Chair of Electrical Energy Storage Technology
TUM School of Engineering and Design
Technical University of Munich

2010 – 2025

15 Year Anniversary

Chair of Electrical Energy Storage Technology

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Foreword

The transport and energy transitions are two of the greatest challenges and opportunities of our time. In a world that is becoming increasingly aware of the importance of sustainable and renewable energy sources, battery storage systems play a central role. They enable fossil fuels to be replaced, efficient storage of electricity from wind, solar, and other renewable sources and made available as needed, and contribute to the stability of our energy grid. This makes them a crucial building block for a future-proof, independent, and environmentally friendly energy supply.

Prof. Dr.-Ing. Andreas Jossen

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With this brochure, I would like to give you a comprehensive insight into the activities of the EES Chair, which was founded 15 years ago. You will learn about the topics we are working on in battery research, how we pass on our knowledge to young talents in lectures, seminars, and internships, and how we are involved in the scientific community and academic autonomy.
I would like to emphasize that we work very closely with groups from other engineering disciplines, chemistry, and physics within the Technical University of Munich, and have been collaborating with other institutes and universities in Bavaria and Germany for many years as part of joint projects. We are engaged in intensive exchange with international partners from England, France, Singapore, Taiwan, Australia, and the USA.
I cordially invite you to explore the opportunities and challenges of battery storage. Let yourself be inspired and contact us if you are interested in an exchange or collaboration.
I hope you enjoy reading this brochure.

Andreas Jossen, Oktober 2025

Facts & Figures

Research & Development Projects & Funding
86 & ~€13.5m

Battery Test Channels	Journal Publications
820	215

Master Theses	Doctoral Dissertations
493	54

Bachelor Theses	Examinations
228	15.493

Cumulative figures for the 15-year period from 2010 – 2025

Members of the Chair

Head of Chair
Prof. Dr.-Ing. Andreas Jossen

Research Management
Dr. rer. nat. Gudrun Rahn-Koltermann

Administrative Staff
Stefanie Käfer
Antonella Schumacher

Technical Staff
Jens Dietrich

Research Staff
Julius Bahrke
Hannah Bosch
Santiago Cornejo Vorbeck
Axel Durdel
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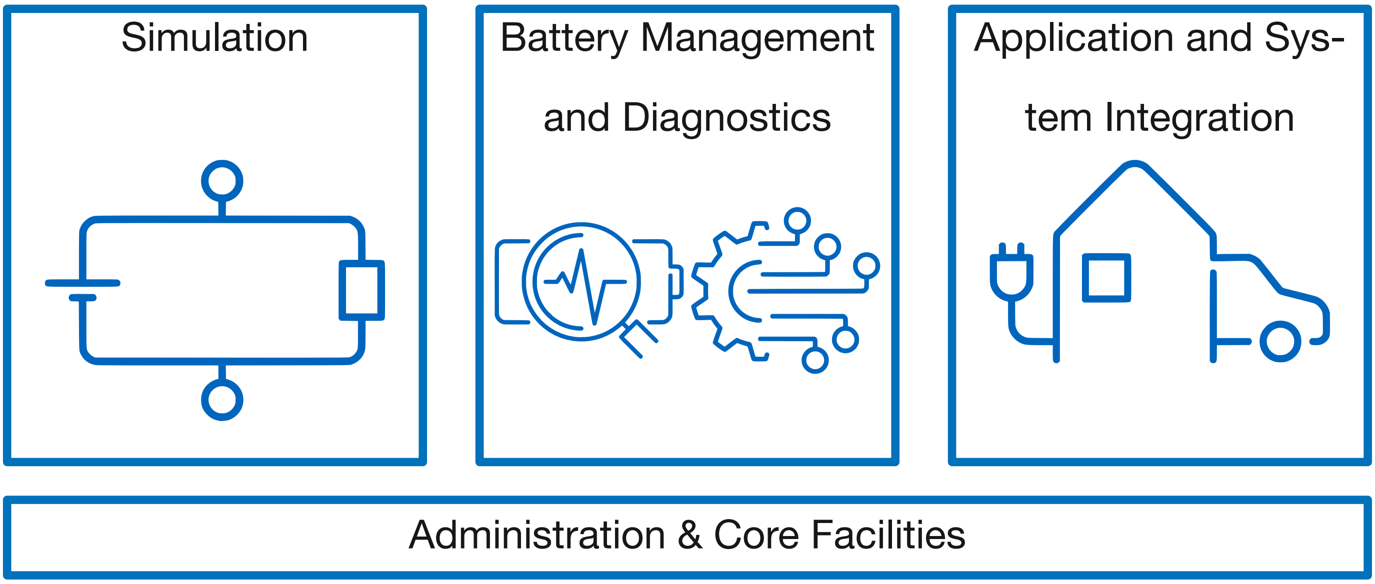
Sammy Jablonski
Simon Kücher
Christoph Macho
Christopher Mauersberger
Marco Neudecker
Yaroslava Pavlenko
Mathias Rehm
Yannis Riedel
Marcel Rogge
Franz Röhrer
Manuel Rubio Gomez
Vitaly Savvin
Stefan Schäffler
Michael Schrattenberger
Veronika Vachenauer
Henry Winner
Elia Zonta

Research Activities

Experimental research activities are conducted in laboratories operated by the EES and by partner institutes. The laboratories are located at three locations – at the main EES premises (Karlstr. 45 in Munich, Germany), at the TUM main campus (Arcisstr. 21 in Munich, Germany), and at the Research Center for Energy and Information (Lichtenbergstr. 4a in Garching, Germany). The three research groups at EES engage in highly collaborative research across the entire chain in battery research.

Research Groups



Research at EES is conducted within three research groups focusing on broad aspects of battery research. Crucial collaboration and support from the administration, technical staff and laboratory facilities enables cutting-edge research to take place smoothly at the chair.

Simulation

With spatially resolved and detailed physicochemical models, the electrochemical, mechanical, and thermal properties of lithium-ion batteries are investigated in order to understand, describe and optimize the underlying mechanisms. The scope of modeling and simulation typically includes experimental validation using various test setups.

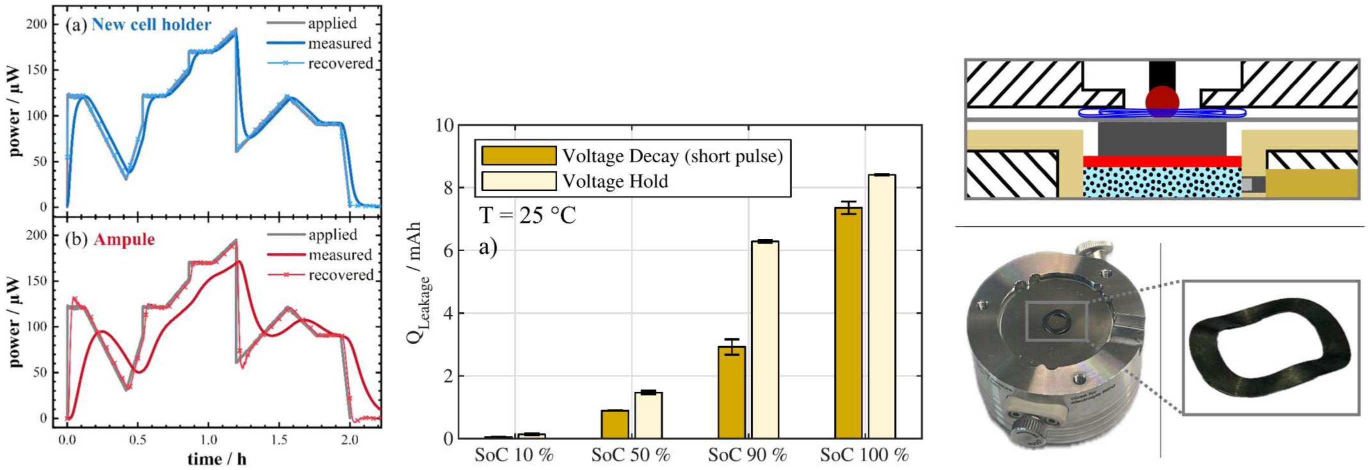
Battery Management and Diagnostics

The Battery Management and Diagnostics team investigates the safe and efficient operation of batteries at both cell and system levels. Research focuses on predicting aging, assessing performance and safety, and analyzing electrical and thermal inhomogeneities. Diagnostic methods enable the estimation of internal states and early detection of safety-critical conditions. Using advanced measurement techniques, modeling, and targeted experiments, the team develops and refines strategies for improved battery management, reliability, and longevity across various applications.

Application and System Integration

The team Application and System Integration investigates the design, optimal operation, and performance of energy storage systems to enhance efficiency, extend longevity, and improve economic viability. By employing mathematical optimization, machine learning, and diverse modeling techniques, we produce insights that directly inform techno-economic and techno-ecological assessments.

Cell and Material Testing



(left) Improved heat flow signal using the custom-build cell holder for a micro-calorimeter. (center) Comparison of two measurement techniques to quantify the capacity lost via side reactions using a high precision coulometer. (right) Schematic and photographs of the adjusted dilatometer cell including a spring washer to apply pressure onto the working electrode.

Researchers

Alexander Kunz*
Luiza Streck*
Simon Kücher
Tom Schabenberger*
Christopher Mauersberger
Christoph Macho
Hannah Bosch

Publications

A. Kunz et al., Time-Resolved Electrochemical Heat Flow Calorimetry for the Analysis of Highly Dynamic Processes in Lithium-Ion Batteries, Journal of the Electrochemical Society, 2022.

L. Streck et al., A Comparison of Voltage Hold and Voltage Decay Methods for Side Reactions Characterization, Journal of the Electrochemical Society, 2023.

S. Kücher et al., Investigating the Impact of Various Binder Contents and Compression on Graphite Single-Electrode Dilatometry Measurements, Journal of the Electrochemical Society, 2025.

T. Schabenberger et al., Impact of applied and preceding pressure on performance and reversible swelling of lithium-ion pouch cells with varying microporous separators, Journal of Energy Storage, 2024.

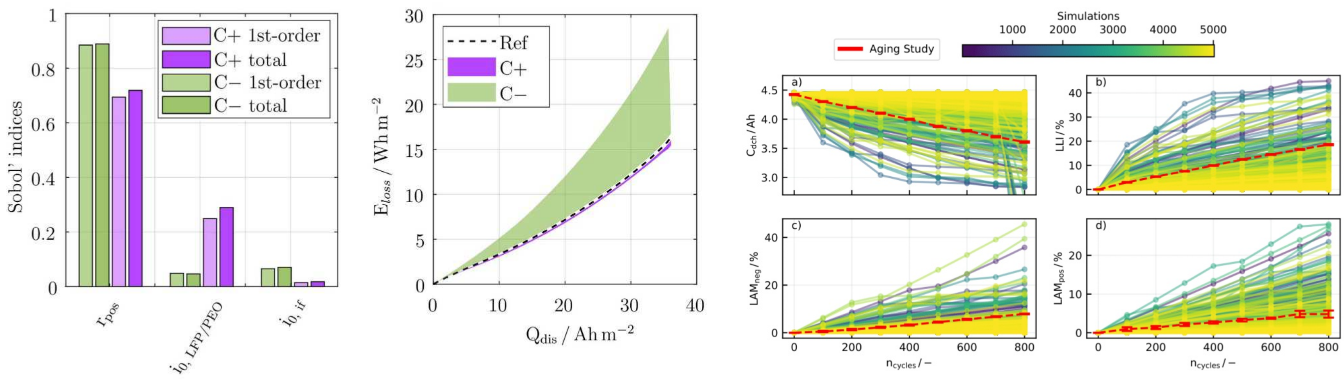
Testing on material level, component level, and cell level is essential to understand the different facets of batteries. This includes heat generation, mechanical behavior, as well as electrical behavior, all of which are often interconnected by the multi-disciplinary nature of batteries.

Using custom-built test equipment or optimizing commercially available testing devices allows us to gain detailed and novel insights into the different aspects. High precision micro calorimetry allows for the deconvolution of the generated heat flow of samples. Once determined on small-scale electrode level, we utilize the data in model-based scale-up studies to predict the behavior of large-scale batteries. High precision coulometry combined with voltage hold measurements enables a swift detection of increased side reactions and thus of potentially faulty batteries. Single-electrode dilatometry determines the reversible and irreversible volumetric swelling on electrode level. Our optimized device that allows for applied pressure during testing yields more stable and reproducible results, revealing a more application-relevant component behavior. Compression tests on electrode and full cell level can be used to determine not only the overall compressibility, but also to investigate the optimal pressure during module assembly to enable optimal performance.

Almost all data retrieved from those tests not only increase the understanding of batteries but are essential for model parametrization and validation. Using such models, we enable cost-efficient virtual testing and predictions of cell behavior.

* Researchers graduated and do not currently work at the Chair

Statistical Methods for Parametric Effects and Parameter Estimation



Results of a sensitivity study regarding the effect of design parameters of polymer interlayers on all-solid-state battery performance (left), and aging trajectories simulated to evaluate the effect of model parameters (right).

Researchers

Manuel Rubio Gomez
Johannes Natterer
Elia Zonta
Sammy Jablonski
Maximilian Scheller*

Publications

M. Rubio Gomez et al., Statistical analysis for robust battery state estimation: Demonstrating ANOVA-driven feature selection with electro-chemical impedance spectroscopy, Journal of Power Sources, Under Review.

E. Zonta et al., Time-dependent global sensitivity analysis of the Doyle-Fuller-Newman model, Journal of Energy Storage, Under Review.

E. Zonta et al., Global sensitivity-guided calibration of physicochemical aging models, Oxford Battery Modelling Symposium, 2025.

M. Scheller et al., Impact of Polymer Interlayers on All-Solid-State Battery Performance Using a Physicochemical Modeling Approach. Journal of the Electrochemical Society, 2024

Statistical Evaluation of Parametric Effects

Many questions in applied battery research boil down to quantifying the effect of one or multiple parameters on some quantity of interest.

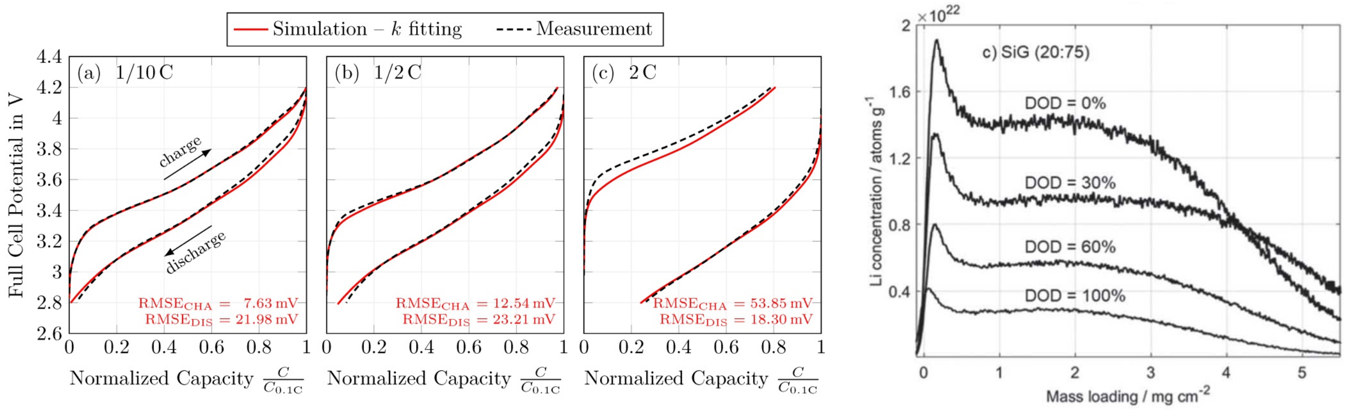
For example, when trying to estimate the temperature of a cell from measured impedance values, one is interested in whether the interaction of temperature and impedance is influenced by other factors such as state of charge. Treating such problems requires careful selection of methodology. In experimental settings, analysis of variance (ANOVA) provides a powerful framework for investigating the interactions of parametric effects and allows for the selection of statistically optimal features for estimation tasks.

In model-based research, variance-based sensitivity analysis provides a similar utility to ANOVA. Employing novel algorithms, which let us examine the effect of parameters on time-dependent voltage responses or impedance spectra, enables better model-based decision-making and potentially simplifies parameter estimation.

Parameter Estimation

Parameters for battery models are traditionally obtained from direct measurements and fitting to experimental data. This approach has the downside of ignoring the potential existence of multiple parameter combinations yielding good fits. Statistical methods such as Bayesian inference try to address this ambiguity by finding probabilistic estimates for the parameters, thereby quantifying the confidence in the obtained values.

Silicon as Anode Material



Full cell potentials after final fitting at C-rates of C/10, C/2, and 2C (left), Lithium concentration profiles for different SiG electrode compositions at 100% DOD (right).

Researchers

Axel Durdel
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Vitaly Savvin
Alexander Kunz*
Luiza Streck*
Erfan Moyassari*
Sven Friedrich*

Publications

A. Durdel et al., Modeling Silicon-Dominant Anodes: Parametrization, Discussion, and Validation of a Newman-Type Model, Batteries, 2023.

L. Streck et al., Analysis of Transient Current and Heat Flow during Voltage Holds: For 70 wt% Silicon Anode Lithium-Ion Cells, Journal of the Electrochemical Society, 2024.

E. Moyassari et al., Cycle Characterization of SiO-Based Lithium-Ion Batteries Using Real Load Profiles, Journal of the Electrochemical Society, 2023.

S. Friedrich et al., Degradation Mode Analysis for Lithium-Ion Cells with Silicon-Dominant Anodes Using Reference Electrodes.Journal of the Electrochemical Society, 2025.

Silicon is a highly promising anode material due to its large specific capacity, however its strong volume changes pose major challenges for cycle stability and modeling.

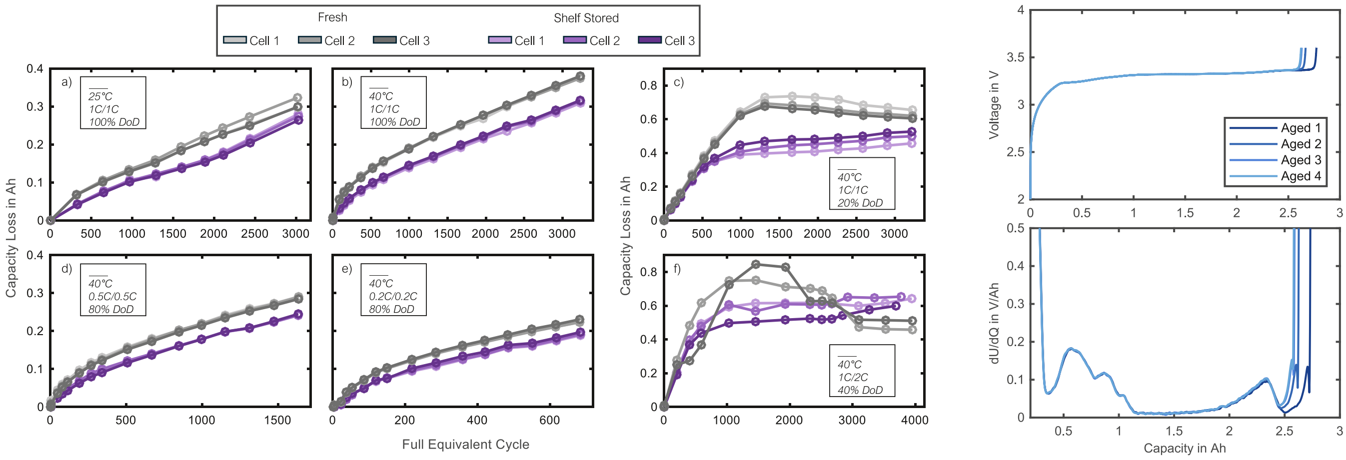
Silicon-Based Electrode Modelling and Characterization

To address these challenges, a range of approaches has been explored — from parameterizing electrochemical models to studying relaxation and degradation behavior. A validated Newman-type p2D model for a silicon-dominant anode coupled with a high nickel cathode demonstrates accurate potential predictions over multiple C-rates. Experimental investigations employing isothermal microcalorimetry and voltage hold techniques reveal that relaxation hysteresis and inhomogeneity equalization in silicon-based cells are dominated by intrinsic material effects, strongly affecting leakage currents and thermal responses across different battery formats.

Aging and Lithium Distribution Analysis

Fast charging and long-term stability are key challenges for silicon-based electrodes. Degradation mode analysis and neutron depth profiling (NDP) provide complementary insights into lithium distribution and capacity fade mechanisms. For silicon-dominant and silicon-graphite composite electrodes, voltage reconstruction identifies the loss of lithium inventory as the primary aging driver, leading to electrode imbalance over cycling. NDP reveals homogeneous but irreversible lithium accumulation throughout the electrode depth, increasing with silicon content. Studies on SiOx cells show that higher silicon fractions and elevated state-of-charge ranges accelerate capacity fade. Fast-charging investigations of Si/NCA pouch cells further confirm lithium inventory loss as the main degradation mechanism, independent of charging protocol, while high ΔSoC windows amplify aging and extend charging times.

Aging of LFP/C Cells



Comparison of cycle aging in fresh and decade-stored LFP/C cells (left), and exemplary degradation mode analysis of an LFP/C cell using open-circuit potential and differential voltage (right).

Researchers

Yaroslava Pavlenko (maiden name Fedoryshyna)
Yannis Riedel
Christoph Macho
Veronika Vachenauer
Josef Eizenhammer

Publications

M. Naumann et al., Analysis and Modeling of Calendar Aging of a Commercial LiFePO4/Graphite Cell, Journal of Energy Storage, 2018.

M. Naumann et al., Analysis and Modeling of Cycle Aging of a Commercial LiFePO4/Graphite Cell, Journal of Power Sources, 2020.

V. Vachenauer et al., Shelf life of lithium-ion batteries: Recommissioning LiFePO4/C cells after ten years of uninterrupted calendar aging, Journal of Power Sources, 2025.

Experimental Aging Studies

Lithium iron phosphate (LFP) cells offer excellent thermal and chemical stability, but show distinct aging behavior compared to other chemistries. At our chair, long-term aging studies over several years provide detailed insights. Earlier works comprising calendaric and cyclic aging studies over several years confirmed the high stability of LFP under diverse conditions. Recently, we examined cells stored for over ten years at cool ambient temperatures, demonstrating that LFP cells remain highly usable even after a decade of storage.

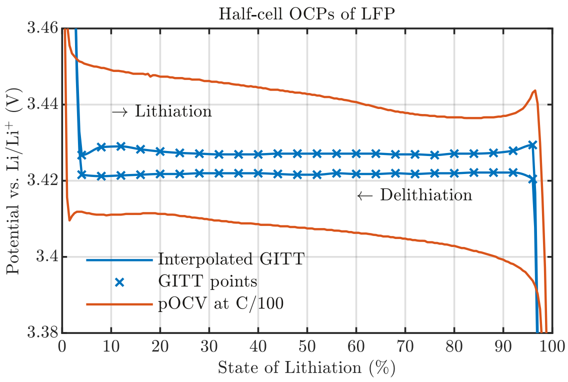
Degradation Mode Analysis

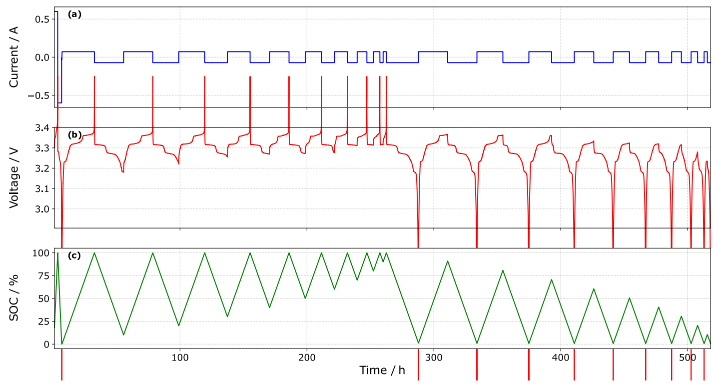
We assess whether degradation mode analysis — well established for NMC and NCA cells — can also be applied to LFP/C cells despite their flat voltage profile. Software-based analysis methods deploying voltage profiles of pristine and aged LFP cells are validated through post-mortem examination and coin-cell reconstruction of aged electrodes to verify which degradation modes occur in the materials.

Physico-Chemical Aging Modelling

We develop and utilize physics-based models to describe aging phenomena in LFP/C cells. Building on established modeling approaches to describe aging mechanisms like SEI growth and active material loss, we test their applicability to LFP/C systems. The models draw on extensive laboratory aging data and are validated using long-term field data from residential energy storage fleets, enabling realistic representation of degradation under real operating conditions.

Hysteresis Behavior of Electrodes





LFP half-cell measurement vs. Li/Li+ emphasizing its hysteresis by comparing pOCPs at C/100 vs. GITT-interpolated OCPs (left); minor-loop measurements on full-cell level for parametrizing an ECM-based hysteresis model (right).

Researchers

Yaroslava Pavlenko (maiden name Fedoryshyna)
Yannis Riedel
Christoph Macho
Veronika Vachenauer
Manuel Rubio Gomez
Simon Kücher
Michael Schrattenberger
Axel Durdel
Luiza Streck*

Publications

A. Durdel et al., Modeling Silicon-Dominant Anodes: Parametrization, Discussion, and Validation of a Newman-Type Model, Batteries, 2023.

L. Streck et al., Analysis of Transient Current and Heat Flow during Voltage Holds: For 70 wt% Silicon Anode Lithium-Ion Cells, Journal of the Electrochemical Society, 2024.

Ongoing research activities at the chair focus on understanding and modeling hysteresis phenomena in lithium-ion cells with different electrode materials, particularly silicon- and LFP-based systems.

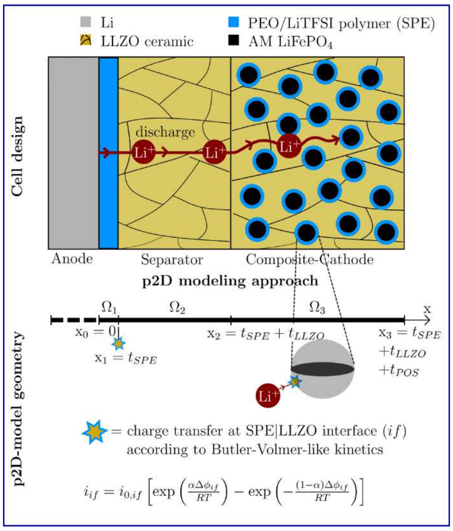
Silicon

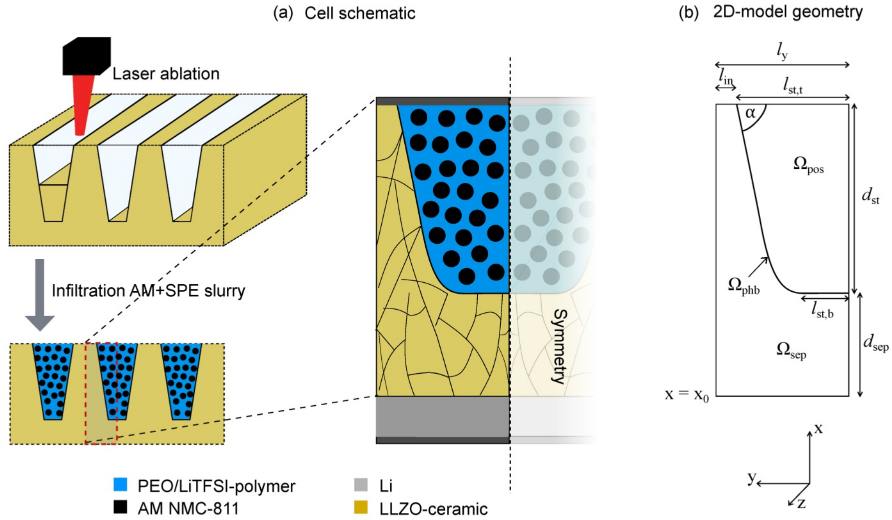
Due to its pronounced volume changes and intrinsic hysteretic behavior, silicon significantly influences both the electrochemical and thermal response of the cell. Recent studies show that relaxation hysteresis and inhomogeneity equalization are more evident electrically than thermally. It has been shown that relaxation currents correlate with voltage hysteresis during voltage hold experiments. In parallel, modeling activities have yielded a validated Newman-type p2D model for cells with silicon-dominant anodes. By incorporating voltage hysteresis, the model provides a reliable foundation for electrochemical simulations of silicon-based systems. While simplified approaches can capture specific operating conditions, employing more advanced hysteresis models could further enhance the accuracy of silicon-based system simulations.

LFP

Experimental investigations on LFP-based systems reveal hysteresis effects such as voltage overshoots and transitions that deviate from the expected enveloping curves. Current work focuses on identifying the underlying mechanisms responsible for these phenomena. To accurately simulate the hysteretic behavior of LFP-based systems, advanced hysteresis formulations beyond conventional literature models are being explored for use in both equivalent circuit and physics-based simulation.

Solid State Electrolytes and Battery Cells





(left) Schematic of a hybrid polymer-ceramic solid-state battery including model adjustments for interfacial effects. (right) Schematic of a 3D-structured ceramic solid-state separator as used for model-aided optimization studies.

Researchers

Christopher Mauersberger
Marco Neudecker
Maximilian Scheller*
Nour Adrah

Solid Electrolytes

Solid-state electrolytes (SSEs) are a promising technology for next-generation battery systems, offering higher energy density and improved safety compared to conventional liquid electrolytes. Depending on the material class, they can be categorized into polymers, ceramics, and sulfides, each with specific strengths and limitations. Ceramic electrolytes combine good ionic conductivity with high mechanical stability, yet form poor interfacial contacts. Polymers provide excellent flexibility and interface quality but suffer from low conductivity. Sulfide electrolytes show the highest ionic conductivity but are often chemically unstable toward electrode materials.

Ongoing research

Ongoing research aims to better understand and improve these materials through advanced simulation and characterization methods. Key aspects include optimizing interfacial properties, addressing contact resistances and current constrictions, and enhancing mechanical and chemical stability. In addition, studies focus on the thermal behavior of solid-state cells compared to liquid systems, as well as on scaling strategies from laboratory prototypes to practical applications. The overall goal is to develop reliable models, methods, and materials that accelerate the commercialization of solid-state batteries.

Publications

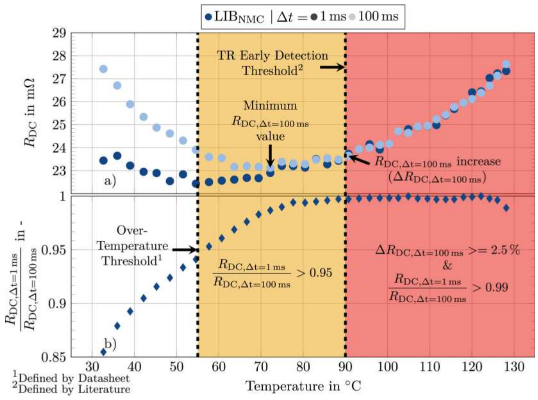
M. Scheller et al., Model-Based Performance Evaluation of Hybrid Solid-State Batteries: Impact of Laser-Ablated Geometrical Structures, Batteries, 2024

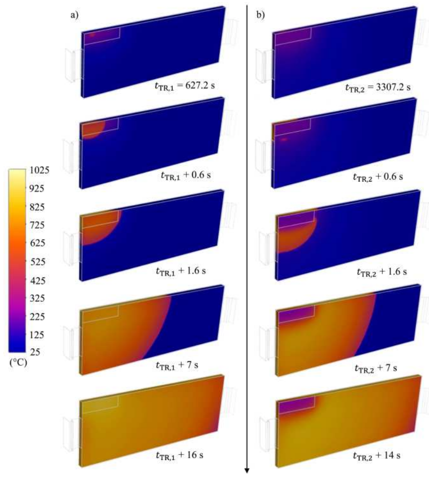
M. Scheller et al., Impact of Poly-mer Interlayers on All-Solid-State Battery Performance Using a Phys-icochemical Modeling Approach, Journal of the Electrochemical Society, 2024

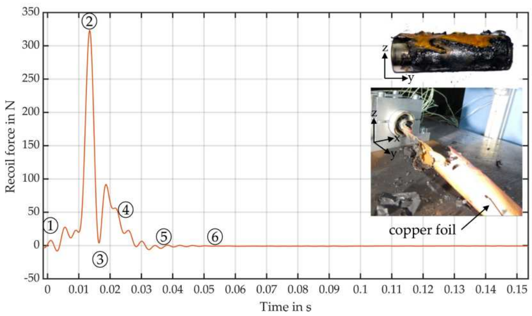
M. Neudecker et al., Performance of Structured Composite Cathodes Containing a Hybrid Polymer-Ceramic Solid Electrolyte, Advanced Battery Power, 2025

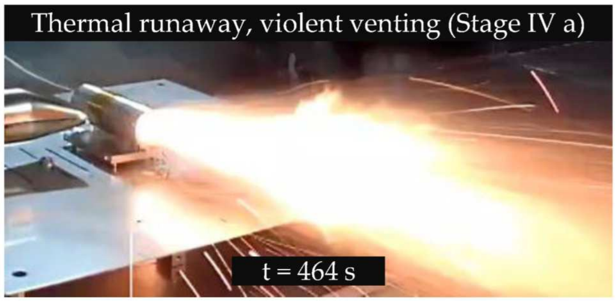
C. Mauersberger et al., From Lab to Application: Assessing Sulfide-Based All-Solid-State Battery Performance by Model-Based Scale-Up Techniques, ECS Meeting Abstract, 2025

Battery Safety









Researchers

Elisabeth I. Gillich (maiden name Kolp)
Yaroslava Pavlenko (maiden name Fedoryshyna)
Manuel Rubio Gomez
Stefan Schäffler

Publications

E. Gillich et al., Mechanical Measurement Approach to Characterize Venting Behavior during Thermal Runaway of 18650 Format Lithium-Ion Batteries. Batteries, 2024

Y. Fedoryshyna et al., Quantification of venting behavior of cylindrical lithium-ion and sodium-ion batteries during thermal runaway. Journal of Power Sources, 2024

S. Schaeffler et al., In situ measurement and modeling of internal thermal runaway propagation within lithium-ion cells under local overheating conditions. Journal of Power Sources, 2024

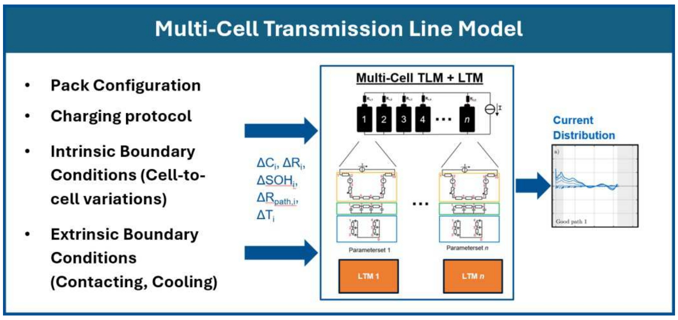
M. Rubio Gomez et al., A novel pulse resistance based thermal runaway early detection approach for lithium-ion and sodium-ion batteries, Journal of Energy Storage, 2025

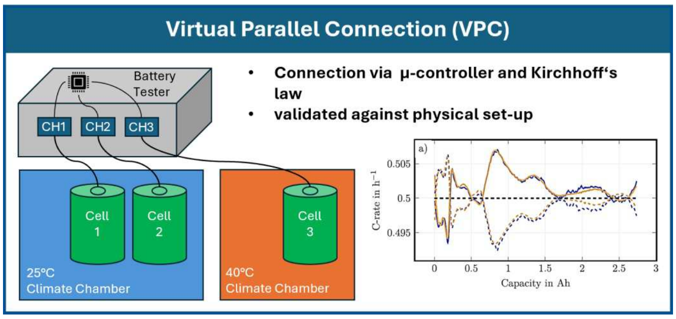
Battery safety research focuses on understanding the physical and chemical processes that can lead to failure in energy storage systems and on developing strategies to prevent and mitigate such events. Modern high-energy batteries, such as lithium-ion and sodium-ion systems, can experience critical conditions when exposed to mechanical, electrical, or thermal abuse, potentially triggering a thermal runaway event.

We investigate the mechanisms that govern thermal runaway initiation, propagation, and venting, as well as the influence of temperature gradients, internal structure, and cell chemistry on these processes. Advanced experimental methods, including in-situ temperature measurements, localized overheating, and gas-flow characterization are combined with modeling approaches to better describe the complex interactions within cells during failure.

In addition, innovative diagnostic techniques, such as temperature estimation from pulse resistance, are explored for early detection of hazardous states, providing new tools for real-time safety monitoring. The generated insights support the design of safer batteries and modules, improve thermal management and simulation accuracy, and contribute to the development of reliable, high-performance energy storage systems for electric mobility, stationary applications, and other technologies requiring safe and efficient power delivery.

Investigation of Short- and Long-Term Behavior in Interconnected Cell Systems





Researchers

Franz Röhrer
Philipp Jocher*
Andreas Graule*

Publications

P. Jocher et al., A novel measurement technique for parallel-connected lithium-ion cells with controllable interconnection resistance, J. Power Sources, 2021

P. Jocher et al., Scaling from cell to system: Comparing Lithium-ion and Sodium-ion technologies regarding inhomogeneous resistance and temperature in parallel configuration by sensitivity factors, Journal of Energy Storage, 2024

A. Graule et al., Development and Evaluation of a Physicochemical Equivalent Circuit Model for Lithium-Ion Batteries, Journal of the Electrochemical Society, 2024

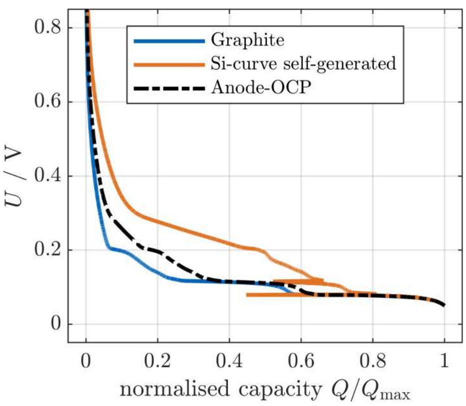
F. Roehrer et al., Real-time replication of battery cells using digital twins: A novel experimental methodology to measure current inhomogeneity in n-parallel configurations, Journal of Power Sources, 2025

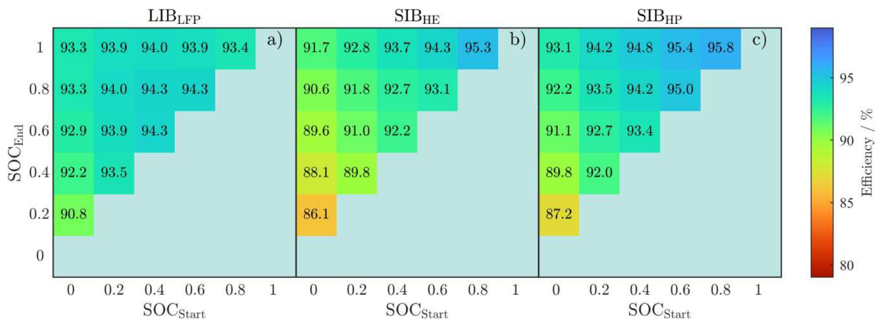
To meet the demands of high-energy and high-power applications such as electric vehicles, battery packs comprise hundreds to thousands of cells interconnected in series and parallel. In parallel-connected cell configurations, the presence of inhomogeneities, e.g., cell-to-cell variations, unequal contacting, or non-uniform thermal boundary conditions, causes unequal current sharing, impacting both short-term performance and long-term degradation.

The measurement of physically parallel-connected cell configurations is prone to inaccuracies and is resource-intensive. Therefore, a Virtual Parallel Connection (VPC) was developed at EES, enabling measurements of parallel configurations without physically connecting the cells. Instead, each cell is independently connected to the battery cycler, and Kirchhoff's circuit laws are applied in real time to virtually connect the cells in parallel. The VPC allows efficient coupling and decoupling of cells and the introduction of clearly defined, reproducible electrical and thermal boundary conditions. It was employed to experimentally investigate how different boundary conditions affect current inhomogeneity across various cell technologies.

In parallel, an electrochemical–thermal multi-cell transmission-line model (TLM) has been developed to enable simulative investigations of series–parallel cell configurations. The model is based on equivalent circuits and, for each cell, resolves the physical processes and internal states represented in the standard Doyle–Fuller–Newman model. A flexible through-plane discretization enables a trade-off between computational speed and fidelity. Because the TLM is physics-based, application-relevant, production-induced cell-to-cell variations can be introduced, and internal states (e.g., local overpotential) can be observed—enabling studies of fast-charging strategies governed by the limiting cell in the pack. Going forward, this framework will be used to simulate the aging behavior of interconnected cell configurations under different cycling conditions and inhomogeneities, and to compare those results with experimental aging studies based on the VPC.

Method-Applicability on New Materials





Researchers

Mathias Rehm
Manuel Rubio Gomez
Hannah Bosch
Julius Bahrke
Cedric Kirst
Franz Röhrer

Publications

M. Rehm et al., Comparing the electrical performance of commercial sodium-ion and lithium-iron-phosphate batteries, Journal of Power Sources, 2025

M. Rehm et al., Detecting Internal Short Circuits in Commercial Sodium Ion Batteries by Measuring Their Cryo-Resistance, ECS Meeting Abstracts, 2024

P. Jocher et al., Scaling from cell to system: Comparing Lithium-ion and Sodium-ion technologies regarding inhomogeneous resistance and temperature in parallel configuration by sensitivity factors, Journal of Energy Storage, 2024

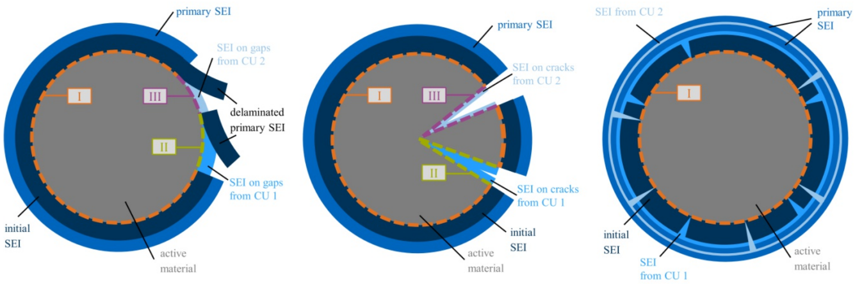
F. Roehrer et al., Real-time replication of battery cells using digital twins: A novel experimental methodology to measure current inhomogeneity in n-parallel configurations, Journal of Power Sources, 2025

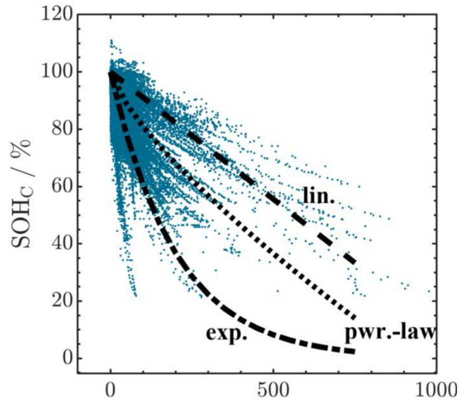
Advanced Materials in Battery Storage Systems

With the increasing demand for energy storage, the development of advanced electrode materials is a central research focus. Conventional lithium-ion batteries are nearing practical limits in energy density and cost. Silicon is a promising anode due to its much higher theoretical capacity than graphite, but its large cycling-induced volume changes cause mechanical degradation; additionally, higher hysteresis poses a problem when applying algorithms optimized for conventional anodes. We investigate how production parameters and test conditions govern aging in silicon-containing cells, examining, for example, electrolyte additives and the impact of depth of discharge. For silicon-dominant and silicon-graphite blends alike, decoupling the independent aging of silicon and graphite is essential for degradation-mode analysis; further, absent or inaccurate silicon OCP data in commercial cells complicates robust fitting.

In parallel, sodium-ion batteries (SIBs) are advancing as a resource-abundant, potentially lower-cost alternative for selected applications, despite lower energy density. Our current work focuses on layered-oxide cathodes (e.g., $NaNi_{1/3}Mn_{1/3}Fe_{1/3}$). In practice, SIBs can function as near drop-in replacements in some systems and are less susceptible to current-sharing inhomogeneities in parallel strings due to a steeper cell OCV slope, whether in 2p or n-p configurations. Conversely, elevated resistance at low SOC, primarily from hard-carbon anodes, induces strong SOC-dependent energy efficiency. Aging behavior remains insufficiently resolved, in part because both electrodes exhibit relatively flat OCP curves that hinder diagnostic separation of mechanisms, and because some observed issues may reflect prototype-cell immaturity rather than intrinsic material limitations.

Aging Assessment of Li-Ion Batteries





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Publications

M. Rogge et al., Path-Dependent Ageing of Lithium-ion Batteries and Implications on the Ageing Assessment of Accelerated Ageing Tests, Batteries & Supercaps, 2024

A. Karger et al., Modeling Particle Versus SEI Cracking in Lithium-Ion Battery Degradation: Why Calendar and Cycle Aging Cannot Simply be Added, Journal of The Electrochemical Society, 2024

M. Fischer et al., How Degradation of Lithium-Ion Batteries Impacts Capacity Fade and Resistance Increase: A Systematic, Correlative Analysis, Journal of Power Sources, 2025

Aging Characterisation

Our team established a comprehensive understanding of battery aging as a coupled electrochemical–mechanical process influenced by cycling, storage, temperature, and state of charge. We demonstrated that capacity fade, resistance growth, and interfacial cracking evolve simultaneously, governed by the interaction of SEI formation, particle fracture, and lithium redistribution. By revealing the strong path dependency of degradation, we clarified how operational history shapes both aging progression and partial recovery phenomena.

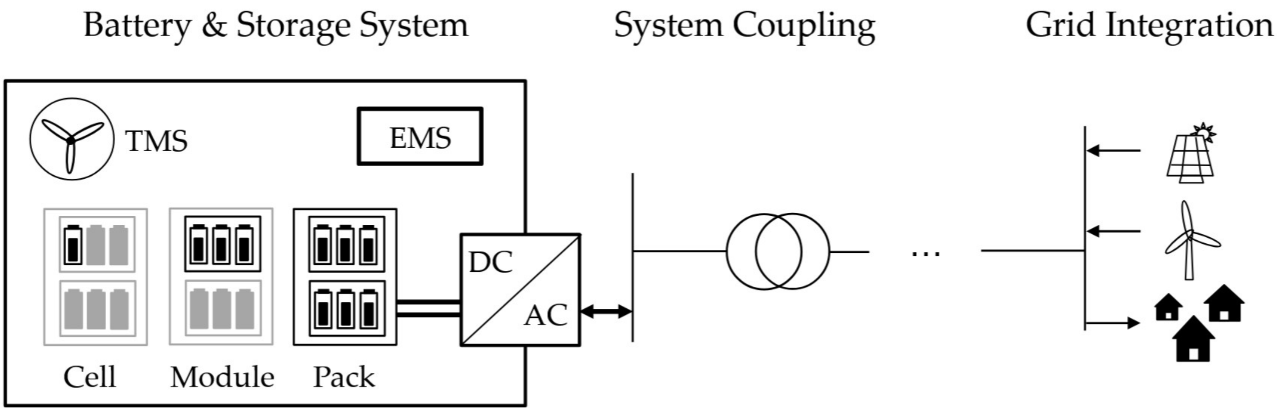
Aging Diagnosis

We developed diagnostic frameworks that combines capacity, resistance, and impedance evolution with advanced analytical tools such as capacity difference and degradation mode analyses. These approaches enable the detection of lithium heterogeneity, identification of reversible aging, and quantification of degradation pathways under realistic operating conditions. Our methods enhance the accuracy and robustness of state-of-health determination across multiple chemistries and testing regimes.

Aging Modelling

We created predictive aging models that unify physical understanding and empirical accuracy. Our parameterized and power-law formulations capture coupled SEI growth, particle cracking, and capacity loss, while dynamic path-aware models incorporate operational history to predict aging and recovery trends. These models significantly improve lifetime forecasting and provide a foundation for adaptive control, system optimization, and the design of longer-lasting energy storage technologies.

Holistic Modeling and Tecno-Economic Analysis of Battery Systems



Researchers

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Publications

A. Parlikar et al., Quantifying the carbon footprint of energy storage applications with an energy system simulation framework — Energy System Network, Energy Conversion and Management, 2024

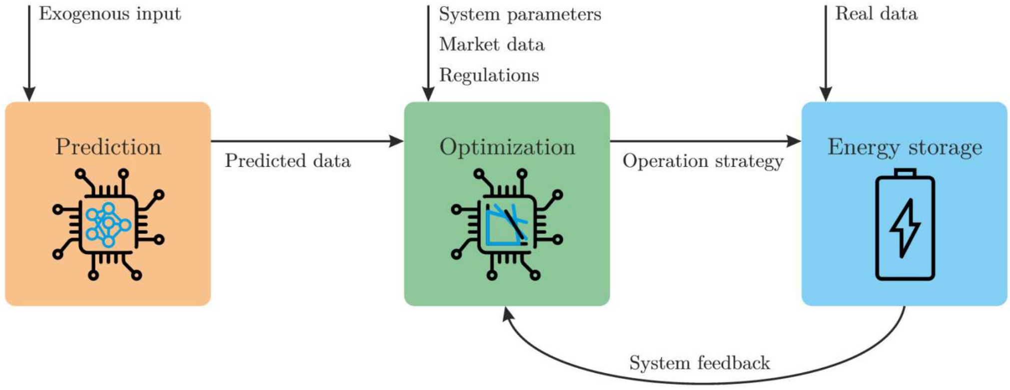
B. Tepe et al., Lithium-ion battery utilization in various modes of e-transportation, eTransportation, 2023

M. Möller et al., SimSES: A holistic simulation framework for modeling and analyzing stationary energy storage systems, Journal of Energy Storage, 2022

Modern lithium-ion batteries provide a wide range of solutions for the sustainable integration of renewable energies, supporting grid stability with stationary storage systems and facilitating the electrification of the transport sector. However, their effective deployment raises several questions: How will these batteries perform in terms of efficiency and lifetime for various applications? Under what conditions will their use yield economic benefits or reduce carbon footprints? How do design choices and operational strategies impact overall system performance? Which battery technologies are best suited for specific applications? Addressing these questions requires models capable of evaluating various scenarios.

SimSES is a time-series-based simulation tool designed for energy storage systems. It employs a holistic approach with a detailed model that not only incorporates a comprehensive battery model but also accounts for conversion efficiency using power electronics and auxiliary consumption related to thermal management. Long-term simulations are conducted to examine the behavior of storage systems across a range of applications. This encompasses the analysis of aging effects, efficiency, and both economic and environmental impacts. The tool models lithium-ion batteries with varying cell chemistries, as well as redox flow batteries and hydrogen storage. Moreover, hybridization of all modeled storage technologies is possible, allowing for the analysis of advanced energy storage systems. SimSES is available as an open-source Python tool and can be integrated with other software platforms.

Optimized Operation of Battery Energy Storage Systems



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Publications

M. Cornejo et al., Data-driven model enhancement of late-life lithium-ion batteries, Future Batteries, 2025

N. Collath et al., Increasing the lifetime profitability of battery energy storage systems through aging aware operation, Applied Energy, 2023

S. Englberger et al., Unlocking the Potential of Battery Storage with the Dynamic Stacking of Multiple Applications, Cell Reports Physical science, 2020

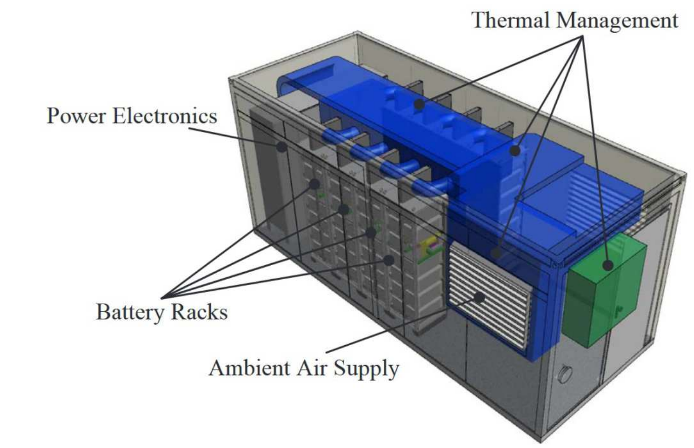
To make the most out of the flexibility of stationary battery storage systems and their successful deployment, it's important to develop intelligent operational strategies that maximize availability, efficiency, lifespan, and economic performance.

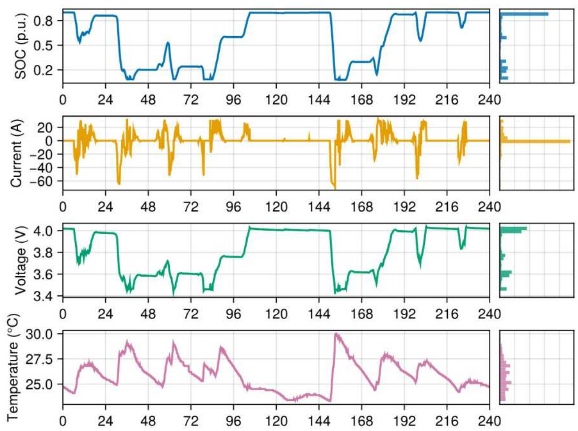
An effective approach is model predictive control, which manages battery systems by predicting future states and optimizing control actions over a rolling horizon. Utilizing prediction models that accurately reflect real system behavior enhances operational efficiency, boosts revenue generation, and ensures reliable adherence to planned power setpoint schedules.

When coupled with a detailed battery degradation model, this framework enables aging-aware operation to maximize profitability throughout its lifespan. A critical component of this approach is accurately weighting degradation costs to balance the risk of premature battery failure with potential revenue loss from underutilization.

Further economic performance can be gained by dynamically stacking multiple applications such as spot market trading, a frequency containment reserve, peak shaving, self-consumption increase. Leveraging synergies allows this strategy to fully exploit the capabilities of the storage system boosting economic efficiency.

Data-Analytics and Battery Digital Twins





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Publications

M. Cornejo et al., Data-driven model enhancement of late-life lithium-ion batteries, Future Batteries, 2025

S. Jablonski et al., Analysis and Characterization of the Energy Consumption in an Electric Bus Fleet, NEIS 2023; Conference on Sustainable Energy Supply and Energy Storage Systems, 2023

D. Kucevic et al., Standard battery energy storage system profiles: Analysis of various applications for stationary energy storage systems using a holistic simulation framework, Journal of Energy Storage, 2020

In today's digital age, data collected from the operation of battery systems is crucial for understanding real operating conditions. Analyzing field data facilitates the identification of typical loading profiles, which in turn enables more realistic testing and benchmarking of battery models.

Data analytics offers valuable insights into the real performance of battery systems across various applications. For instance, our research includes examining how operating conditions influence conversion losses, auxiliary losses and the resulting roundtrip efficiency of large stationary storage systems. Another example is analyzing the data of a fleet of home storage systems to reveal typical battery stress factors and degradation trends. In mobile applications, a study on a fleet of electric buses highlights the significant impact of weather conditions on typical energy consumption per kilometer, particularly emphasizing the effects of climatization.

Furthermore, field data can be leveraged to create individualized models that closely replicate real system behavior, known as digital twins. These models continuously adapt to field measurements, improving monitoring, diagnostics and offering valuable insights for refining operational strategies. Challenges arise from the uncontrollable nature and measurement accuracy limitations from field data, which contrasts with typical laboratory conditions. Thus, it is essential to implement methods that account for uncertainty.

Projects at EES

Collaborative research is highly desired and actively encouraged by the Technical University of Munich. This includes not only collaboration among research groups at each institute and with other TUM institutes, but also within the broader scientific community. The EES, in pursuit of its objective to establish robust knowledge transmission linkages, collaborates with a range of partner universities, research facilities, and corporate partners at the national, European, and global levels.

Completed Projects

QaliBat	Methods for battery quality control	Industry
Pilebi	Charge algorithms fon NiMH batteries	Industry
LiSSi	Investigation into lithium-sulfur technology	BMBF
VisioM	Novel concepts for electric vehicles in urban areas	BMBF
SafeBatt	Active and passive measures for inherently safe batteries	BMBF
ExZellTUM I & II	Excellence center for battery cells at TUM	BMBF
ABattReLife	Second-life investigations	BMWi
ESPEN	Comparison of electrochemical energy storage with other technologies	BMWi
FORELMO	Electric powertrains of tomorrow	BFS
PowerLab	Competence center for hybrid and fully-electric aviation powertrains	StMWi
DriveBattery	Investigations into large-scale and modular battery systems	BMWi
DriveBattery II	Modular battery technology based on parallel/series connection of high-voltage batteries	BMWi
iHEM	Intelligent home energy management system and optimization	BMWi
Spicy	Silicon and polyanionic chemistries, architectures of Li-ion cells for high-energy batteries	EU
MiBZ	Multi-functional intelligent battery cells	BMBF
EffiForm	Efficient cell production for enhanced lifetime, reliability, safety and cost reduction	BMBF
Everlasting	Enhanced range, lifetime and safety through ingenious battery management for electric vehicles	EU
NexHOS	Achievable yields of automotive batteries in stationary applications	Industry
DIMG – EMS	Planning and design of control, prediction and optimization for island microgrids with distributed energy storage systems for reduction of diesel generator usage	BMBF

Completed Projects

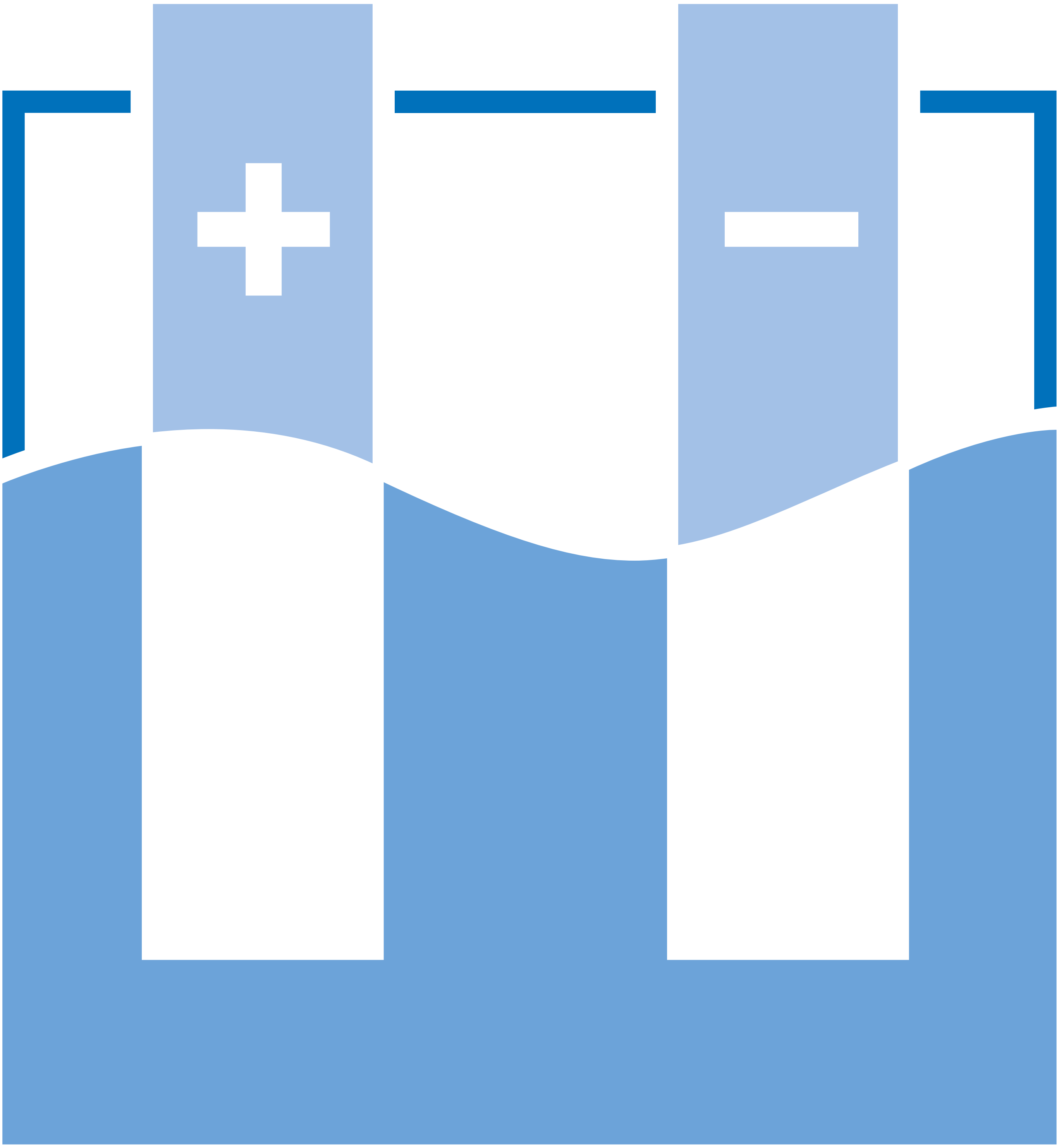
EE-Batt	Local stationary energy storage for using renewable energies efficiently and supporting grid stability	StMWi
INI.TUM	Lithium-Ion cells for application in electric and hybrid commercial vehicles	Industry
Second-Life-Study	Second life concepts for lithium-ion cells from electric vehicles	VDE
HighSafe	Sustainable, environmentally friendly, safe high-energy lithium-ion batteries: materials, cells and modeling	BMBF
ReViSEDBatt	Resonances, vibrations, shocks, external force application and detection methods for lithium-ion batteries	BMWi
Grid-Control-Study	Research questions around grid frequency regulation with energy storage systems	Industry
Cell-Formation-Study	Literature review into cell formation and end-of-line tests for lithium-ion cells	Industry
INI.TUM II	End-of-life tests in battery production with simulation models	Industry
StorageLink	Prediction-based optimization of operating strategies for multi-use of large-scale energy storage systems	StMWi
OparaBatt	Optimal parallel connections of batteries	BFS
open_BEA	Integration and coupling of battery models with open-source grid models	BMWi
KlemA	Classification of electro-mechanical aging of lithium-ion cells	BMBF
InnoCase	Innovative housing concepts for large-format lithium-ion cells	BMBF
ProFeLi	Production techniques for solid-state batteries with lithium-metal anodes	BMBF
iMoBatt	Innovative integrated functional module design for modular battery packs	BMWi
EffSkalBatt	Efficient and scalable battery system design for stationary applications	BMWi
LImeS	Lithium-Ion cells for integration with enhanced sensor technologies	BMBF
SmartB4P	Smart battery control in industrial application scenarios	BFS

Completed Projects

ExZellTUM III	Extension of ExzellTUM II	BMBF
Base.V	Blockchain-based peer-to-peer energy trading with stationary energy storage systems and electric vehicles in the flexible distribution grid	StMWi
FormEL	Investigation of process-quality-interdependencies between the formation process and the end-of-line quality check with the aim of an optimization and functional integration of these final production processes	BMBF
GreenBat2Use	Accompanying project: 2nd Use & Green Battery – GreenBat²Use	BMBF
HighSafe II	Sustainable, environmentally friendly, safe, and high energy density batteries: materials, cells and models	BMBF
NuBase	Novel Investigation Methods for Battery Safety	BMBF
OSLiB	Online dignostic methods of lithium-ion systems in operation	BMBF
BALd	Accelerated aging tests and prognosis of life cycle for Lithium-ion batteries	BMBF
HysKaDi	Investigation of next-generation active materials such as silicon for the anode and lithium- and manganese-rich NCMs for the cathode	BMBF
SimBAS	Simulation of battery cells and applications in storage systems	BMBF
MADAM4Life	Mechanical aging diagnostics with strain gauges, dilation, pressure, acoustics and modal analysis for lifetime prediction	BMBF
accuRate	Fast and accurate evaluation of used lithium-ion batteries	BMWK
CAESAR	Cell chemistry based on silicon anode and Nickel-rich oxide cathode – Facilitation by additives and electrolyte optimization	BMWK
BoLeRO	Research on the aging process of stationary battery energy storage systems with cloud-based methods	BMBF
TUBE	TUM Battery Center of Excellence - foundations and infrastructure for future-oriented battery research along the entire value chain	BMBF
INI.TUM III	Empirical and simulative investigation of pressure propagation within cell modules for the optimization of initial mechanical bracing	Industry

Running Projects

StorageMultiApp	Improving the performance of commercially used energy storage systems	BMWK
KI-M-Bat	AI-based modular battery systems for commercial and grid applications	BFS
ProMoBis	Progressive multi-cell composite concepts for battery systems with integrated sensors	BMWK
BattLifeBoost	Life cycle extension of existing and future stationary battery storage systems through hybrid condition prediction	BMWK
EMADI	Developing an economical measurement and billing system for dynamic wireless power transfer systems	BMWK
HighSafe III	Sustainable, environmentally friendly, safe, and high energy density batteries: materials, cells and models	BMBF
ProHybrid	Production technology for hybrid solid-state batteries with lithium metal anode	BMBF
FB2-SAFE	Thermal safety analysis of sulfide solid-state batteries	BMBF
HEALTHBatt	Efficient and integrated sensor technology for intelligent, sustainable, and safe battery systems	BMWK
ADMirABLE	Artificial intelligence-supported digital twins for modeling aging to optimize the operational management and service life of energy storage systems	BMWK
LIMA	Linking Manufacturing, Quality, and Aging Behavior Variances	BMFTR



Teaching at EES

The Chair of Electrical Energy Storage Technology offers TUM students a variety of lectures, seminars, and practical courses in the field of electrical energy storage. Most of our students are pursuing a degree with the TUM School of Computation, Information, and Technology; however, a large part of our teaching program is also open to students from mechanical engineering, management, and technology programs.

Teaching

Bachelor

Electrical Energy Technology

As mandatory 4th semester lecture in the electrical and computer engineering programm, this lecture covers generation and distribution of electrical energy, energy storage and electrical maschines.

Fundamentals of Electrical Energy Storage

This course covers basic concepts of energy storage. Participants learn about the physics behind a variety of energy storage technologies such as pumped-storage hydroelectricity and compressed air.

Photovoltaic Stand-Alone Systems

How do we combine solar generators with batteries to supply electrical energy in off-grid areas? The working principles of solar generators, charge controllers and lead-acid batteries as well as system dimensioning and economic evaluation are covered.

Master

Battery Storage

Foundational electrochemistry concepts, battery system fundamentals, and methods for evaluating, designing, and comparing electrochemical storage technologies across applications are introduced, while also considering sustainability and economic impacts. Core topics including thermodynamics, kinetics, diffusion, cell design, performance optimization, and major battery chemistries such as lead-acid, alkaline, lithium-ion, sodium-ion, and emerging solid-state systems are covered. The lecture is held twice a year, once in English and once in German language.

Battery System Technology

Battery module and pack design as well as operational aspects of battery systems like charging methods, detection and monitoring of state variables, temperature control and safety precautions.

Battery Applications

This module provides a comprehensive overview of battery technologies and their diverse applications, emphasizing both technical and economic considerations. Participants learn to evaluate different battery types for specific use-cases, analyze performance metrics, and design systems tailored to application needs. The course also covers cost-effectiveness, sustainability, and the social impact of battery systems.

Teaching

Laboratory Courses

Electrical Energy Storage Lab

In this laboratory course, students learn the appropriate handling of battery cells and testing equipment. Fundamental and advanced characterization methods and cell technologies are reviewed in theory and practice.

Modeling of Lithium-Ion Cells Lab

After some specific classes on physico-chemical modeling of lithium-ion batteries, students put theory to practice in an intense, 1-week lab phase, where they learn how to use commercial modeling tools effectively.

Hardware Design for Battery Systems

A deep dive into hardware engineering. Participants develop, design, manufacture and assemble their own microcontroller-based battery management system in small groups. The course is concluded with individual project presentations.

Seminars

Advanced Seminar on Electrochemical Energy Storage

In this seminar, students work on advanced research topics in the field of electrochemical energy storage and learn how to write a scientific paper. The seminar concludes with individual oral presentations in front of peers and EES staff.

Seminar on Energy Storage Technologies

This seminar is exclusively for students of the Master's program Power Engineering (MSPE). Participants learn how to write a scientific paper on an electrical energy storage topic and present their findings in front of peers and researchers.

Efficient Scientific Writing

Participants learn the basics of scientific writing and project management for bachelor's and master's theses. The course also covers effective research and evaluation of literature.

Doctoral Dissertations

A total of fifty-four doctoral theses have already been successfully defended at EES under the supervision of Prof. Dr.-Ing. Andreas Jossen. Most theses combine theoretical, experimental, and modeling/simulation topics to achieve new results within their research field. Since 2017, in addition to monographic theses, cumulative theses have also been accepted. This format can be advantageous to doctoral researchers, as they benefit from early feedback from independent reviewers and can streamline the entire research process and thesis writing.

Lepiorz, Matthias (2015)	Operation-Dependent Aging of Lithium-Ion Batteries in Stationary and Mobile Applications
Schuster, Simon (2016)	Reuse of Automotive Lithium-Ion Batteries: An Assessment from the Cell Aging Perspective
Erhard, Simon (2017)	Multi-Dimensional Electrochemical-Thermal Modeling of Lithium-Ion Batteries
Osswald, Patrick (2017)	Advanced Thermodynamic Measurements as Degradation Tracking Technique in Lithium-Ion Cells
Rieger, Bernhard (2017)	Methodology to Model the Mechanical Behavior of Lithium-Ion Cells
Bauer, Marius (2017)	Electrical and Mechanical Methods for the Detection of Aging Effects in Lithium-Ion Batteries
Huber, Christian (2017)	Phase Change Material in Battery Thermal Management Applications: An Assessment of Efficiency and Safety
Keil, Peter (2017)	Aging of Lithium-Ion Batteries in Electric Vehicles
Kindermann, Frank (2017)	Implications of Current Density Distribution in Lithium-Ion Battery Graphite Anodes on SEI Formation
Brand, Martin (2017)	Behavior of Lithium-Ion Battery Cells and Systems under Dynamic Electric Loads
Koch, Reinhold (2017)	On-line Electrochemical Impedance Spectroscopy for Lithium-Ion Battery Systems: Estimation, Compensation and Avoidance of Measurement Deviations
Campestrini, Christian (2018)	Practical feasibility of Kalman filters for the state estimation of lithium-ion batteries
Martiny, Nora (2018)	Temperature Inhomogeneity in Lithium Ion Pouch Cells

Doctoral Dissertations

Müller, Marcus (2018)	Stationary Lithium-Ion Battery Energy Storage Systems
Naumann, Maik (2018)	Techno-Economic Evaluation of Stationary Battery Energy Storage Systems with Special Consideration of Aging
Wu, Yao (2018)	Non-Invasive Aging Detection Methods of Lithium-Ion Batteries
Arunachala, Raghavendra (2018)	Influence of Cell Size on Performance and Lifetime of Lithium-Ion Batteries
Rumpf, Katharina (2018)	Causes and Effects of Inhomogeneity in Lithium-Ion Battery Modules: A Physicochemical Modelling Approach
Schimpe, Michael (2019)	System Simulation of Utility-Scale Lithium-Ion Battery Energy Storage Systems: An Assessment of the Energy Efficiency, the Battery Degradation, and the Economics of System Operation
von Lüders, Christian (2019)	Experimental and Simulative Investigation of Lithium Plating and Lithium Stripping in Lithium-Ion Cells
Rheinfeld, Alexander (2019)	Performance and Safety of Lithium-Ion Electrodes and Cells: Modeling, Simulation, and Validation at Elevated Temperatures and Currents
Truong, Cong Nam (2019)	Assessment and Optimization of Operating Stationary Battery Storage Systems
Nguyen, Tam (2019)	Degradation of Automotive Lithium Batteries during Mobile and Stationary Load through Big Data Analysis
Makinejad, Kamyar (2019)	Advanced Monitoring Algorithms for Battery Storage Systems in Electric Vehicles
Hofmann, Markus (2020)	Current Distribution in Parallel-Connected Battery Cells
Zilberman, Ilya (2020)	Influence of Initial Cell-to-Cell Variations, Different Self-Discharge and Aging Rates on the Utilization of Large Lithium-Ion Battery Packs
Heil, Thomas (2020)	Equivalent Circuit Models of Diffusion and Charge Transfer in Lithium-Ion Cells

Doctoral Dissertations

Sturm, Johannes (2021)	State-Estimation of Lithium-Ion Batteries using Physicochemical Models and Experimental Characterization Techniques
Wilhelm, Jörn (2021)	Diffraction Analysis of Anode Inhomogeneity in Lithium-Ion Batteries
Berg, Philipp (2021)	Structural Dynamics and Vibration Durability of Lithium-Ion Cells
Kraft, Ludwig (2021)	Enhancing the Performance of Lithium-Ion Cells via New Active Materials and Improved Electrode and Cell Design
Schindler, Markus (2021)	Analyzing the Influence of Differing Charging Profiles and Initial Cell-to-Cell Variations on the Aging Behavior of Lithium-Ion Cells Connected in Parallel
Keil, Jonas (2021)	Linear and Nonlinear Aging of Lithium-Ion Cells
Englberger, Stefan (2022)	Optimized Energy Management for Battery Energy Storage via Multi-Use and Multi-Storage Operation
Kucevic, Daniel (2022)	Simulation of Stationary Lithium-Ion Battery Energy Storage Systems in Urban Distribution Grids
Landinger, Thomas (2022)	Electrochemical Impedance Spectroscopy and Power Line Communications for Automotive Battery Management Systems
Spingler, Franz (2022)	Non-Uniform Physical Properties and Operating Conditions in Lithium-Ion Batteries
Steinhardt, Marco (2022)	Experimental Investigation of the Thermal Conductivity through the Layers of the Electrode-Separator Stack in Lithium-Ion Cells
Schmitt, Julius (2023)	State of Health Estimation for Lithium-Ion Batteries
Ludwig, Sebastian (2023)	Sensorless Internal Temperature Estimation for Lithium-Ion Batteries
Möckl, Maximilian (2023)	Cell-Level Improvement Strategies for Large-Scale Implementation of Hydrogen Production by PEM Water Electrolysis
Zhao, Yulong (2023)	Parameter Estimation of Lithium-ion Batteries using Distribution of Relaxation Times
Spielbauer, Markus (2023)	Crashworthiness of Lithium-Ion Cells: Safety, Detectability and Modeling

Doctoral Dissertations

Schroeder, Benedikt (2024)	Assessment of Vehicle-to-X Concepts Based on Investigations of Stationary and Mobile Battery Storage Applications
Jocher, Philipp (2024)	Parallel Configuration of Battery Cells: Determining Influencing Factors of an Inhomogeneous Current Distribution
Hamar, Jacob (2024)	Data-Driven Battery State Estimation
Moyassari, Erfan (2025)	From Graphite to Silicon-based Anodes in Lithium-Ion Batteries
Collath, Nils (2025)	Aging Aware Operation of Lithium-Ion Based Battery Energy Storage Systems
Parlikar, Anupam (2025)	The Carbon Footprint of Stationary Lithium-Ion Battery Energy Storage Systems
Karger, Alexander (2025)	Modeling the Degradation of Lithium-Ion Batteries during Calendar and Cycle Aging
Aufschläger, Andreas (2025)	Characterization of Mechanical and Thermal Operating Conditions of Lithium-Ion Batteries Regarding the Fast-Charging Behavior, Cycle-Life, and Swelling
Roth, Thomas (2025)	Lateral Concentration Gradients in Lithium-Ion Batteries
Streck, Luiza (2025)	Detection and Analysis of Side Reactions for Li-Ion and Na-Ion Batteries
Scheller, Maximilian (2025)	Physicochemical Modeling for Performance Evaluation and Design Optimization: Advancing from Liquid- to Solid-State Li-Ion Batteries

Highly Cited Publications

Lithium-Ion Battery Storage for the Grid — A Review of Stationary Battery Storage System Design Tailored for Applications in Modern Power Grids

H. C. Hesse, M. Schimpe, D. Kucevic and A. Jossen, Energies, 2017

This review paper serves as a guideline for the best choice of battery technology, system design and operation for lithium-ion based storage systems to match a specific system application. It provides an overview of lithium-ion battery technologies and their characteristics with respect to performance and aging as well as state-of-the-art system design, which is analysed in detail based on an evaluation of real-world projects. The review also provides a summary of typical storage system applications and publicly available modelling tools for technical and economic analysis. Optimization approaches for system sizing, positioning, and dispatch operation are also evaluated.

Calendar Aging of Lithium-Ion Batteries

P. Keil, S. F. Schuster, J. Wilhelm, J. Travi, A. Hauser, R. C. Karl and A. Jossen, Journal of The Electrochemical Society, 2016

Calendar aging of lithium-ion batteries is strongly influenced by anode potential. This paper presents an experimental calendar aging study, conducted using three different lithium-ion chemistries. A special feature of this study is its high resolution in the states of charge (SoC), at which the cells were stored. The 16 SoCs from 0 to 100% demonstrate that calendar aging does not increase steadily with the SoC. Instead, there is a strong correlation between the capacity fade and the potential of the graphite anode: lower anode potentials aggravate the degradation. To maximize battery life, the times spent at the region of lowest anode potential should be minimized.

Nonlinear aging characteristics of lithium-ion cells under different operational conditions

S. F. Schuster, T. Bach, E. Fleder, J. Müller, M. Brand, G. Sextl and A. Jossen, Journal of Energy Storage, 2015

Although the reuse of aged lithium-ion batteries has been investigated by many authors, there is a lack of understanding of the dynamics of aging in such batteries. Despite the linear relationship between cyclic capacity loss to charge throughput, a transition to nonlinear aging progression is observed after an approximate loss of capacity of 20%. Its appearance is accelerated by high charging rates and voltages as well as low temperatures. SEM images reveal thick surface films at the anode, suggesting that Solid Electrolyte Interphase (SEI) growth is the dominant aging mechanism before the turning point is reached. Afterwards, lithium plating occurs even at moderate temperatures and charging rates. An optimized operational strategy could extend the life of lithium-ion batteries by retarding the appearance of the turning point.

Highly Cited Publications

Charging protocols for lithium-ion batteries and their impact on cycle life—An experimental study with different 18650 high-power cells

P. Keil and A. Jossen, Journal of Energy Storage, 2016

This paper assesses charging strategies for lithium-ion batteries and presents experimental findings from tests on three different cell types. Results show that charging currents have a significant impact on cycle life, often exceeding the effect of discharging currents. High currents can degrade cycle life at both high and low states of charge. Pulse charging, however, does not reduce cycle life if pulses are short and average current and voltage remain low. Pulses under 1 second yield a similar cycle life to continuous charging. The study also examines how charging parameters affect capacity utilization, charging time, and efficiency, thereby aiding in the development of optimized protocols.

Lithium plating in lithium-ion batteries at sub-ambient temperatures investigated by in situ neutron diffraction

V. Zinth, C. von Lüders, M. Hofmann, J. Hattendorff, I. Buchberger, S. Erhard, J. Rebelo-Kornmeier, A. Jossen and R. Gilles, Journal of Power Sources, 2014

Lithium plating in $LiNi_{1/3}Mn_{1/3}Co_{1/3}O$ / graphite cells at sub-ambient temperatures was studied by neutron diffraction. Lithium plating consumes a portion of the active lithium in the cell. As a result, the degree of graphite lithiation during and after charge is lower. Comparison of graphite lithiation after a fast charging cycle with a much slower reference cycle revealed a lower degree of graphite lithiation in the first case, as more LiC12 and less LiC6 were present. If the cell is subjected to a rest period after charge, a gradual transformation of the remaining LiC12 to LiC6 can be observed, indicating lithium diffusion into the graphite. During the rest period, the degree of graphite lithiation can be estimated to increase by 17%, indicating that at least 17% of the active lithium is involved in lithium plating.

Lithium-ion cell-to-cell variation during battery electric vehicle operation

S. F. Schuster, M. J. Brand, P. Berg, M. Gleissenberger and A. Jossen, Journal of Power Sources, 2015

A total of 484 new and 1908 aged lithium-ion cells from two identical battery electric vehicles were analyzed for capacity and impedance to study distribution changes with aging. Aging shifts cell parameter distributions from normal to left-skewed Weibull, with increased variation and more outliers, typically showing reduced capacity. Operational data was examined to identify causes, but no link to temperature gradients or balancing issues was found. The random nature of abnormal cells suggests the need for battery management systems to reliably detect outliers and balance state-of-charge deviations to ensure safe storage operation.

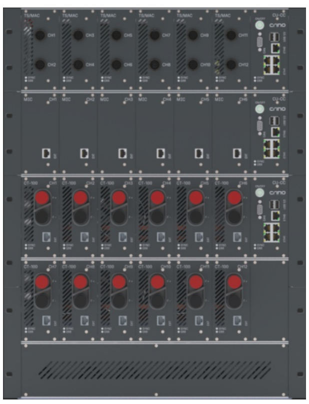
Spin Offs

Li.plus GmbH

Providing an innovative approach for industrial battery testing, since 2016 Li.plus has introduced its microinvasive pulse-based battery testing hardware in automotive battery production lines worldwide. Li.plus devices are used wherever complex and valuable battery systems need to be tested for performance, reliability and safety. By applying a specific patented current pulse and recording the specimen's voltage response, all relevant parameters of a battery's equivalent circuit network can be analytically obtained within fractions of a second. The high-def data recorded allows to be calculated across multiple stages of the value chain, providing customers with complete transparency, not only in terms of product but also process quality. The underlying principle is universally applicable to all cell formats and cell chemistries, with test devices ranging from the inspection of mere electrical joints, e.g. weld seams, over single cells to large-scale battery packs. Regardless of the specific task, the test itself always remains fast, precise and simple.
Complementary to its patented test methodology, Li.plus offers its customers numerous solutions for battery contacting and special purpose testing as well as support in designing state of the art inline-test-stations.

Battery Dynamics GmbH

Battery Dynamics was founded in 2018 by Dr. Peter Keil and develops high resolution battery testers. The testers provide an outstanding long-term precision in current measurements and ampere-hour integration. This enables high precision coulometry measurements, which identify even small amounts of aging side-reactions, such as lithium plating. Moreover, the high voltage resolution of the testers makes them ideal for voltage relaxation and entropy measurements.
Battery Dynamics also offers battery testing and consulting services to help engineers and researchers better understand the degradation behavior of their lithium-ion batteries and optimize the lifetime of their battery systems.



crino GmbH

Crino GmbH specializes in precise thermal and electrical measurement instruments as well as customized battery testing solutions for R&D and cell manufacturing. The product portfolio includes isothermal microcalorimeters, cell-level active cooling systems, and high-precision battery testers. Standardized interfaces enable seamless integration of third-party sensors and actuators, ensuring flexible system configuration.
The platform supports machine learning–based analysis for long-term test operations, proactively detecting issues in both the device under test and the test bench.
In addition, Crino offers services for parameterization and validation of thermal and electrical cell models, as well as specialized cell aging experiments under application-oriented conditions.

Spin Offs

STABL Energy GmbH

STABL Energy offers battery storage solutions for industry based on a unique, modular multilevel inverter technology that redefines efficiency, reliability, and sustainability. At the heart of the technology is a decentralized inverter architecture that individually controls and monitors each battery module. This allows batteries with different states of health to be optimally combined and fully utilized, without any central weak points. Even with partial degradation, the performance of the overall system remains stable, and individual modules can be replaced during operation. This architecture enables the economical use of zero- and second-life batteries, reduces material consumption and emissions, and simultaneously increases the availability and life span of the systems. With this solution, STABL Energy is enabling a sustainable and stable energy future, actively contributing to the integration of renewable energies into the power grid.

STABL

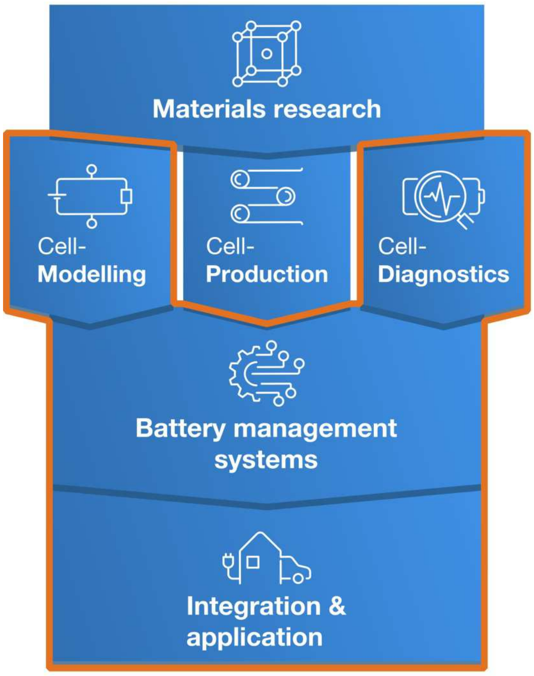
Amperiox battery GmbH

Amperiox Battery GmbH is a spin-off from the Chair of Electrical Energy Storage Technology at the Technical University of Munich (TUM). The company focuses on both standard and highly specialized measurement and analysis services for lithium-ion cells and modules. Amperiox operates over 300 test channels ranging from 5 A to 800 A and employs proprietary test benches as well as climate chambers capable of simulating temperatures from –40 °C to +80 °C. This setup enables realistic testing of various cell formats — from cylindrical to pouch and prismatic cells. The service portfolio covers three main areas: prototype benchmarking (e.g. capacity, DCIR, OCV, swelling-force), life-cycle validation (cyclic and calendaric aging, real-world load profiles, actively controlled fast-charging profiles), as well as specialized testing for active cell temperature management and mechanical compression of lithium-ion batteries.

With this specialization, the company plays a key role in Germany's battery development and testing landscape — particularly in the context of the energy transition and the growing demand for reliable energy storage systems.

AMPERIOX BATTERY

Battery Research at TUM



PARTNER INSTITUTES AT TUM

Chair of Electrical Energy Storage Technology

Professorship of Physics of Energy Conversion and Storage

Chair of Inorganic Chemistry with Focus on Novel Materials

Chair of Technical Electrochemistry

Chair of Functional Materials

Professorship of Synthesis and Characterization of Innovative Materials

Wacker Chair of Macromolecular Chemistry

Professorship of Solid-State Electrolytes

Chair of Digital Catalysis

Chair of Electron Microscopy with research emphasis on Energy Materials

Institute for Machine Tools and Industrial Management

Chair of Automotive Technology

Institute for Computational Mechanics

Research Neutron Source Heinz Maier-Leibnitz (FRM II), Group of Advanced Materials

TUMint.Energy Research GmbH

The TUM Venture Labs - The Battery Startup Incubator (BaStI)

In addition to the EES, battery research at the Technical University of Munich (TUM) is aggregated within the interdisciplinary TUM.Battery network. This aims to present the expertise and research activities taking place at TUM in the field of battery research to the global community at large.

Battery systems across their entire value chain are researched in an interdisciplinary association of eight different chairs and two institutes with thirteen professors and more than 100 scientists from different disciplines at the Technical University of Munich. For the development of various state-of-the-art and future storage technologies, interdisciplinary research activities range from the fundamental materials research at the atomic level undertaken in the natural sciences to the integration of lithium-ion cells and their applications from a user's perspective. The findings of the electrochemists and electrical engineers relating to cell development and process technologies are integrated into production technologies developed by mechanical engineers. Once in operation, battery management systems supervise interconnected lithium-ion cells. The transfer of know-how from research to application is facilitated through strong networks with industrial, economic, and political partners. Further information can be found on the websites of the individual partners listed on the left to find out more about their respective research areas.

The EES focuses on cell modeling, cell diagnostics, battery management systems, as well as integration and applications. For cell modeling, detailed, spatially resolved physicochemical, thermal, and mechanical models, as well as aging models and models to describe multi-cellular systems, are parameterized, simulated, and validated. Cell diagnostics at EES attempts to quantify and ensure safe and reliable operation using methods including state-of-charge determination and cell balancing systems. The chair optimizes intelligent battery management systems to address electrical, thermal, and mechanical issues that arise in interconnected lithium-ion cells. The integration of stationary energy storage in power supply systems covers a range of topics from network connection topology, optimization of operating, and control strategies to economic and ecological considerations.

For further information, visit
www.mep.tum.de/mep/energy-systems/battery

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