

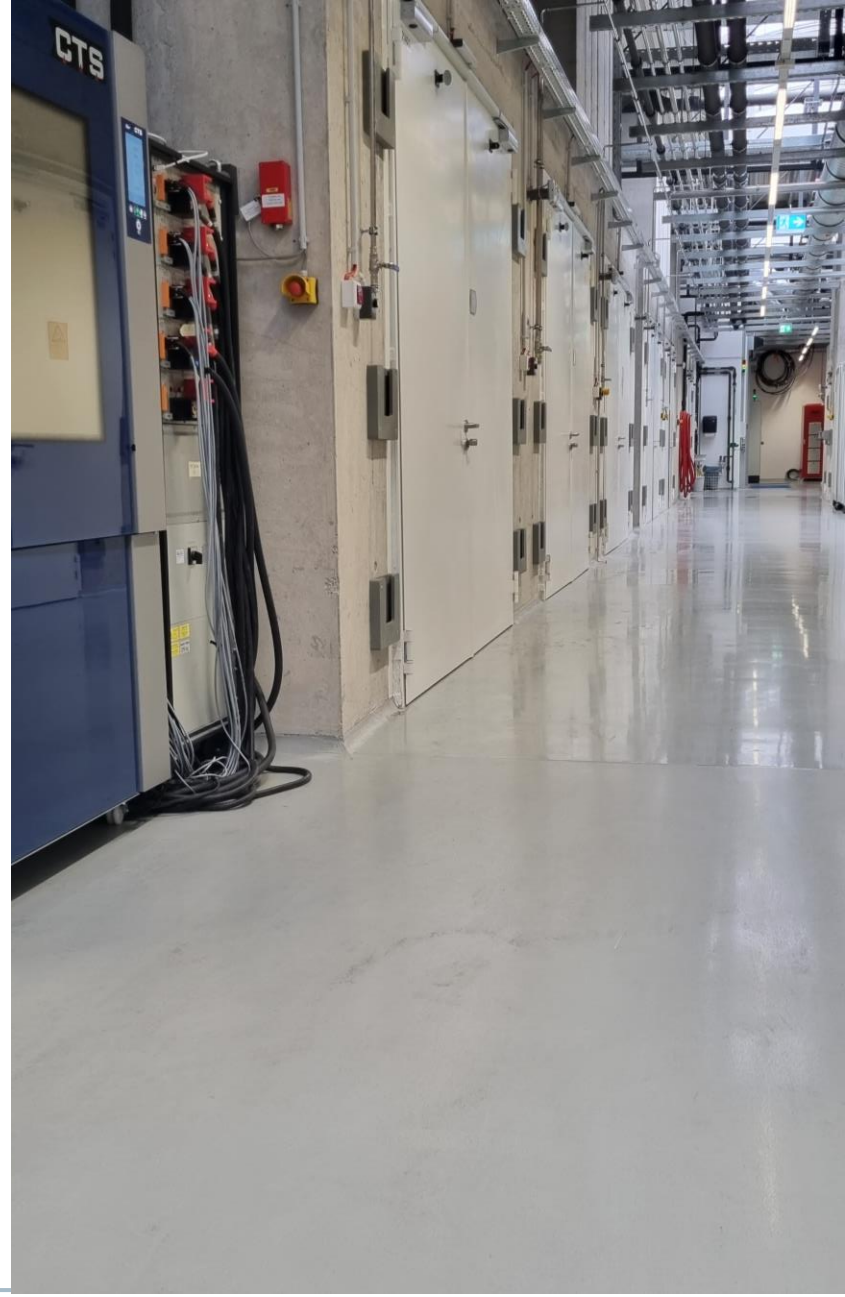
Dr. Moritz Kroll
6th Fraunhofer Innovation and Technology Platform (FIT)
Bangalore, 07 September 2023

Scientific Testing of Battery Cells and Systems: Insights from Comprehensive Laboratory Investigations

Scientific Testing of Battery Cells and Systems

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1. Introduction

Global Battery Market

- The **global market** for lithium-ion batteries (LIBs) is **experiencing remarkable growth**.
- In the **EU**, there's a mandate **from 2035** onwards to **suppress** vehicles with internal **combustion engines**.
- German automobile manufacturers are actively transitioning their fleets to battery-electric propulsion.
- This shift is driving the establishment of **numerous gigafactories in Germany and Europe**, demanding significant testing capacities for consistent quality control.
- LIBs are subject to **extremely short innovation cycles**, necessitating regular and comprehensive certifications.
- Furthermore, as battery modules are increasingly being returned, reliable methods for **second-life battery qualification** are crucial.

Consequently, Battery Testing has never been more critical.

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2. Battery Safety

Importance of Battery Testing

- Batteries store **vast amounts of energy**
- During transportation or operation, they are exposed to **extreme stresses** such as significant temperature fluctuations, vibrations, and even accidents involving deformation.
- An uncontrolled release of stored energy poses a **significant threat** to people and structures.
- Typically, batteries contain flammable liquid electrolytes, and local overheating, often triggered by internal short circuits, can lead to ignition.
- As heat increases, a phase transition occurs in the cathode material, releasing oxygen and intensifying the reaction, resulting in what is known as **Thermal Runaway**.
- This can **propagate** to adjacent cells, leading to severe challenges in containment and mitigation.



Source: https://www.youtube.com/watch?v=UsuYxFBHsiQ

Therefore, Testing and realistically simulating extreme scenarios are of paramount importance in enhancing LIB safety and preserving trust in this vital technology.

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3. Testing Methods

Performance Testing

- Battery characterization is necessary at various stages of their life cycle: **post-production, during use, and for second-life qualification**.
- Testing can be categorized into three key areas:
  - Performance Testing
  - Electrical Abuse Testing
  - Mechanical Abuse Testing
- Performance Testing aims to replicate **aging scenarios**, typically involving cyclic aging.
- It assesses the effects of **calendar aging** at various states of charge.
  - **Accelerated aging** can be achieved through experiments **high states of charge and high temperatures.**
  - **Low temperatures and high charging** currents can also exacerbate aging effects, such as Lithium-Plating.

To replicate field conditions as closely as possible in the laboratory, intelligent test plan design is essential. At the Fraunhofer ISE, we have accumulated extensive experience through various industrial projects.



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3. Testing Methods

Electrical Abuse Testing

- To **adequately simulate the behavior of battery cells, modules, and systems** in extreme situations, batteries must undergo Abuse Tests with stringent safety precautions.
- These encompass **Electrical Abuse Tests**, examining behavior under external short circuits, overcharging, or deep discharging of cells, among others.
- The behavior of battery cells in Abuse Tests is categorized using the **Hazard levels**



Propagation experiment

1. Thermal Runaway is triggered by heating.
2. High temperature leads to decomposition of the liquid electrolyte and venting.
3. A persistent rise in temperature leads to the point of no return, marked by a significant venting event and an escalating phenomenon known as thermal runaway.

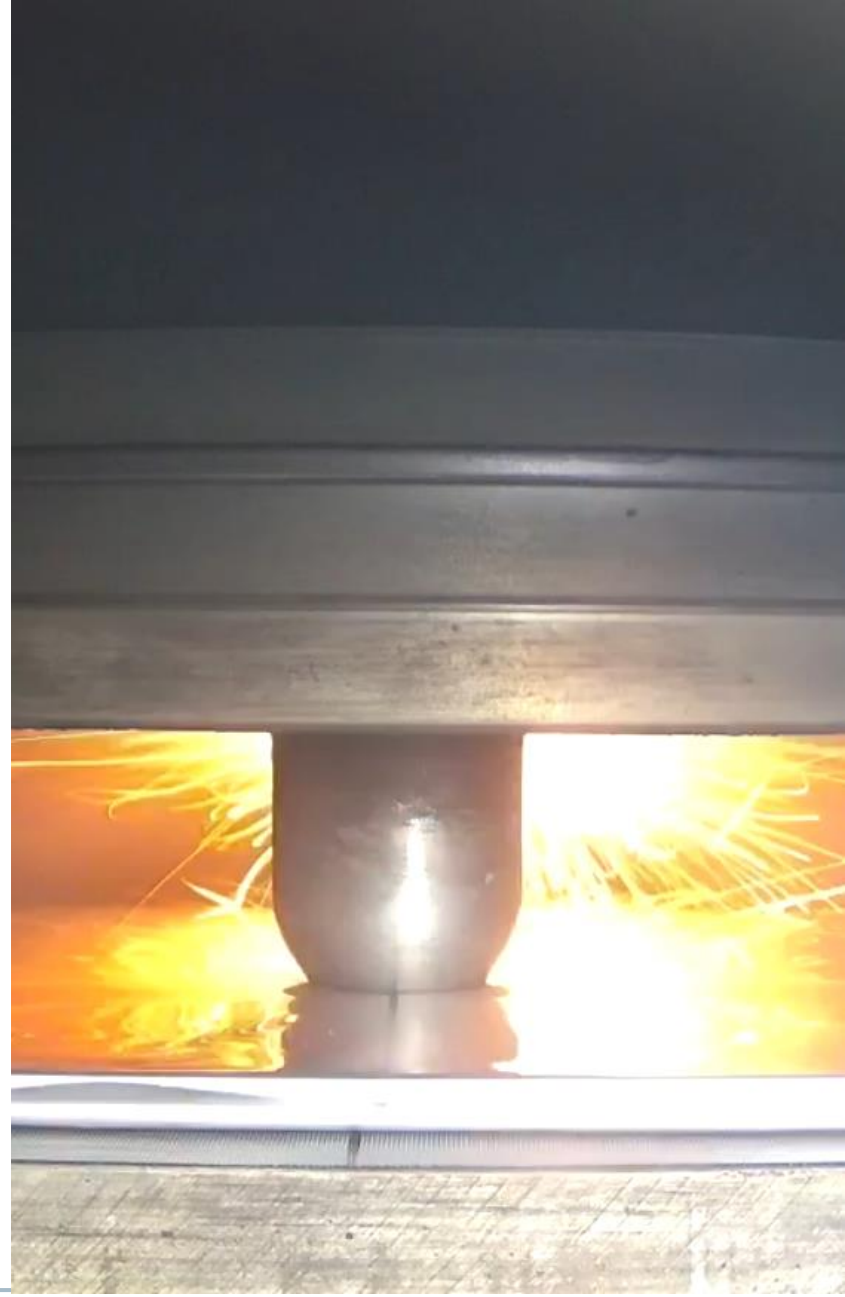
Hazard Level	Description
0	No effect
1	Passive protection devices activated
2	Defect / damage
3	Leakage
4	Venting
5	Fire or flame
6	Rupture
7	Explosion

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3. Testing Methods

Mechanical Abuse Testing

- Simulating mechanical **external influences** such as vibration, shocks, and even crushes during accidents or drop tests is significantly more complex.
- Each time, the **most extreme realistic scenario** should be considered.
- All these tests represent extreme misuse, **necessitating strict safety precautions** during execution to mitigate risks.
- These can include serious **fires, even explosions, as well as sparks, arcs, and toxic gases.**



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4. Test Norms vs. Individual Test Plans

- Various applications of battery storage are guided by **numerous European, US, and Chinese test standards**.
- The most renowned test standard is the **UN38.3 transport test**, encompassing altitude simulation, temperature shock, vibration, shock, external short circuit, crush, overcharge, and deep discharge.
- In the **automotive sector**, manufacturers adhere to the **strictest norm** or exceed it.
  - For example, the Chinese standard GB 38031 mandates a **5-minute pre-warning** time for vehicle occupants in case of a critical event involving the battery.
  - Simultaneously, we notice that automakers like VW or Mercedes develop their **own testing standards**, often with considerably stricter criteria for the qualification of their battery systems.

At Fraunhofer, we regularly collaborate with our customers to develop customized testing procedures, enhancing safety standards. Furthermore, through disassembly, examination, including post-mortem investigations, we can uncover the reasons behind malfunctions.



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Battery Research Center at Fraunhofer ISE

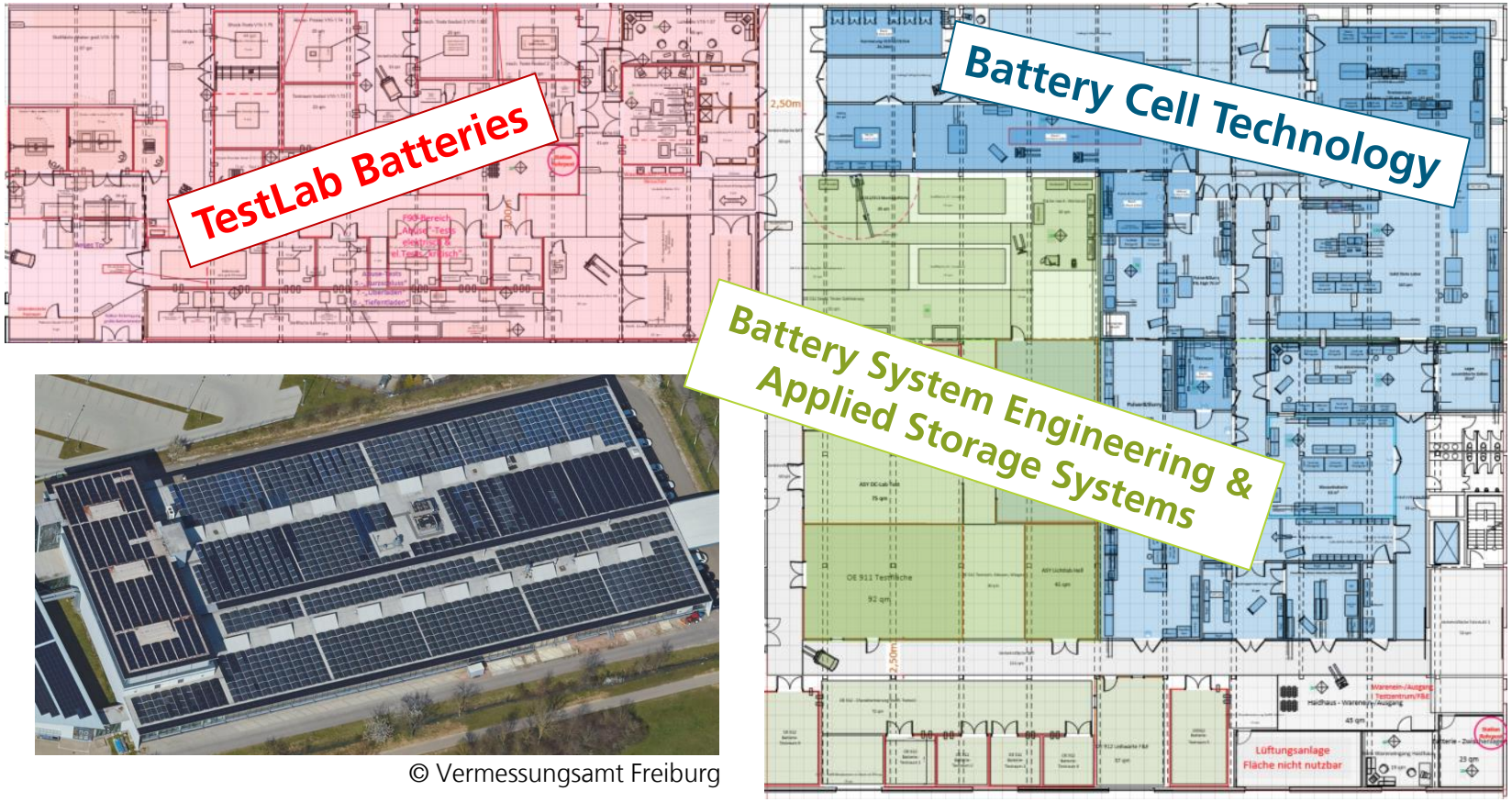
Planned, built and launched from 2018 until today

Battery Research Center at Fraunhofer ISE

- Total area of about 5500 m²

The laboratories cover important steps along the battery value chain:

- Development of novel materials and alternative battery concepts
- Innovative production processes
- Formation
- Battery system technology
- Optimized operation management
- Modeling and simulation
- Testing and certification



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Department Electrical Energy Storage

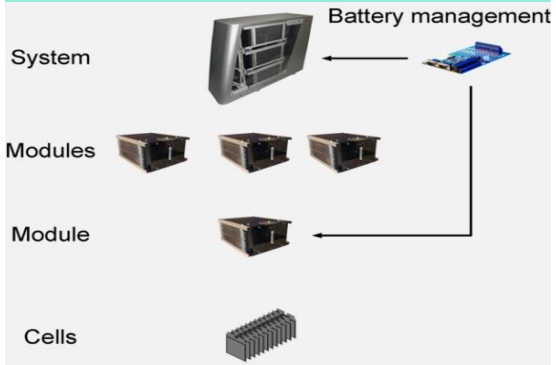
Overview – Research, Development and Services

Battery Cell Technology
materials, architecture, production



- Development and characterization of materials and battery cells
- Development of process technologies
- Aqueous systems for stationary energy storage
- Lithium-ion battery cells
- Solid state battery cells
- Technical and economical analysis
- Life cycle analysis

Battery Engineering
from cells to systems



- Cell formation
- Cell and system characterization
- Ageing and performance scrutiny
- System design and engineering
- Thermal management
- Battery management
- Algorithms for state estimation and lifetime prediction
- Optimized charging and operating control strategies

Applied Storage Systems
system design, integration and quality assurance



- Realization of lighthouse projects
- Business case development
- Consulting during complete life cycle of storage projects
- System modelling, analysis and optimized system design
- Simulation based storage sizing
- Energy management systems
- Technical due diligence: Site inspection, testing and monitoring

TestLab Batteries
electrical, thermal, mechanical testing



- Ageing: calendric and cyclic
- Safety: components and systems including functional safety
- Reliability: consideration of operating conditions and system behavior with aged components
- Performance: efficiency and effectiveness
- End-of-line quality control for cell production

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5. Battery TestLab at Fraunhofer ISE, Freiburg, Germany

- Since **2022**, Fraunhofer ISE has operated a battery test center on approximately 1200 m^2 of laboratory space.
- Here, we **conduct performance tests, electrical** and **mechanical abuse tests**, as well as **examinations** and **post-mortem analyses**.
- Capability to investigate batteries in **all common form factors** (coin, cylindrical, prismatic, pouch), from **cells to modules**, and even systems (1000 V, 1.5 t).
- With nearly 20 **fire and explosion-protected rooms** and experienced laboratory engineers at our disposal, we work with our customers to develop test plans and **scientifically investigate battery safety questions**.
- This includes research into propagation-inhibiting materials or determining the causes of field failures.
- Moreover, we actively share our laboratory setup experiences with customers worldwide and are open to collaborations.

If interested, please don't hesitate to contact us.



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Our Expertise

Building Battery Laboratories

Our experts have built up the battery research center in Freiburg in recent years. Our team possesses a wealth of experience in every aspect of establishing and operating battery laboratories.

Determining Project Scope

- We excel in precisely defining the scope and objectives of battery laboratory projects, aligning them with specific research and development goals.

Facility Design and Planning

- Our team is skilled in designing battery research labs from inception to execution, ensuring optimal layouts for efficient and safe operations.

Seamless Laboratory Commissioning

- With our hands-on experience, we guarantee smooth and successful commissioning of battery research facilities, minimizing downtime and maximizing productivity.

Subject Matter Experts

- Along each stage of the value chain, we have specialized experts who understand the unique requirements of individual laboratories

Bridging Science and Industry

- Our profound understanding of the market allows us to anticipate future developments and align our research strategies with industry demands effectively.

Addressing Industry Needs

- We comprehensively understand the diverse requirements of various industries, covering applications from cells to modules and complete battery systems.

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6. Future Directions and Conclusions

- The **battery market is highly dynamic**, continuously introducing adapted product series with new battery chemistry.
- **New technologies** like All-Solid-State Batteries, silicon-containing anodes, and Sodium-Ion Batteries are **investigated at Fraunhofer ISE**
- **Aqueous Zinc-ion systems** are also increasingly in focus in the **stationary storage sector**.
- **Each new battery generation must prove its safety and reliability anew.**
- This necessitates a precise **understanding of battery chemistry, and testing standards** must be continually developed.
- Only through **scientific investigations** of battery **failures can these be understood**, leading to insights for new safety measures.
- Routines must be established to reliably and safely qualify used batteries for **second-life** approaches.



Fraunhofer ISE actively works on this and fulfills its role as a link between applied research and industrial development, contributing to a sustainable circular economy.

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