be considered during delivery. Other materials can create challenges while conveying and dosing. The EU-funded GIGABAT project examines the handling of bulk materials for the various process steps in WP4.2. Building on this, a deliverable on ”Best practices for powder handling, tracking and tracing for GFs” has been published, which is to be presented on the poster
In order to design plants and processes, the powder properties must be known. Insufficient knowledge of the bulk materials used leads to various issues in production, but is often neglected during plant design, as the handling itself does not provide any added value. Some issues are dust generation, leading to environmental and health risks; contamination of the product, leading to degradation of the battery performance; mixing of product charges, impeding quality control; blockages, leading to interrupted production. The poster presents a general overview of governmental work-safety regulations and required equipment design for selected handling steps such as a mass-flow silo. Relevant bulk solid properties and the measurement techniques essential for designing selected handling steps are discussed, followed by exemplary measurement data of GIGABAT reference materials used in NMC-based lithium-ion battery production.

## Methodological Investigation of Degassing Timing During the Formation Process of Lithium-Ion Batteries

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Degassing is a critical process step during the formation of lithium-ion batteries, as the removal of gases generated by electrolyte decomposition directly influences subsequent cell processing and performance. However, determining the appropriate degassing timing remains a challenge, as gas evolution strongly depends on the progression of electrochemical formation.
This study presents a methodological investigation of degassing timing based on the Archimedes principle. An in-situ measurement approach was implemented to continuously monitor gas evolution during the formation process, enabling the identification of characteristic degassing points without interrupting cell formation. Based on the measured gas evolution, several degassing time points were selected and experimentally evaluated.
The influence of degassing timing on electrochemical performance was assessed using internal resistance measurements, capacity tests, and C-rate performance tests. In addition, the impact of the selected degassing timing on the long-term aging behavior was investigated through cycling tests to evaluate potential effects on cell degradation and performance retention. The results were compared to identify the influence of early and late degassing on both the initial electrochemical characteristics and long-term stability of the cells.
Furthermore, the Archimedes-based approach was benchmarked against alternative methods for determining the degassing timing, highlighting its advantages and limitations regarding measurement effort, applicability, and sensitivity.
The presented methodology provides a practical and non-destructive approach for identifying suitable degassing timing during lithium-ion battery formation. The findings contribute to a better understanding of gas evolution behavior and its relationship to cell performance and aging, supporting the optimization of industrial formation and degassing processes.

## Formation of an artificial SEI layer to improve the performance of lithium-ion batteries

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In lithium-ion-batteries the formation of a protective solid electrolyte interphase (SEI) is essential to ensure long lifetimes, and high cycle stability. Vinylene carbonate (VCA) is commonly used as a liquid electrolyte additive to promote the formation of a stable SEI during initial charging, thereby suppressing undesirable side reactions at the anode and enhancing cycle stability. However, VCA is electrochemically unstable on the surface of high-voltage cathode active materials (CAM), leading to undesirable side reactions. Therefore, alternative strategies are needed to preserve the benefits of VCA while enabling the use of high-voltage cathodes.
In this study, the approach to form an artificial SEI by coating the anode active materials with poly(vinylene carbonate) (PVCA) using a fluidized bed reactor is investigated. This approach aims to retain the SEI-forming advantages while avoiding side reactions at high-voltage cathodes. Process parameters, like the spraying rate, temperature and concentration, are evaluated with regard to particle size distribution. Afterward the influence of the varied parameters is investigated with regard to the electrode manufacturing (adhesive strength, conductivity) and cell performance (cycling stability, capacity loss). Long-term cycling of full cells with PVCA-coated anode particles shows performance comparable to reference cells with uncoated anode particles and VCA in the electrolyte. Furthermore, full cells with PVCA-coated anode particles exhibit significantly improved in cycling stability compared to cells without any VCA, demonstrating that artificial SEI formation via PVCA coating is a promising strategy.

## Continuous Processing and Inline Characterization of Electrode Slurries Using Twin-Screw Extrusion

*Kevin Raczka*
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Electromobility and the storage of renewable electrical energy place significant demands on the performance and cost efficiency of lithium-ion cells. Achieving these goals requires optimized electrode manufacturing with precise control of process parameters to ensure both high cell performance and stable production. The approach employs a twin-screw extruder for continuous electrode slurry production, representing the first step in the battery manufacturing chain. Adaptive process control ensures high-quality slurries with a high degree of automation and minimal energy input, reducing raw material waste and slurry losses. Compared to conventional batch processes, this approach aims to reduce downtime and setup times by up to 20%. The presentation provides insights into key quality criteria for electrode slurries and an overview of the lithium-ion battery manufacturing chain. Alongside conventional graphite-based anode slurries, a high-performance graphite–silicon anode material and a water-based LFP cathode are investigated. Fundamental slurry properties, including viscosity and particle size distribution, are monitored using inline sensor technology, enabling real-time process monitoring, early detection of quality deviations, and feedback control during continuous operation. The electrical properties of the coated electrodes are subsequently analyzed, and coin cells are assembled to evaluate electrochemical performance. Finally, the influence of process parameters, including screw speed, as well as formulation changes on slurry dispersion quality is discussed.

## Synthesis of nickel-rich cathode active materials in automated precipitation systems

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In recent years, advanced lithium-ion batteries have gained increasing importance, particularly for electric mobility applications, due to their high energy and power density. Lithiated layered oxides, such as Li[NixCoyMnz]O2 (NCM), are widely used as cathode active materials but remain major cost and environmental drivers in lithium-ion battery production. Therefore, optimizing their manufacturing processes is of significant interest. An industrially established synthesis route for NCM is the coprecipitation of a transition metal hydroxide precursor followed by calcination to obtain the layered oxide structure. This process enables tailoring of particle morphology and composition through precise control of synthesis parameters. However, achieving targeted material properties requires a comprehensive understanding of the underlying process-structure-property relationships.
This study investigated the influence of dynamic and less explored coprecipitation parameters on the properties of the hydroxide precursor and the calcined CAM. Ammonia concentration, specific energy input, and solid content during coprecipitation were monitored and varied using an automated coprecipitation system for flexible parameter variation, reproducible process control, and scalability. The produced hydroxide precursors and the calcined CAM were characterized with respect to chemical composition, morphology, particle size distribution and crystal structure. Apart from the physicochemical properties of the CAM, the electrochemical properties were also investigated to evaluate the impact of the modified process conditions. This work highlights the importance of dynamically adjusted coprecipitation parameters, enhanced by automated coprecipitation equipment. Consequently, it provides relevant information on precise control of precursor formation and supports the optimization of cathode active material production for lithium-ion batteries.

## Accelerated Infrared Drying of NMP-Based Cathodes: Scaling Production for Efficient Battery Life Cycles

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Electrode drying is the primary energy bottleneck in battery manufacturing, representing up to 48% of total energy consumption. This study implements high-intensity infrared (IR) drying for NMP-based NMC cathodes to reduce energy demand, dryer length, and cycle time while maintaining necessary adhesion and microstructure.
The methodology utilized a two-phase approach: stationary trials to determine the impact of four IR emitter technologies on the drying kinetics of NMC slurries (70 wt.% solids), followed by scaling these findings to a roll-to-roll (R2R) pilot coater. The study

evaluated Specific Radiative Heat Input by varying web speeds from 1 to 3 m/min and adjusting emitter power settings, using online IR pyrometers for temperature monitoring.
Results indicated that total optical power is the dominant factor in drying kinetics. Increasing power to 14 kW/m² achieved a 90% reduction in drying time, while an optimal "sweet spot" at 7 kW/m² yielded a 280% throughput increase with adhesion remaining above 1 N/mm². In R2R scaling, web speed was successfully tripled and energy demand was halved from 1.4 to 0.7 kWh/m². Although accelerated drying can induce capillary-driven binder migration toward the surface, IR-assisted convection proved more energy-efficient than induction or laser alternatives. The emitters provide convective heating without complex cooling-water infrastructure, and online markers like color shifts and surface roughness were used to track pore closure and segregation. In conclusion, 7 kW/m² is established as the benchmark for maximizing R2R cathode throughput, effectively halving the dryer footprint for sustainable giga-scale manufacturing.
This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101104094.

### Material-to-Process: Design of Multilayer Anodes for Scalable Battery Production

*Tobit Eckey*
*RWTH Aachen University*

Multilayer anodes enable local adjustment of material composition and electrode structure across the electrode thickness, offering additional degrees of freedom compared with conventional homogeneous electrodes. Gradients in active material, particle size, porosity, binder, or conductive additives may improve ionic and electronic transport as well as mechanical stability. However, the wide range of design options requires functional electrode properties to be considered together with processability and scalability of wet-coating processes. The aim is therefore to identify suitable material combinations and design parameters for multilayer anodes and translate them into manufacturable electrode concepts.
Anode materials and multilayer design parameters are assessed based on physical, electrochemical, and process-related properties. Particular attention is given to active-material characteristics, particle-size distributions, layer thickness and sequence, porosity, and layer-specific binder and conductive-additive distributions. Selected concepts are transferred into layer-specific slurry formulations and laboratory-scale coating experiments. Porosity, electrical resistance, adhesion, layer homogeneity, and interface quality are evaluated to identify material–process–structure relationships.
The systematic assessment narrows the possible configurations to material and structural combinations that meet both functional and manufacturing requirements. Relevant layer-specific parameters and their interactions are translated into experimentally accessible multilayer anode architectures, providing the basis for formulation development and validation.
The selected architectures are currently being transferred to laboratory-scale multilayer coating to validate processability and structural quality. Further development will focus on continuous two-layer slot-die coating and scalable process windows.

## Recycling & Sustainability: Direct Recycling & (Re-)Synthesis (DRS)

### Transferability of Mechanical Brush Delamination for Direct Recycling of Sodium-Ion Battery Anode Electrodes

*Florian Kaltwasser*
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Direct recycling is becoming a more relevant resource-efficient alternative to hydrometallurgical and pyrometallurgical processes. It preserves the morphological integrity of active materials and enables direct reintegration into electrode production. Although mechanical brush delamination has been validated for lithium-ion battery (LIB) graphite anodes, its applicability to new cell chemistries is still unknown. Sodium-ion batteries (SIBs) based on hard carbon anodes are entering the market for stationary and mobility applications. However, there are no direct recycling routes for SIB electrodes.

This work presents an experimental investigation into the transferability of a validated brush delamination process to hard carbon anodes (Kuraray) on copper current collectors. Brush rotational speed and contact pressure are systematically varied. Delamination rate, black mass purity, and particle surface morphology serve as primary quality metrics. The process can be transferred successfully to SIB hard carbon electrodes with targeted parameter adjustments. High delamination rates are achieved within the identified process window, with no measurable foil damage across all tested conditions. A further analysis confirms black mass purity comparable to LIB benchmarks. Differences in binder system and hard carbon particle morphology require adaptation of contact pressure and rotational speed relative to graphite electrodes. Concrete process recommendations for scalable direct recycling of SIB anode electrodes are derived.

### Manufacturing and Validation of Resynthesized NMC Cathodes

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The efficient recycling of spent cells and production scraps is essential in order to meet the growing demand for raw materials for cathode active materials. Transition metals recovered from old cells using hydrometallurgical processes can be used to resynthesize new cathode active materials, thereby facilitating closed-loop recycling.
However, these processes inevitably leave behind impurities in the form of foreign metal ions. These impurities can later be found in the resynthesized active material and have been shown to significantly affect its properties such as the crystal structure and particle morphology. In order to develop an effective recycling process, it is necessary to understand how the type and quantity of foreign metal impurities affect the manufacturing and electrochemical performance of these cathodes.
In this study, NMC622 synthesized from different recyclate qualities as well as with intentionally introduced impurities (Fe, Cu, Al) are systematically investigated in regard to their material properties and subsequent electrode processing. An extensive analysis of the electrochemical performance of these cathodes was conducted in single-layer pouch cells, including long-term stability tests and an assessment of internal resistances.
Even low concentrations of certain impurities (0.01 at.%) were found to have a significant impact. Selected materials were processed into large-area electrodes via slot-die coating and subsequently validated in multi-layer pouch cells to demonstrate their scalability to industrial processes.

## Recycling & Sustainability: Material Supply Chains & Circular Economy (MSCE)

### Separation of LIPF6 and EC via solvent extraction from shredded LIBs on a pilot scale

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To improve sustainability, the EU aims to increase the recycling quota for end-of-life (EoL) batteries to over 70% by 2030. The push for greater efficiency in recycling extends beyond the core components of batteries to encompass the recovery of other essential materials. For instance, certain processes can now recover electrolyte components that are typically lost through thermal decomposition during current recycling methods.
Advanced recycling methods, such as dry mechanical recycling, involve gently drying crushed battery materials in a vacuum. 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 can decompose into hydrogen fluoride gas. This study therefore investigates how the drying temperature influences the decomposition of LiPF6 in a vacuum and the composition of the resulting electrolyte condensate. Furthermore, the quantities of conductive salt and less volatile components, such as EC, within the black mass are determined.
As part of the ElRec project, the pilot recycling plant at TU Braunschweig was expanded to include a solvent extraction process. It has been demonstrated that over 80% of the LiPF6 contained in the cells can be extracted from the crushed material without

decomposing it. This material, along with the extracted EC, could be used to produce new LIB electrolytes. Recovering all three main electrolyte components increases the overall recycling rate by approximately 15%, depending on the electrolyte content in the cell. However, the greatest advantage lies in the subsequent processing steps, in which HF formation is significantly reduced. By removing these components, product handling, particularly further classification and black mass processing, is greatly facilitated.

## Gas Analysis as a Key for Safety, Quality, and Sustainability throughout the Lifecycle of Batteries

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Gas emissions occur throughout the battery lifecycle: during the first charge, while aging, during failure modes like thermal runaway, and at end-of-life recycling. These gas emissions simultaneously represent a safety hazard, a diagnostic signal for internal cell reactions, and an indicator of recycled material purity. Although gas analysis is performed at each of these stages independently, its role as a continuous, traceable signal spanning the full battery lifecycle remains underexplored in literature. In this contribution, we discuss gas emission signatures across four lifecycle stages and why their monitoring matters at each step–based on a literature review. First, during the initial formation charge, reductive electrolyte decomposition at the graphite anode forms the solid electrolyte interphase and releases CO2, CO and C1–C3 hydrocarbons; measuring this gas evolution provides an early-stage quality metric. Second, even without cycling, parasitic reactions during calendar aging cause slow gas generation (e.g., H2, CO2), supporting gas monitoring during long-term storage. Third, under electrical, thermal, or mechanical abuse, evolving gases such as CO, H2 and light hydrocarbons can precede voltage, temperature, and acoustic signals, making gas one of the earliest available indicators for early-warning systems. Finally, recycling processes exhibit characteristic vent gas signatures: electrolyte evaporation and binder decomposition during pyrolysis release CO2, CO, HF, and hydrocarbons, while pyrometallurgical and hydrometallurgical steps add further species relevant to worker safety and process quality control.

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## Comparative Analysis of Trace Sodium, Cobalt and Copper Contamination Effects in Lithium-Ion Batteries for High-Power Applications

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In this study, the impact of Na+ Cu2+ and Co2+ contamination in LP572 electrolyte on the electrochemical performance of high-power NMC831–graphite full cells was systematically investigated. The presence of $Na^+$, a larger alkali-metal cation, adversely affects interfacial stability at both electrodes. Degradation phenomena such as intraparticle cracking and graphite exfoliation are observed, likely arising from increased mechanical stress associated with enhanced volume changes during cycling. Although $Na^+$ can, in principle, insert into graphite under certain conditions, its larger ionic radius alters both interfacial chemistry and structural evolution within the electrodes. The degradation effects induced by Na+ Cu2+ and Co2+ contamination were further analyzed through post-mortem characterization, including morphological analysis of aged graphite anodes and NMC831 cathodes.

# Sustainable Battery Production: Dry & Semi-Dry Electrode Coating Processes (DSEC)

## Retrofit of Twin-Screw Extruder for Continuous Mixing in Battery Cell Production – Transition from Wet to Semi-Dry and Dry Electrode Manufacturing

*Maximilian Hofmann*
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The transition from solvent-based to dry electrode manufacturing requires adapting existing mixing equipment for economic reasons, in order to continue utilizing the existing plant infrastructure rather than replacing the entire system. This work presents a systematic approach to retrofitting a twin-screw extruder for reduced-solvent and solvent-free mixing from solvent-based electrode paste mixing, addressing mechanical reconfiguration and process parameter adjustment.
The retrofit focuses on redesigning the screw configuration. Kneading and shear elements are repositioned to the middle processing zone to accommodate the higher viscosity and cohesive energy input required for dry compounding. Meanwhile, relaxation elements at the discharge end prevent thermal degradation and ensure homogeneous material output. A directed design structure matrix (DSM), built from a systematic literature review and compared against an established DSM for aqueous processing, identifies parameter dependencies that shift under dry conditions. Pareto analysis reveals which parameters require reassessment after retrofitting.
Experiments with varied screw speed, mass flow rate, and barrel temperature quantify the effect of these parameters on fibrillization behavior and electrode quality under dry processing conditions. Fibrillization depends heavily on all three parameters. Based on these findings, specific recommendations are being developed at the plant and process levels for converting existing wet-mixing plants to semi-dry and dry processing methods.

## Conductive graphite additive as solid lubricant to improve processability of dry coated NMC811 cathodes

*Svenja Schreiber*
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Although dry coating processes for battery electrodes eliminate the use of solvents, improving production sustainability, they introduce significant mechanical challenges. Unlike conventional wet processing, the particle-binder matrix is connected by the binder PTFE, which fibrillates under shear stress. The absence of liquid lubricants results in higher friction, increased machine wear and greater particle fragmentation, especially for abrasive cathode materials, e.g. NMC. Converting the cathode mixtures into fibrillated powders and electrode coatings requires high stress intensities and increased machine torque, especially during calendering. This imposes substantial stress on material and equipment, therefore narrowing the processing window.
The objective of this study is to systematically investigate the influence of conductive graphite (CGr) on the calender-based dry coating process for NMC811 cathodes. Therefore, the practical benefits of CGr in enhancing processability due to the improved lubricity and compactability, as outlined in existing literature are investigated. The overall content of conductive additives (CA) carbon black (CB) and CGr was kept constant at 2 wt.-%. The ratio of CB:CGr was varied in the range of 1:0 to 1:1. The mixing process, utilizing a twin-screw extruder, was maintained constant to produce granules with varying CA composition. Subsequently, the granules were characterized in terms of their flow properties, electrical conductivity and particle size distribution. These properties are correlated with processability in a two-roll calender, and the resulting freestanding films and electrodes are characterized in terms of their structure (porosity, el. conductivity) and electrochemical properties (EIS, half-cells, single-layer pouch). A formulation strategy that optimizes the use of conductive additives (CGr and CB) is derived.

### Extrusion and Lamination of Double-Sided NMC Electrodes for Polymer-Based Lithium Batteries: From Electrode Manufacturing to Cell Integration

*Chazelle Sophie*
*CEA*

The development of sustainable and scalable manufacturing processes is essential for the deployment of next-generation lithium batteries. Within the framework of the European collaborative project SOLVE (Horizon Europe, Grant n°: 101147094), this work explores the fabrication of double-sided NMC ($LiNiMnCoO_2$) cathodes using an extrusion process followed by lamination, as an alternative to conventional slurry-based coating technologies.
The extrusion-based approach enables the processing of electrode materials on both sides of the current collector, offering potential advantages in terms of manufacturing efficiency, solvent reduction, and process scalability. Process parameters such as feeding of the extruder with components premix, rotational speed, filling ratio, temperatures, were optimized to obtain homogeneous extrudate with suitable viscosity. This allowed to manufacture electrode coatings after lamination steps, exhibiting areal capacity of 4 mAh/cm², high bulk density (> 2.8 g/cm3), and good mechanical integrity. The resulting electrode properties were compared with those of conventionally coated NMC electrodes through morphological, mechanical, and electrochemical characterization.
Beyond electrode development, the study addresses the integration of the extruded electrodes into pouch cells employing a polymer-based electrolyte membrane and lithium metal as anode. Special attention was paid to the electrode–electrolyte interface and to the influence of cell assembly conditions on overall battery performance.
The results demonstrate the feasibility of combining extrusion and lamination technologies with polymer-electrolyte-based battery architectures and provide valuable insights into the relationship between manufacturing process, cell assembly conditions, and electrochemical performance. This work contributes to the development of sustainable manufacturing routes for advanced lithium batteries with improved safety and scalability.

## Sustainable Battery Production: Innovative Fluorine-Free Binder Materials (FFB)

### Influence of different polymeric binders and densities on the capacity retention and expansion of silicon-dominant composite anodes for lithium-ion batteries

*Sebastian Scherer*
*University Ulm*

One possibility for achieving a high volumetric capacity while maintaining sufficient stability in lithiumion batteries is the utilisation of a silicon/carbon composite (Si/C) as an anode active material. Si/C can be used either as the sole active material or in a graphite blend. To further increase volumetric capacity, highly densified electrodes are crucial while still maintaining sufficient cycle stability. To achieve this, the chemo-mechanical degradation resulting from the large volume expansion of silicon during lithiation must be overcome. The type of binder plays a major role in mitigating anode pulverization, contact loss and irreversible anode swelling. Therefore, this study investigates the impact of different types of binder (polyurethane-based (PU), polyacrylate-based (PAA) and styrene-butadiene-rubberbased (SBR)) on the capacity retention of lithium-ion cells. The influence of morphological changes in the electrode is evaluated through cell expansion measurements and post-mortem analysis of cycled anodes. The results show that low-density anode coatings exhibit sufficient capacity retention regardless of the type of binder. However, with increasing electrode density, capacity retention decreases rapidly for PAA- and PU-based anodes. This decrease in stability correlates well with an increased anode expansion during charging and more pronounced cracking in the aged anode film. In contrast, SBR-based anodes maintain high-capacity retention despite exhibiting comparable expansion and cracking at high electrode densities. This difference is attributed to the greater flexibility of the SBR binder. These findings identify SBR as a promising binder for highly densified Si/C-dominant anodes and provide a viable pathway toward higher volumetric capacity anodes for lithium-ion batteries.

# POSTER ABSTRACTS I Day 2

## Modeling & AI-Assisted Battery Production: Machine Learning & Data Analysis (MLDA)

### Calendering-Aware Thermal Conductivity Modeling for AI-Assisted Battery Production

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The problem: battery production changes thermal transport, but existing closures miss the calendering-dependent non-monotonic behavior. Towards this end, a differentiable, calendering-aware analytical closure with contact evolution is developed. This reproduces the characteristic u-shape during calendering and reduces error strongly.
Relevance: supports process understanding and future inline QC / AI-assisted production.

## Modeling & AI-Assisted Battery Production: Simulation Methods (DEM, CFD, FEM & beyond) (SIM)

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

*Kashfia Mahin*
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Silicon-graphite composite anodes promise major gains in cell-level energy density but suffer accelerated mechanical aging whose origin is granular: inter-particle contacts are repeatedly loaded, unloaded, and reformed across the polymeric binder and the solid-electrolyte interphase (SEI), and it is this contact-level history, not the continuum stress inside any one particle that sets the pace of electrode-level degradation. We present a particle-resolved discrete element method (DEM) framework for the cyclic breathing of nano-Si/μ-graphite composite electrodes, implemented in LIGGGHTS. Each particle carries a lumped-parameter ODE for its average lithium concentration with separate lithiation and delithiation time constants, encoding the volumetric hysteresis of silicon, and drives an isotropic chemical-strain update of the multiplicative deformation gradient at every timestep. Pairwise interactions follow the Thornton-Ning-JKR contact law, whose work of adhesion is treated as a slowly evolving state variable that encodes binder and SEI ageing across cycles. The stack-level boundary condition is imposed by a force-controlled servo wall whose setpoint is the prescribed stack stress times the wall area, with a PID controller maintaining constant force during particle breathing. We perform a parametric study across the stack stress from a free upper boundary, through lightly braced (150 kPa) and the 0.5 MPa pouch-cell pre-load, up to firmly clamped (~1 MPa) together with the silicon mass fraction, the Si-to-graphite size ratio, and the inter-particle cohesion. From 50 charge/discharge cycles we extract the order parameter of the electronic-contact percolation network, persistent-versus-reformed contact statistics, the reversible/irreversible split of electrode thickness change, and the evolution of pore-throat-size distributions and geometric tortuosity. The framework delineates regimes in which mechanical bracing buffers irreversible electrode growth and those in whic

### A stress-based multi-contact elasto-plastic model for solid-electrolyte separator and cathode densification: DEM Simulation

*Cerun Alex Varkey*
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Advancements in high-performance all-solid-state batteries (ASSBs) require separators and cathodes with high relative densities to ensure sufficient ionic and electronic transport. Combining experiments with Discrete Element Method (DEM) simulations enables particle-level insights into microstructure evolution, contact-network formation, and force transmission during compac-

tion. However, predicting densification with conventional DEM remains challenging, as particles are represented as rigid bodies interacting through local soft-contact, an assumption that becomes increasingly inaccurate at low porosities where contact networks are highly constrained. In addition, the coupled effects of pronounced plasticity and evolving contact areas during compaction are difficult to capture with standard contact models. A modeling approach for simulating the densification of ASSB cathodes and separators by integrating an elasto-plastic contact model with plastic contact-deformation approach is defined [1]. The framework overcomes local-contact limitations by employing non-local force calculations based on stress-driven multi-contact formulations. The proposed model is compared against the Hertz contact model, the Thornton–Ning elasto-plastic model, and experimental data for both unimodal and bimodal particle size distributions. At higher load levels, the model captures stronger nonlinear behavior in high-stress regions and shows improved agreement with experiments in the dense compaction regime. This approach helps to optimise pressure-dependent densification during cell assembly, and for identifying suitable processing conditions that improve the electrochemical performance of ASSB components.

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### Unlocking Dispersion Mechanisms in High-Speed Dissolvers Using SPH Simulations

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Despite the widespread use of high-speed batch mixers such as dissolvers, the underlying dispersion mechanisms are still not fully quantified. In particular, the influence of process parameters and suspension viscosity on dispersion efficiency and product quality remains difficult to quantify using conventional modelling approaches.
Smoothed Particle Hydrodynamics (SPH), a mesh-free, Lagrangian-based simulation method, offers unique capabilities for modelling highly dynamic free-surface flows, complex fluid deformation, and multiphase interactions. These characteristics make SPH a promising tool for investigating dispersion processes in batch mixing systems and for gaining insights that are difficult to obtain experimentally.
This contribution demonstrates the application of SPH to the dispersion of battery slurries in a high-speed dissolver. A parametric study is presented to evaluate the influence of key operating parameters, including impeller tip speed, dissolver disc position, and additional process settings, on flow behaviour and dispersion performance. Quantitative metrics derived from the simulations are used to assess dispersion effectiveness and to establish correlations between operating conditions, mixing quality, and scale-up strategies.
The presented results highlight the potential of SPH as a modelling approach for process understanding and optimization of dispersion operations at lab scale. By providing detailed insight into the hydrodynamics governing batch mixing, SPH enables a more systematic evaluation of process parameters and supports the development of more efficient and robust dispersion processes.

## Next-Generation Battery Systems: Lithium-Sulfur Batteries (LSB)

### Multifunctional Chitosan–based Aqueous Composite Binder for Enhanced Electrochemical Performances of Lithium-sulfur Batteries

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Lithium-sulfur batteries (LSBs) are considered as one of the most promising next-generation energy-storage devices because of their high energy density. However, the long-term use of LSBs is mainly limited by polysulfide shuttling and cathode structural degradation caused by volume changes during charging and discharging [1, 2]. To address these issues, a multifunctio-

nal, high-performance aqueous binder is developed by modifying a natural polysaccharide with multi-walled carbon nanotubes (MWCNTs). The catechol-conjugated chitosan (CCS) acts as the binder, showing strong polysulfide adsorption, while the MWCNTs covalently bonded to CCS enhance the mechanical toughness and electronic conductivity. The resulting CCS-MWCNTs composite binder exhibits higher tensile strength than that of CCS. As a binder for sulfur cathodes, the CCS-MWCNTs binder demonstrates superior cyclic stability and rate capability. At a sulfur loading of 2.0 mg $cm^{-2}$, it delivers an initial capacity of 1016 mAh $g^{-1}$ at 0.2 C and retains 690 mAh $g^{-1}$ after 100 cycles, significantly outperforming commercial polyvinylidene fluoride (PVDF), sodium carboxymethylcellulose/styrene butadiene rubber (CMC/SBR), and CCS binders. This study demonstrates the potential applications of polysaccharide binders in metal-sulfur batteries by innovatively incorporating carbon nanotubes into the biopolymer binder, providing a promising alternative for environmentally friendly energy storage [3].

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# Next-Generation Battery Systems: Solid-State Batteries (SSB)

## Thermal Management of Vehicles with Solid-State Battery Systems

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Solid-state batteries (SSBs) are among the most promising for Next-Generation Battery Systems in electric mobile systems. They offer higher energy densities, extended driving ranges, longer life times and enhanced safety in comparison to conventional liquid-electrolyte lithium-ion batteries. However, SSBs exhibit distinct thermal properties and operating windows, demanding innovative thermal management strategies.
In this contribution, a summary of the specific thermal properties and thermal management requirements of SSBs is provided and discussed. This includes a comprehensive literature review combined with experimental measurements of selected thermal properties, whose direct impact on the battery system design is analyzed. These insights are incorporated into a concept synthesis methodology which is used as a basis to derive a tailored thermal management system (TMS) architecture for a high-performance battery-driven vehicle.
The TMS utilizes a reversible heat pump operating with the natural refrigerants propane (R290) and CO2 (R744). Using a full-vehicle simulation model, the system's performance is evaluated under challenging ambient conditions and demanding operational scenarios, including sub-zero starts and long-distance trips involving high-power fast charging.
The results highlight that while SSBs outperform conventional systems due to their superior energy density and higher permissible operating temperatures, they also present challenges due to increased internal electrical resistance at specific operating points. Ultimately, this work demonstrates how the proposed TMS successfully mitigates these challenges, effectively leveraging the potential of SSBs for future vehicle integration.

## Advanced Multilayer Coating and Drying for Lithium-Ion Battery Electrodes

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Sulfide-based all-solid-state batteries (ASSBs) are considered a promising next-generation energy storage technology due to their high energy density and improved safety. However, their practical implementation requires production processes capable of handling the extreme moisture sensitivity of sulfide electrolytes while enabling scalable multilayer electrode architectures. To

support systematic investigations of these challenges, dedicated experimental infrastructures have been established for studies of coating, drying, and multilayer fabrication of ASSB electrodes.
This work outlines key processing challenges and potential solution strategies currently under investigation. Challenges include maintaining material integrity during handling, ensuring homogeneous layer formation when processing sulfide particles, stabilizing multilayer interfaces, and preventing structural damage during drying.
The available experimental infrastructure includes glovebox-integrated coating systems, controlled coating environments, and vacuum as well as convection drying modules. These setups enable investigations of the influence of temperature, humidity, pressure, and binder systems on drying behavior, structural properties, and degradation mechanisms. To analyze drying kinetics and sorption equilibria of sulfide particles and processing solvents, a magnetic suspension balance has been integrated into a glovebox environment with dew points down to –70 °C.
The combination of inert handling systems, advanced coating and drying environments, analytical tools, and scalable multilayer coating strategies supports the exploration of key challenges and potential solutions and contributes to the development of scalable, high-performance all-solid-state battery electrodes.
The authors would like to acknowledge financial support of the Federal Ministry of Research, Technology and Space (BMFTR) via the project "NEPTUNE" (03XPB034D).

## Synthesis and Characterization of Novel Cathode Materials for All-Solid-State Batteries

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This doctoral thesis focuses on the development of advanced nickel-rich layered oxide cathodes for lithium-ion batteries (LIBs) and sulfide-based all-solid-state batteries (ASSBs) to achieve safer, higher-energy-density, and more sustainable energy storage. The research addresses key challenges associated with conventional LIBs, including safety concerns and reliance on critical materials such as cobalt, by employing compositional engineering strategies such as manganese substitution, aliovalent co-doping (Sb–Fe, $Mg^{2+}$, $Y^{3+}$, and $La^{3+}$), and surface modification.
The synthesized cathode materials were comprehensively characterized to evaluate their structural, chemical, morphological, and electrochemical properties in both liquid and solid-state battery systems. The results demonstrate that controlled doping and microstructural optimization improve structural stability, suppress cation mixing, enhance lithium-ion diffusion, reduce interfacial resistance, and significantly improve cycling performance. In ASSBs, $LiNbO_3$ surface coatings and optimized electrode architectures further enhance cathode–electrolyte compatibility and long-term stability.
Density functional theory (DFT) calculations complemented the experimental work by revealing the atomic-scale mechanisms responsible for dopant-induced stabilization and improved lithium diffusion. Overall, the thesis establishes clear structure–property–performance relationships and provides effective strategies for designing cobalt-reduced or cobalt-free nickel-rich cathodes, contributing to the development of safer, more durable, and sustainable next-generation lithium-based energy storage technologies.

## From Powder to Performance: How Sulfide Electrolyte Particle Size Governs Dry Processing and Electrochemical Performance of Solid-State Cathodes

*Philipp Haase*
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The dry processing of solid-state batteries (SSBs) offers significant advantages over conventional wet-processing routes in terms of cost, energy efficiency as well as microstructure control. Unlike traditional lithium-ion batteries, SSBs lack a liquid electrolyte that can infiltrate pores and ensure contact. Consequently, the electrochemical performance relies entirely on solid-to-solid interfaces, which imposes exceptionally high demands on the morphology and contact area of the particles. In this context, sul-

fide-based solid electrolytes have proven particularly promising due to their superior ionic conductivity and ductility. To optimize the interfaces, the particle size and the cathode's overall porosity emerge as the decisive factors.
To analyze the influence of SE particle size, a scalable process route based on high shear mixing and dry calendering was developed using two solid electrolyte variants (Li6PS5Cl) with different particle size distributions (D50= 0.8 µm and D50=12 µm). Based on a comprehensive cathode characterization, fundamental material-process-structure-property relationships were investigated.
The results demonstrate that friction during dry calendering is the key parameter for achieving homogeneous and optimized mass loadings. Concurrently, the SE particle size serves as the primary factor influencing cathode performance. Smaller SE particles promote the formation of a homogeneous, coherent network of all composite components, leading to an increase in electrochemical storage capability from 154 mAh g-1 up to 168 mAh g-1. Furthermore, by specifically reducing the porosity to 10 % to 15 %, ion pathways were optimized and the contact area to the active material was maximized. This resulted in an additional significant increase in the discharge capacity of up to 17 %.

# Process Optimization for Lithium-Ion Battery Production: Advanced Assembling Technologies (AAT)

## Quantifying Stacking Quality in Automated Battery Cell Assembly: Development and Validation of a KPI-Based Evaluation Framework

*Nils Topp*
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The increasing demand for high-performance battery cells requires precise and reproducible manufacturing processes. The stacking of battery sheets is a critical process step that directly influences cell quality and performance. This work investigates the automated stacking process of battery sheets using two SCARA robots, which currently exhibits limited stacking accuracy due to positioning deviations, process dynamics, and system-inherent tolerances.
This work introduces a novel Key Performance Indicator (KPI) specifically developed to quantify stacking quality based on the lateral and angular offset of individual battery sheets within a stack. The KPI aggregates multi-dimensional positional deviations into a single, interpretable score, enabling objective comparison of process states and improvement measures.
To capture the required positional data, a camera-based measurement system was designed and integrated into the existing robotic cell. Using image processing algorithms, the system detects sheet edges and calculates positional deviations in real time. This non-contact measurement approach allows for inline quality assessment without interrupting the stacking process.
The KPI was validated experimentally and applied to benchmark multiple improvement concepts, demonstrating its effectiveness as a reliable and industrially applicable quality metric for automated battery cell manufacturing.

# Process Optimization for Lithium-Ion Battery Production: Hybrid Production and New Cell Finishing Concepts (HPCF)

## Microenvironments as Modular Dry Zones for Existing Battery Production Lines

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Existing production lines for lithium-ion batteries often rely on large-scale dry rooms to provide the low-humidity atmosphere required for sensitive process steps. While these infrastructures are effective, they are associated with high energy demand, limited adaptability, and considerable effort when existing production environments need to be modified or expanded. Microenvironments offer an alternative approach by limiting the conditioned dry atmosphere to the immediate process and handling area.

Building on previous experimental investigations into the functional design and energy-related assessment of microenvironments, the focus is extended to their practical integration into existing production environments. In this context, key interfaces between the microenvironment, process equipment, and building infrastructure are considered. These include, in particular, the mechanical integration and sealing towards the surrounding environment, the integration of material and media flows, the connection to automation and handling systems, and the assurance of maintenance and operator access. In addition, requirements for process monitoring, dew-point control, and logistical integration into existing process chains are taken into account.
The proposed approach does not consider the microenvironment as an isolated enclosure, but rather as a functional production module embedded within a larger process chain. Key evaluation criteria include dew-point stability, recovery behavior after interventions, energy demand, space-use efficiency, accessibility, and implementation effort. The concept highlights the potential of microenvironments

### Numerical Analysis of Mixing Behavior in Dry Extrusion of Cathode Materials Using DEM

*Lena Fuhrmann*
*Karlsruhe Institute of Technology (KIT)*

The TROMBIBATT project aims to develop and optimize solvent-free dry processing technologies for lithium-ion battery electrodes, with a focus on scalability, energy efficiency, and environmental sustainability. By replacing conventional slurry-based coating with extrusion-based dry processing, the project seeks to eliminate the use of toxic solvents, reduce energy-intensive drying steps, and enable robust industrial implementation of dry-coated electrodes.
Ensuring a homogeneous distribution of active material, conductive additives, and binders is essential for achieving consistent electrochemical performance. In this context, this study investigates the influence of screw configuration, mass flow rate, and screw speed on the mixing quality of cathode composites processed by dry twin-screw extrusion. DEM simulations were used to analyse particle trajectories, contact behavior and residence time distributions inside the kneading zones. The numerical results were then compared with experimental extrusion data to validate the simulated mixing behavior.
The results demonstrate that both kneading zone design and process parameters strongly affect the homogeneity of particle distribution within the extruder. Higher screw speeds improved dispersive mixing while simultaneously influencing particle residence times. Increasing mass flow rates altered the frequency and intensity of particle interactions and therefore affected overall mixing efficiency. Certain kneading configurations showed significantly enhanced mixing performance due to improved particle rearrangement. The findings provide detailed insights into the relationship between screw design, operating conditions and mixing behavior in dry extrusion processes. The study contributes to the optimization of extrusion-based dry electrode manufacturing and supports the development of scalable and energy-efficient processing strategies in line with the objectives of the TROMBIBATT project.

## Process Optimization for Lithium-Ion Battery Production: Process Analytics & Quality Assurance (PAQA)

### The Coupled Effects of Calendering Degree and Electrolyte Formulation on LFP Cathode Performance

*Ross Sloan*
*CIC energiGUNE*

Battery research has traditionally focused on the development of new active materials, additives and electrolyte formulations as the main route to improve cell performance. However, electrode manufacturing parameters, although less frequently highlighted, can have an equally decisive impact on practical battery behaviour. The calendering step, for example, modifies electrode density, porosity, tortuosity, particle contact and adhesion to the current collector. However, excessive calendering can be detrimental to cell performance, and thus it is a process that requires optimisation according to the electrode and electro-

lyte characteristics and the intended cell application. In this work, the influence of calendering degree on the mechanical and electrochemical performance of both NMC and LFP cathodes for Li-metal cells was investigated. Cathodes were calendered to different degrees of thickness reduction and mechanically and electrochemically characterised to assess how increasing densification influences cathode properties and cell performance. The interaction between cathode calendering and electrolyte formulation was also investigated by evaluating the calendered electrodes with different electrolyte systems, including conventional liquid electrolytes and in situ cross-linked gel polymer electrolytes. By comparing the behaviour of NMC and LFP cathodes across these electrolyte systems, the work explores whether the optimal calendering condition is primarily determined by the electrode characteristics or whether it is also strongly dependent on the electrolyte formulation. Part of the work presented in this study has been conducted within the framework of the EU-funded Horizon Europe SOLIDBAT project under grant agreement No 101147533.

## Accelerating battery cell characterization through data analytics of cell formation data

*Raphael Friedrich*
*RWTH Aachen University*

Large-scale battery manufacturing requires process chains that dynamically adapt to continuous cell innovations, evolving performance demands, and variable architectural features. While robust data-driven analysis forms the cornerstone of inline quality management, maintaining the contextual integrity of generated data is paramount for precise quality predictions in near-series environments. To meet demands for higher energy density, safety, and sustainability, the battery sector relies on rapid optimization cycles. Promising designs transition from initial laboratory-scale proofs of concept to industrial-scale applications via tailored process specifications. This transition requires a design of experiments (DoE) framework for prototype testing that simultaneously accelerates parameter configuration and ensures scalability to serial production. This paper introduces a holistic methodology integrating traditional DoE with machine learning (ML) to derive optimized parameter configurations. Demonstrated through a case study in pouch cell finishing, the approach highlights the methodology's capacity to deliver predictive insights and decision support across diverse cell-finishing applications.

## A Dimensionless Quantity Approach to Predicting Process Instabilities During Cell Chemistry Variations in Slot Die Coating

*Justus Benteler*
*Fraunhofer research institution for Battery Cell Production FFB*

Current battery production is characterized by high resource consumption and extremely short innovation cycles. In practice, new cell chemistries or modified additives often encounter rigid, established production lines. When running in these new materials, scrap rates regularly spike, leading to severe inefficiencies. The complex process step of slot-die coating is particularly vulnerable, as numerous influencing factors converge here. For a stable production process, it is therefore essential to understand which parameters have the greatest impact on coating stability. To investigate this, expert interviews were conducted with industry specialists, supplemented by a systematic meta-analysis of electrode coating, and the findings were comparatively discussed. The goal is to identify the most critical parameters. In a second step, using the pilot line at the Research Manufacturing Battery Cell (FFB) in Münster, dimensionless quantities were utilized to demonstrate how the various physical variables correlate and where they occur. This reduces the complex coating process to a few key dimensionless numbers. On this basis, the paper outlines the specific impacts to be expected from changes in cell chemistry. Furthermore, it demonstrates which preliminary investigations are necessary and how dimensionless quantities can be used to detect and interpret process changes at an early stage.

## From Carbon Material to Cell Output: Rapid Electrochemical Evaluation of Negative Electrode Powders for Lithium-Ion Batteries

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

The global shift to renewable energy has led to a significant demand for lithium-ion batteries, driving parallel advances in battery diagnostics and recycling. To optimize recovery processes and comply with forthcoming EU regulations, precise electrochemical evaluation of reclaimed materials is crucial. However, all existing methods require time-consuming fabrication of test electrodes before any cell-level measurement can be performed. A technique that would allow active material powders to be screened directly, without prior electrode processing, could accelerate the discovery and optimization of novel compositions by delivering battery-relevant performance data in a fraction of the time.
In a battery-relevant cell configuration, the direct powder electrode cell (DPEC) reproduces the electrochemical impedance and internal resistance of conventional graphite electrode half cells. Capacity differences originate from the absence of a continuous conductive network. Systematic variation of cell parameters confirms that performance limits stem from intrinsic material and particle-contact properties rather than from the PAT-cell setup. When coupled with local current-density mapping, this approach reveals transport bottlenecks at the single-particle level. Applied to biomass-derived carbons, DPECs rapidly identifies subtle performance variations, thereby accelerating synthesis optimization. By eliminating electrode fabrication steps, the DPEC workflow shortens development cycles for next-generation battery materials and remains open to further enhancements to address capacity shortcomings.

## Influence of Structure Calendering on the Electrochemical Performance of High-Loading Graphite Anodes

*Markus Driller*
*Technical University of Munich*

Lithium-ion batteries inherently face a trade-off between high energy- and high power density. This trade-off becomes particularly critical for high-loading electrodes, where lithium-ion transport limitations within the porous microstructure intensify. Introducing microstructures shortens effective transport pathways and thus offers a promising route to mitigate this trade-off. Structure calendering is an attractive process because it offers good scalability and thus has strong potential for industrial implementation. While the benefits of electrode structuring have been demonstrated, a systematic understanding of how structure calendering and the resulting porosity influence electrochemical performance is still needed.
This work investigates structure calendered high-loading graphite anodes of 6mAh cm-2 across a porosity range from 27.5% to 35% and the resulting electrochemical behavior. Impedance spectroscopy reveals reduced tortuosity for all structured anodes, including the highest relative tortuosity reduction at 30% porosity. Rate capability between 0.5C and 3C improves consistently for structured electrodes, with the largest gains at lower porosities. Life-cycle tests, including fast-charging cycles at 1.4C, reveal pronounced, porosity-dependent improvements, with structured anodes extending cycle life by up to roughly fourfold compared to unstructured reference cells.
Overall, this study establishes a clear link between the structure calendering process, the resulting porosity, and the electrochemical performance of high-loading graphite anodes. The findings identify a porosity of roughly 30% as an optimum at which the trade-off between energy and power density is mitigated most. These findings further support structure calendering as a scalable and industrially viable route to improving the rate capability and fast-charging cycle life of high-loading electrodes, thereby advancing the development of high-energy dense graphite-based lithium-ion batteries.

## Combined Ultrasonic and Eddy-Current Technique for Inline Slurry Quality Monitoring

*Fabian Kux*
*Fraunhofer research institution for Battery Cell Production FFB*

The global demand for lithium ion battery (LIB) cells is rising steeply, with production capacity projected to grow from 230 GWh/a in 2020 to about 5600 GWh/a in 2030. Yet cell production still suffers from scrap rates of 10% to 30%, one of its largest cost drivers, especially early in production. A key cause is limited process understanding, reinforced by opaque processes and mostly offline quality control. This is particularly critical for the electrode slurry, which is still characterized offline on samples, so deviations escape detection in real time and correction in a closed loop.

Inline metrology is a promising route. A combined system is designed to capture, nondestructively and in the process stream, the key slurry properties: solid content, density, viscosity and electrical conductivity. So far demonstrated only at laboratory scale (proof of concept, Fraunhofer IKTS), it now requires systematic qualification for industrial use.

This work delivers that qualification for graphite anode slurry in two steps. First, samples with systematically varied recipes are characterized in the laboratory to establish whether the method can resolve these properties; this step is complete. Second, the system is integrated into the process at two positions, downstream of the continuous mixer (a twin screw extruder) and, in the coater, between the feed pump and the slot die; this inline step is ongoing.

First measurements show that the eddy current signal correlates with both solid content and CMC content. Building on this, the data are evaluated to identify the operating parameters that maximize sensitivity to each recipe variable, to quantify the correlations between signal and slurry properties, and to determine the system limits. The results provide a basis for detecting process deviations in real time and, ultimately, closed loop process control.

## Mapping Industrial Needs for Inline Process Control in Battery Slurry Mixing: Towards a Contactless Eddy Current Sensor Specification

*Tim Jaspert*
*RWTH Aachen University*

The properties of electrode slurries largely determine the quality of battery electrodes and, consequently, the performance of the battery cell. Inhomogeneities in the mixing process, such as an uneven distribution of conductive additives, directly affect cell performance. The scale-up to gigafactory level increases the demand for reproducible material quality and puts additional pressure on process control. Quality assurance is currently still performed predominantly offline and with a time delay. Feedback into the ongoing mixing process is therefore hardly possible. This results in higher scrap rates and increased costs. Existing inline approaches are mostly limited to single measurands.

Within the ZIM-funded project MixItUp, a contactless eddy current sensor is therefore being developed that captures multiple slurry-relevant properties simultaneously and in real time. The aim is to enable continuous process monitoring and control during mixing. Before the sensor hardware is specified, the industry's requirements for the sensor are systematically determined. For this purpose, an expert interview study is conducted with mixer manufacturers, cell manufacturers, and research institutions. The goal is a systematic mapping of the industrial need for inline-capable process control during mixing, as well as a resulting requirements catalog, validated by industry and end users, to serve as the basis for sensor development.

The poster presents the design and methodological approach of the study: the composition of the expert panel, the combined survey format with prior prioritization of relevant slurry parameters including the option to add further parameters, followed by in-depth interviews to contextualize the ratings, as well as the mixed quantitative-qualitative evaluation logic.

Presented are the methodological framework as well as the resulting prioritization of slurry parameters and measurement locations as the basis for the sensor specification.

## From Lab to Production: Scaling Sustainable Battery Manufacturing in Europe

*Luca Schneider*
*Leclanché GmbH*

Leclanché is a European energy storage provider developing lithium-ion cells and systems for stationary, marine, and mobility applications, with a strong focus on sustainable and scalable production. [1]
As part of the EU-funded BATMACHINE project, Leclanché contributes to improving resource-efficient battery manufacturing by supporting the transfer of laboratory-scale innovations toward industrially relevant conditions. The project addresses key challenges such as energy consumption, material efficiency, and environmental impact.
This poster presents Leclanché's work on the assessment and optimisation of electrode slurry mixing during scale-up. Using a novel NETZSCH mixing unit, different formulations and mixing strategies were investigated under controlled conditions. Experiments were conducted at laboratory and prototype scale, enabling a solid process understanding and allowing projection towards industrial application. The studies covered the full process chain from binder solution preparation to slurry production and electrochemical testing.
The work focuses on optimising process time and energy consumption while evaluating PFAS-free, water-based chemistries, including NMC/NMCA cathodes and silicon-graphite anodes. Over ten weeks, multiple trials were performed, including systems with and without carbon nanotubes and selected dispersion approaches.
The results support the transfer of process knowledge into industrial practice and contribute to ongoing development of advanced lithium-ion cells (e.g., 65 Ah NMC and 72 Ah NMCA). [2]
Overall, the poster highlights how targeted process optimisation and material innovation can enable more sustainable and scalable battery manufacturing in Europe.
[1] BATMACHINE Blog Post 24th of February 2026. https://batmachineproject.eu/2026/02/24/from-lab-to-production-scaling-sustainable-battery-manufacturing-in-europe/
[2] Leclanché Homepage. https://www.leclanche.com/

## Storage Stability of a $LiNi_{0.6}Mn_{0.2}Co_{0.2}O_2$ Positive Electrode Slurry Produced by an Innovative High-Shear Rotor–Stator Mixing Process: Time-Dependent Rheo logical and Physical Characterization

*Julia Hövels*
*Fraunhofer research institution for Battery Cell Production FFB*

The production of high-performance lithium-ion batteries requires precise control of all process steps, as process-induced variations can propagate throughout the manufacturing chain and ul-timately affect cell performance. In particular, the importance of the mixing and dispersion pro-cess is often underestimated, as the relationship between slurry properties and the relevant oper-ational requirements is not yet sufficiently understood. [1] Since these properties determine the processability and coating behavior of the slurry, changes in particle and network structures can directly affect electrode quality and, consequently, battery performance. [2] Also, the evolution of these structural characteristics during storage strongly influences slurry stability and defines the available processing window between mixing and coating. [3], [4]
A detailed understanding of slurry stability is of high industrial relevance, as it enables more accu-rate and efficient process planning, reduces production scrap, and contributes to a more robust and cost-effective electrode production. Therefore, this study examines the storage stability of an NMC based slurry using a rotor-stator mixing system designed for high shear performance. The objective is to quantify time-dependent changes in the dispersion properties and processability. This involved comprehensive rheological analyses, including viscosity measurements, amplitude and frequency sweeps to characterize time-dependent changes in flow behavior, network struc-ture, and viscoelastic properties of the NMC based slurry during storage in a stirred storage tank. In addition, analyses of particle size distribution and solid content were conducted over time. Combining these measurement methods, the storage stability of the slurry and suitable pro-cessing windows between mixing and coating are identified. The obtained insights enable im-proved process control and provide a basis for optimizing electrode manufacturing conditions.

# Recycling & Sustainability: Direct Recycling & (Re-)Synthesis (DRS)

## Direct Recycling of Commercial NFPP Cathodes: Comparison with Pristine and Production Scrap Feedstocks

*Gemma Maskell*
*University of Birmingham*

The rapid commercialisation of sodium-ion batteries increases the need for sustainable recycling strategies that retain the value of functional electrode materials whilst reducing processing steps and resource consumption. Direct recycling has the potential to reintroduce recovered cathode materials into battery manufacturing with minimal regeneration; however, given its recent entrance to the market, Na4Fe3(PO4)2P2O7 (NFPP) has received limited attention.

This work investigates the direct recycling of NFPP recovered from commercial sodium-ion cells and compares its properties with both pristine NFPP and in-house production scrap generated during electrode manufacturing. Commercial cells are safely discharged, dismantled and the cathode material is recovered from the current collector. Structural, chemical and thermal characterisation, including XRD, ICP-OES and TGA[GM1.1], are used to evaluate the similarities and differences between the pristine NFPP, production scrap and the recovered commercial NFPP in a post-formation state.

Recovered, production scrap and pristine NFPP are processed into new electrodes using an identical manufacturing route and evaluated by half-cell[GM2.1] testing to determine the feasibility of directly reusing recovered material without extensive regeneration. Additional commercial cells are undergoing electrochemical evaluation, with the available cycling data presented to provide context for the recovered material.

This study assesses whether recovered NFPP can be directly reused as a manufacturing feedstock comparable to production scrap, supporting practical direct recycling and circular manufacturing approaches for next-generation sodium-ion batteries.

## Scaling up direct recycling of lithium-ion battery cathode scrap: A comparative study of dry-mechanical processing on a pilot scale

*Dennis Beusen*
*TU Braunschweig I Institute for Particle Technology (iPAT)*

The direct recycling of lithium-ion battery production scrap is a crucial strategy to enhance the sustainability and economic viability of global cell manufacturing. With growing production capacities, the efficient recovery of valuable cathode active materials from rejected coated foils becomes paramount. Previous laboratory-scale investigations evaluated different direct recycling strategies, including dry-mechanical, thermo-mechanical, and wet-mechanical routes. While the thermo-mechanical and wet-mechanical approaches demonstrated promising separation results in the lab, they present significant drawbacks for industrial application. Thermo-mechanical processing was found to induce material degradation, and the wet-mechanical route requires the handling of hazardous solvents, posing severe safety and handling challenges at larger scales.

Consequently, the dry-mechanical route was selected for pilot-scale scale-up, offering a fast and cost-effective alternative that preserves material integrity without the need for hazardous chemicals. This work presents the scaling of this dry-mechanical approach for cathode scrap to a pilot plant environment. To achieve this, two distinct processing routes were investigated and systematically compared: Approach 1 utilizes an impact mill to induce mechanical stress, whereas Approach 2 employs a shredder followed by a downstream vertical mixer.

The investigation focuses on evaluating the delamination efficiency of the active material from the aluminum current collector foils under these different stress mechanisms. Furthermore, it was analyzed how effectively the resulting target fraction could be purified from residual aluminum impurities through subsequent mechanical separation steps. The results demonstrate that the distinct types of mechanical stress applied in both approaches lead to significantly different separation efficiencies, particle characteristics, and product qualities.

# Recycling & Sustainability: Material Supply Chains & Circular Economy (MSCE)

## From Biomass Waste to Supercapacitors: A Circular Economy Approach to Sustainable Energy Storage for Grid Applications

*Pietro Agola*
*Novac s.r.l.*

Reducing both production costs and environmental impact is a central challenge for the industrial scalability of electrochemical energy storage. Conventional activated carbon for supercapacitors relies on dedicated precursors (coconut shell, coal-derived materials) whose supply chains are resource-intensive and geographically concentrated, thus impacting bothprice and carbon footprint. The ECOCAP project addresses this issue by establishing a circular and locally sourced production chain in Piedmont, Italy, in which lignocellulosic waste from the wood and agricultural industries is valorized through pyro-gasification. This process co-produces syngas, directed toward local energy recovery, and biochar, which is processed into activated carbon for electrode fabrication and conductive inks, turning industrial residues into high-value functional materials at reduced raw material cost. Electrode manufacturing protocols are being established for both coin cell and multilayer pouch cell formats, with the first characterization campaigns focusing on electrochemical characterization, including cyclic voltammetry, galvanostatic cycling, and electrochemical impedance spectroscopy. The experimental work will target cycle life exceeding 100 000 cycles and energy density in-line with commercial EDLC devices, with the aim of validating the proposed solution as a cost-effective, drop-in alternative to alternative precursors. Novac s.r.l. lastly leads the scale-up and advanced characterization activities and will integrate optimized cells into hybrid energy storage systems for electric mobility and aerospace applications 1. Life Cycle Assessment runs in parallel to quantify the environmental and economic gains of the bio-based supply chain, providing the evidence base needed to support industrial adoption at scale.

## Debonding of Adhesive Joints in Battery Systems Using CO2 Lasers

*Hakon Gruhn*
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The accelerating deployment of electric vehicles necessitates efficient End-of-Life (EoL) strategies for lithium-ion batteries. Structural adhesives and thermal interface materials are extensively utilized within battery modules to ensure mechanical stability and effective thermal management. However, these permanent bonds pose significant barriers to disassembly, complicating repair, repurposing, and material recycling. As conventional separation methods often lack the required efficiency and automation capabilities, this study investigates the use of a CO2 laser for the controlled debonding of adhesive joints without damaging critical system components. This approach leverages the efficient coupling of the CO2 laser wavelength into polymers, while being almost completely reflected by metallic surfaces, such as the casings of cylindrical and prismatic cells. Consequently, cell damage is prevented, and the laser beam remains confined despite increasing divergence.

The investigations confirmed that laser-based debonding is economically viable, achieving cutting depths sufficient for current battery systems. Additionally, results demonstrate that the localized heating of adjacent components is limited to below the critical threshold of 70 °C for lithium-ion batteries. Furthermore, the process exhibits high robustness against typical manufacturing variations, including angular misalignment, positional deviations, and fluctuating adhesive layer thicknesses, presenting a scalable and automatable solution for future EoL disassembly processes.

### Challenges and future concepts for automated contacting, characterization and demand-driven discharge of used Li-Ion Battery Systems

*Matthias Kammermeyer*
*Fraunhofer Institute for Manufacturing Engineering and Automation IPA*

Growing volumes of end-of-life Li-ion batteries from EV and ESS require scalable, cost-effective pre-cycling processes. Pre-cycling involves logistics, sorting, disassembly, characterization, and discharge of used battery systems to enable informed circular economy decisions. State of Health (SoH) is a key indicator for determining the optimal pathway–repair, refurbishment, second life, or recycling. Since a single degraded cell can limit the performance of the entire system, characterization at pack, module, and cell level is essential.

Industrial-scale pre-cycling additionally faces major challenges: uncertain conditions of the battery system components containing hazardous materials, strict high-voltage safety requirements, limited BMS access, thermal management, and highly heterogeneous system designs severely hamper scalable automation and standardization. Additionally, rising market shares of LFP and sodium-ion chemistries with lower recoverable material value further increase pressure on pre-cycling cost efficiency.

This paper reviews state-of-the-art characterization methods including resistance measurements, Electrochemical Impedance Spectroscopy (EIS), temperature monitoring, and cycling tests as well as various discharge and deactivation strategies and their potential impact on downstream recycling. We identify key technical bottlenecks and propose an integrated framework combining autonomous robotic systems with flexible end-effectors, standardized workpiece carriers for automated contacting and monitoring, inline fast characterization using model-based EIS and data-driven digital twins, together with demand-driven discharge racks tailored to second-life or recycling preparation. Pre-cycling is thus conceptualized not as a fixed process but as a demand-driven decision stage determining the optimal circular economy pathway. The proposed concepts will be validated in an industrial environment within the funded research project RoB@t2Cell.

## Sustainable Battery Production: Alternative sustainable solvents and drying processes (ASSD)

### Production of Sustainable Lithium-Ion Cells With Water-Based LMFP Electrodes

*Alice Hoffmann*
*Center for Solar Energy and Hydrogen Research Baden Württemberg (ZSW)*

Electric vehicles and other applications demand Lithium-ion batteries with high energy density, long cycle life, high safety and low cost. Increasingly important are avoiding critical raw materials, securing supply chains, and adopting environmentally friendly production – specifically by replacing the toxic solvent NMP in the cathode production process by a sustainable alternative like water.

While Ni-rich NCM as active material dominated research for its high capacity and energy density, it suffers from its sensitivity to water: For its processing into electrodes, expensive dry environment is recommended and the use of water as a solvent causes impairments. Conversely, Lithium Iron Phosphate (LFP) gained prominence in Asia due to iron's abundance, cost efficiency, superior safety, and cycle life, despite a lower energy density.

Lithium Manganese Iron Phosphate (LMFP) emerged by integrating Manganese into LFP, leveraging its high redox potential to boost overall energy density. Further, LMFP offers superior stability versus water. Key challenges remain: Does LMFP fully realize the expected gains while retaining LFP's safety and longevity? How do Chinese export regulations impact LMFP adoption? Most critically, is LMFP compatible with water-based electrode manufacturing?

This presentation describes two water-based production processes for LMFP slurries – a conventional one and an alternative, highly efficient continuous process enabling increased solid content for a lower drying demand. Experimental data is compared against theoretical expectations and against data from LFP and NCM cells. Performance impairments are identified, their root

causes elucidated, and LMFP's unique benefits elaborated. By enabling high energy density without hazardous organic solvents, LMFP represents a pivotal step toward truly sustainable, high-performance battery production in Europe.
(The work was financially supported by BMBF in the project WaBaFli, reference number 03XP0409D.)

### Scalable Roll-to-Roll Coating of NFPP Cathodes: Overcoming Slurry Gelling via Surface Stabilisation

*David Burnett*
*University of Birmingham*

Sodium iron pyrophosphate Na4Fe3(PO4)2P2O7 is a promising low cost, cathode material for sodium ion batteries, offering excellent structural stability and long cycle life. However, translating NFPP from lab scale draw down to roll-to-roll (R2R) manufacturing presents significant processing challenges, most notably slurry gelling, a drawback it shares with many sodium ion cathode materials. This phenomenon, driven by Na-ion dissolution and pH instability, results in cross linking of the polymer chains, leading to viscosity drift, poor pot life, and non-uniform coatings that compromise electrode quality and production yield.
In this work, we present a study on the stabilisation of NFPP slurries for R2R coating. We scrutinise the root causes of gelling through rheological analysis evaluating a series of additives that suppress gelation while maintaining coating rheology suitable for coating using a comma bar. The optimised formulation demonstrates extended slurry stability without sacrificing electrode adhesion, conductivity, areal loading uniformity or specific capacity.
Coated electrodes were processed on a small R2R line, and resulting sheets were assembled into single layer pouch cells vs hard carbon to evaluate electrochemical performance, including rate capability and cycling stability. Additive stabilised NFPP slurries enable consistent, defect free coatings, with pouch cell performance matching that of lab scale reference tests demonstrating the efficacy of the mitigation strategy undertaken.

## Sustainable Battery Production: Dry & Semi-Dry Electrode Coating Processes (DSEC)

### Insights into dry coating of LiFePO4-based positive electrodes on a pilot scale calender

*Volker Lewandowski*
*Fraunhofer research institution for Battery Cell Production FFB*

Lithium-ion battery (LIB) cell manufacturers, especially in Europe, currently face high energy costs that depend on the country of production. In general, energy consumption in cell pro-duction is distributed across the drying process (~17%), formation (28%), dry-room operation (~30%), and other processes (~25%) [1]. In this regard, eliminating the cost- and energy-intensive drying step in electrode production is a key lever for reducing process costs and potentially lowering investment costs [2].
The production of dry electrodes is considered one of the most promising technologies for future battery cell manufacturing and offers significant advantages in terms of energy con-sumption, sustainability, and production efficiency. Starting from active material powders, an electrode film must first be formed and then laminated onto a current collector foil [3]. However, converting dry powder materials into homogeneous, high-quality electrode struc-tures require exceptional process control and machine precision [4]. To meet these requirements, Breyer's latest and most innovative machine concept for dry coating, the IONDry 600 pilot, was installed at Fraunhofer FFB in Münster in 2026 as part of the development of a research-oriented, industrial-scale battery production infrastructure.
This poster provides key technological insights into pilot-scale dry electrode manufacturing for lithium-ion batteries using LiFePO4 as the active material, based on the DRYtraec® pro-cess. Electrode film formation and transfer between the rollers are investigated by varying roller speed, gap width, and temperature using DOE. Particular attention is paid to electrode film thickness through gap control during film formation and lamination. Furthermore, se-lected dry electrodes are subjected to electrochemical characterization, and key electrode quality parameters, such as areal weight, thickness, and homogeneity, are examined.

### PFAS-free Dry Processed Thick Electrodes for High-Energy Lithium- and Sodium-Ion Batteries

*Lea Eisele*
*Fraunhofer Institute for Solar Energy Systems ISE*

Rising demand for higher specific energy in electrochemical storage devices remains a key challenge for sustainable battery chemistries. Sodium-ion batteries (SIBs) have attracted growing interest because sodium is abundant, offering potential cost advantages and a chemical similarity to lithium-ion batteries (LIBs). The realistic benchmark for SIBs is LiFePO4-based (LFP) cells, which are widely available but suffer from the same limitations in specific capacity and energy density. However the environmental impact of SIBs outperforms LIB chemistries, while benefiting from raw-material availability. Economic competitiveness for both chemistries can be improved by adopting low-solvent or solvent-free fabrication routes; such processes also enable thicker electrodes and higher energy densities by increasing active-material loading cutting inactive components. The areal loading of commercial cells is typically limited to about 3.5 mAh/cm2 for slurry-based processes. For stationary storage, the lower power density of thick electrodes due to slower Li+/Na+-ion diffusion is acceptable and can be offset e.g. by coupling with supercapacitors.
In this study we demonstrate porous, thick electrodes for LIB and SIB chemistries, using PFAS-free binders for both cathode and anode. With tunable porosity, excellent mechanical integrity, and areal capacities up to 10 mAh/cm2, these electrodes nearly triple current benchmarks. For LIBs, the importance of electrolyte composition tuned for thick electrodes is demonstrated in an electrolyte study. Finally, we validate the cell concept in a pouch cell with LFP||Gr (>10 mAh/cm2) and SOH80 >300 cycles. For SIBs, thick electrodes (P2-Na0.66Mn0.75Ni0.25O2||Hard Carbon) are investigated in PAT®-Cells, showing the feasibility of increasing the specific energy of SIBs. The findings confirm that a straightforward manufacturing approach can enable thick, high-areal-capacity electrodes with competitive performance using non-fluorinated binders.

## Sustainable Battery Production: Innovative Fluorine-Free Binder Materials (FFB)

### A needle in a haystack – how to make fluorine-free battery binders visible

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

Fluorine-based binder components are very easy to track within an electrode because of the high fluorine signal within e.g. EDX analysis or XPS measurements. However, if we substitute fluorine-based binders in battery applications with polymers without halogenated components we are facing a few difficulties. The European Chemicals Agency (ECHA) has initiated a restriction proposal that calls for a blanket ban on the manufacture, use, and import of an estimated 10,000 PFAS (per- and polyfluorinated alkyl substances). Because of the EU regulations, PFAS-based materials are rather less accepted in industrial products. That is why new binders probably came into the market. The spatial distribution of the binder in the electrode structure is a critical point for the battery performance. It is responsible for the adhesion, the ionic and electric conductivity and for the longevity. The first step is than – how to track the new binder? There are many possibilities towards electrode mapping, tracking agents, and special analytics. With this approach, we aim to demonstrate that identifying the location of the binder is crucial for identifying new substitutes. This problem is well known with anode binders such as CMC and SBR—since we are now altering or reducing the fluorine content, new characterization methods must be developed. In this work, we show different possibilities and their challenge to detect the binder distribution and binder migration. For these investigations, we use tracer materials that interact with the binder. Examples include mechanoluminescent components or materials that facilitate localization in spectroscopic analyses allows a quantification of the binder domain.

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**Measure electrode expansion (half- or full cell) in the nanometer range**




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Mathis

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# BATTERY COATING LINES

## Sheet or Roll to Roll - Coating, Drying, Laminating and Calendering



Werner Mathis AG designs and builds coating, drying and laminating equipment for the battery industries.

The portfolio includes laboratory scale equipment, pilot lines and complete production ranges.

As design and manufacturing are housed under one roof we can customize our standard equipment range to meet all your requirements, building you a Mathis machine that will perfectly match your requirements.

Whether your (coating) solutions are aqueous or contain solvents we can offer you a machine that can handle either or both. Solvent levels in dryers and exhaust systems are monitored via LEL (Low Explosion Level) systems.

Mathis dryers are designed to dry/cure your product in a gentle but efficient way ensuring the integrity of your product.

Mathis drying technology allows you to adjust airflow to top/bottom, regulate recirculating air speed/velocity. Additionally data logging of recipes, nominal and actual parameters is possible. Programmable user and process alarms are an integral part of Mathis equipment.

Sophisticated web guiding and tension control systems allow precise laminating and winding of the finished product for further processing of you product.

Various air handling concepts, suitable for your product are offered for most Mathis equipment.

Mathis offers solvent recovery system technologies, regenerative thermal oxidation (RTO) and catalytic oxidation system (CT).

All relevant regulations and standards like, DIN/EN/ISO are adhered to.



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batteries

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CiteScore 9.8

# Aims and Scope of *Batteries*

Batteries (ISSN 2313-0105) is an international, open access journal of battery technology and materials. It aims to provide a central vehicle for the exchange and dissemination of new ideas, technology and material developments, and research results in the field of battery technology between scientists and engineers throughout the world. The emphasis is placed on original research, both analytical and experimental, covering all aspects of primary and secondary batteries, including chemical batteries and thermal batteries, etc.

## Main research areas include (but are not limited to):

- Fundamental electrochemistry aspects;
- Active and passive materials and components;
- In situ and ex situ material analysis;
- Cell design, module, and pack technology;
- Processing and manufacturing;
- Battery applications;
- Modeling and control;
- Battery performance and testing;
- Charging technologies;
- Battery management system, monitoring, diagnostics, and prognosis;
- Thermal management;
- Hybrid battery systems;
- Safety and reliability;
- Mechanisms and modes of ageing, lifetime;
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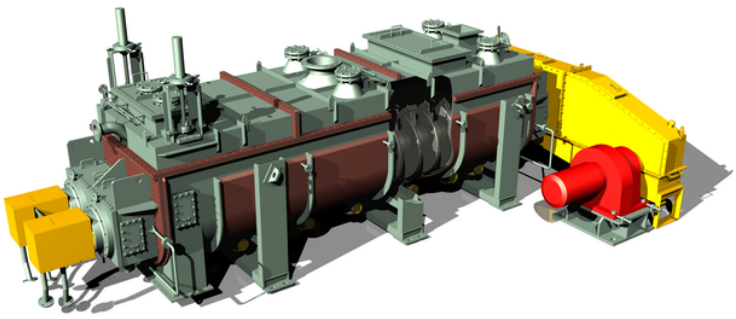

Particle Design

### HYBRIDIZATION SYSTEM

Powder Surface Modification Unit

◆Graphite spheroidization

◆Compositing of Cathode Materials / Graphite & Silicon / Solid State Battery Mateirals



Dryer

### PADDLE DRYER

Heat Transmission Dryer

◆Cathode / Anode Material

◆Lithium hydroxide

◆Precursors such as NMC-NCA

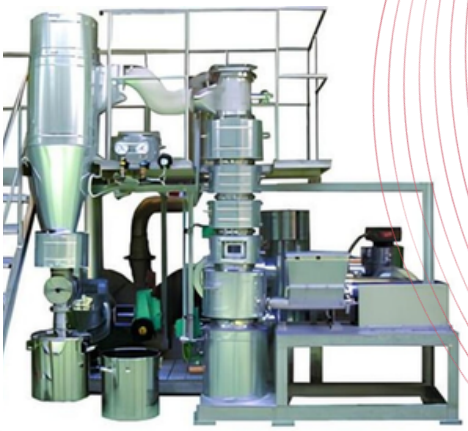


Dryer

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A Unique Dryer Using a Fluidized-bed Process

◆Silicon carbide



Dryer

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# IMPRINT

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