

MATERIALS REPORT

24/25

Editorial



Dear Readers,

In October 2024, I took over as director of Fraunhofer ISC. During my first few months in this role, it was particularly important to me to get to know the people, expertise, and research areas at our institute. I quickly realized the extraordinary depth of expertise that comes together at Fraunhofer ISC. Our employees are deeply committed to developing solutions for some of the most pressing challenges of our time—and that is precisely where our institute’s particular strength lies.

I would also like to express my gratitude to my predecessor, Prof. Dr. Gerhard Sextl, as well as to Prof. Dr. Friedrich Raether. Both have had a decisive influence on Fraunhofer ISC and its research landscape over many years and have laid an important foundation for future development.

The world faces enormous challenges: climate change, resource scarcity, geopolitical uncertainties, and the transformation of industrial value chains require new technological solutions. Materials play a key role in this. They enable innovations in energy, mobility, health, electronics, and many other areas of our daily lives.

This gives Fraunhofer ISC a clear mission: We develop sustainable chemical materials and processes and bring them into practical application. Our goal is not only to gain scientific insights but to translate these into concrete solutions together with our partners from industry and business. Research delivers its greatest benefit when it finds its way out of the laboratory and into products, processes, and technologies that make a real difference.

To fulfill this mission, we are currently sharpening the institute’s strategic profile. The focus is on sustainable chemistry and the accelerated development of new materials through digitalization, automation, and artificial

intelligence. We are convinced that combining excellent materials research with data-driven methods and modern development processes will be crucial for bringing innovations to application faster, more efficiently, and more sustainably.

The articles in this annual report impressively demonstrate the diversity of research activities at Fraunhofer ISC. They document scientific excellence, successful collaboration with partners, and our commitment to achieving concrete societal and economic impact through research.

My heartfelt thanks go to all Fraunhofer ISC employees for their dedication, creativity, and passion for research and innovation. I would also like to thank our partners from industry, science, politics, and society for their trust and close collaboration.

Looking ahead to 2026, we have a very special anniversary coming up: 100 years of the Institute for Silicate Research. This anniversary fills us with pride, but above all with a sense of responsibility. It reminds us that sustainable progress is based on scientific excellence, innovative strength, and the courage to embrace change. We intend to continue living up to this standard in the future—with sustainable material solutions and technologies that contribute to a successful and future-proof industry.

Sincerely,

A handwritten signature in black ink, reading "Miriam Unterlass".

Prof. Dr. Miriam Unterlass
Director
Fraunhofer ISC

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Outlook Industry

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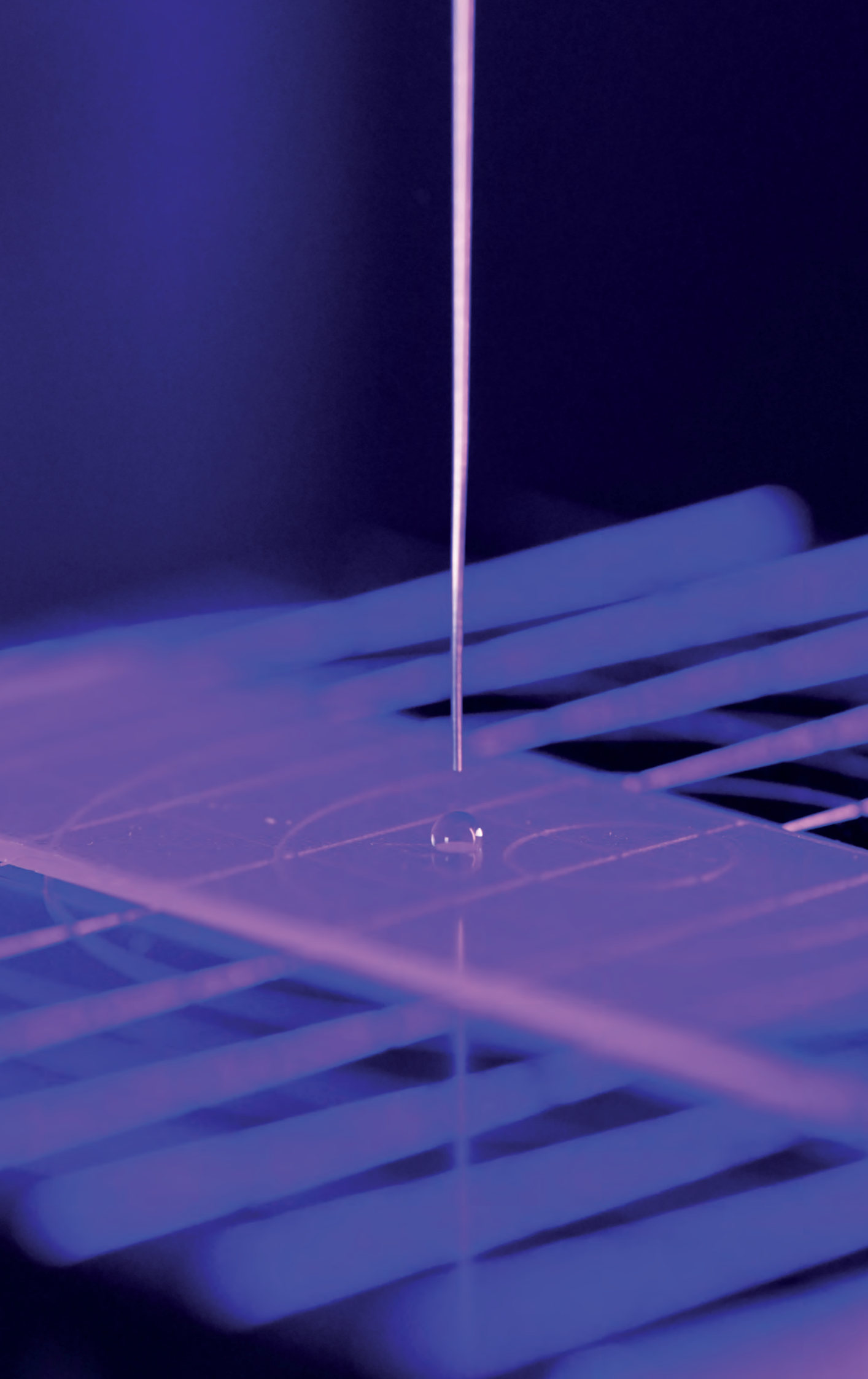
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Organizational chart

The Fraunhofer ISC, headquartered in Würzburg, brings together several specialized institutions under one roof: The Fraunhofer Center for High Temperature Materials and Design (HTL) in Bayreuth focuses on innovative materials for high-temperature applications, while the Fraunhofer Translational Center for Regenerative Therapies (TLZ-RT) in Würzburg develops pioneering materials for medicine. Additionally, the branch office at Kloster Bronnbach near Wertheim houses the Center for Device Development (CeDeD) as well as the International Convention Center for Cultural Heritage Preservation (IZKK), both of which enhance the ISC's portfolio with specialized competencies.



Figures | Data | Facts

Personnel

As of December 31, 2025, Fraunhofer ISC employed 336 staff members. The number of staff members has thus decreased slightly compared to previous years.



Finance

In fiscal year 2024, the institute’s total budget amounted to €33.9 million. Of this amount, €12.7 million came from institutional funding. Revenue from contract research amounted to €21.2 million, underscoring the high relevance of application-oriented research for industry and project partners. In 2025, the budget decreased to €32.8 million, reflecting the difficult overall economic situation.



Invention disclosures – publications

During the 2024/2025 reporting period, seven patents were granted and 20 invention disclosures were filed by Fraunhofer ISC. Overall, the institute maintains a relatively constant number of approximately 150 patent families—the number of new applications filed each year roughly balances out the number of patent families abandoned for economic and/or strategic reasons.



Furthermore, more than 130 scientific publications during the same period demonstrate the diversity of our research activities. A comprehensive overview of scientific publications and granted patents can be found on our website.



Advisory Board

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MR DR. STEFAN WIMBAUER
Head of Department 43
Bavarian Ministry of Economic Affairs, Regional
Development and Energy, München

DR. JÖRG ZIEGLER
Novartis Pharma GmbH, Nürnberg

NEWLY APPOINTED BOARD MEMBERS

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Julius-Maximilians-Universität, Würzburg

PROF. DR. MATTHIAS FROSCH
Dean of the Faculty of Medicine
Julius-Maximilians-Universität, Würzburg

PERMANENT GUEST IN THE ADVISORY BOARD

PROF. DR. PETER GUMBSCH
Chairman of the Fraunhofer MATERIALS Network



**PRO
JECTS**

"Our success is based on the diversity and enthusiasm of our employees."

Prof. Dr. Miriam Unterlass

Sustainability at Fraunhofer ISC

Social Responsibility

As a family-friendly employer, Fraunhofer ISC offers flexible working hours and a wide range of programs designed to help employees balance work and family life. The institute is also committed to promoting science and technology education among children and young people. As of the end of 2025, Fraunhofer ISC employed 336 people. This includes 117 scientific and 67 technical staff in the research divisions, as well as 108 employees in infrastructure and administration, in addition to doctoral candidates, apprentices, research assistants, and interns.

The part-time employment rate was 46%. Training and continuing education are central elements of the institute's human resources policy, with apprenticeships in various professions and annual collaborative projects. Fraunhofer ISC actively promotes equal opportunity, particularly through the TALENTA career program, which aims to increase the proportion of women in leadership positions. In 2025, women accounted for 49.7% of the workforce, while the proportion of women in leadership positions stood at 32.7%. The institute is also committed to diversity in the workplace and has been a signatory to the Diversity Charter since 2011.

Corporate Responsibility

Fraunhofer ISC has defined a clear mission: The institute develops sustainable, chemistry-based materials and translates them into practical applications. Through research and innovation, Fraunhofer ISC contributes to solving societal and industrial challenges.

Fraunhofer Commitment to Universal Sustainability Principles

Since joining the UN Global Compact in 2017, the Fraunhofer Gesellschaft has committed to promoting ten universal sustainability principles. The Fraunhofer Sustainability Network is also active in this regard, comprising 26 institutes dedicated to sustainable development and corporate sustainability aspects. Fraunhofer ISC is part of this network. With the implementation of the Supply Chain Due Diligence Act in 2023, Fraunhofer ISC has established a human rights- and environmental protection-compliant risk management system and is working on sustainable procurement management.

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Fraunhofer ISC makes a significant contribution to sustainable development and the UN Sustainable Development Goals. Through a clear commitment to corporate responsibility and a broad research spectrum, solutions for future challenges are developed, and the transition to a sustainable society is actively supported.

Research and Sustainability

Fraunhofer ISC has built a comprehensive research portfolio that supports the transition from fossil resources to sustainable material cycles. All research areas contribute to sustainability through resource conservation, the use of renewable raw materials, and decarbonization. Particularly, recycling valuable raw materials and searching for sustainable alternatives are of central importance.

The UN Agenda 2030 and the 17 Sustainable Development Goals (SDGs) serve as a guiding framework for the activities. Fraunhofer ISC contributes to a number of UN sustainability goals through its projects. The focal points of our materials development are SDG 3 (Good Health and Well-Being), SDG 7 (Affordable and Clean Energy), SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action), as well as SDG 14 and SDG 15 (Sustainable Use of Terrestrial and Marine Resources).

On the following page, we will present five exemplary projects focused on sustainability.



HUMAN



KARE is redesigning work together with the people in the company and in the circular value chain, creating attractive and future-oriented working conditions.

ENVIRONMENT



KARE promotes sustainable economic development of plastics by transforming from a linear and recycling economy to a circular economy

TECHNOLOGY



KARE develops and tests practical solutions for the specific challenges faced by companies in their plastics industry

KARE—Building Competencies for the Circular Economy of Plastics

The KARE project aims to build expertise in the circular economy of plastics and address environmental problems caused by a lack of recycling options. Fraunhofer ISC plays a key role in this effort, leveraging its expertise in the development of resource-efficient materials and circular processes. A central focus is on increasing recycling rates in the plastics industry.

In the project, Fraunhofer ISC supports the qualification of recycled materials according to specific material specifications. To this end, materials science testing procedures and analytical methods are used to determine quality-defining parameters for injection-molded products. These measures are crucial for minimizing granulate losses and increasing the use of recycled materials in production.

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4 QUALITY EDUCATION

8 DECENT WORK AND ECONOMIC GROWTH

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

In the KARE project, 16 project partners and Fraunhofer ISC are establishing a center of excellence for work research focused on sustainable work design in the field of plastics production and processing in Franconia, and are developing sustainable solutions for new products that can serve as models for other sectors of the plastics processing industry. The institute is thus making a significant contribution to improving working conditions in the industry and supporting internal transformation through targeted training measures for employees. The goal is not only to make companies more sustainable but also to prepare them for the labor market



Competence Centers for Labor Research

INN-PRESSME—bioORMOCER® Supports Sustainable Material Design

Fraunhofer ISC played a central role in the EU-funded project INN-PRESSME, which focused on the development, scaling, and piloting of bio-based material solutions. The project's goal was to establish a European network of eco and pilot plants for sustainable, bio-based products. Fraunhofer ISC was involved in six test cases and developed innovative bio-based functional coatings. The bioORMOCER® layers developed for sustainable packaging could also be adapted for other applications, such as in the automotive sector or for sports equipment.

The scaling of material production at the pilot level was conducted precisely to ensure the quality and functionality of the coatings. Technologies such as a 100-liter lacquer reactor and a roll-to-roll facility were employed, for example, to equip a paper modified with a nanolayer with a bioORMOCER® barrier coating. The project successfully established a network of pilot plants, which will be made accessible to companies through a Single Entry Point in the future. This enables effective support in scaling bio-based solutions while minimizing entrepreneurial risks.

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Free Flow Structuring (FFS)—Near-NetShape Ceramic Manufacturing with Slurry-Based 3D Printing

The Fraunhofer Center for High Temperature Materials and Design (HTL) successfully researches slurry-based 3D printing, known as Free Flow Structuring (FFS). This process uses aqueous slurries instead of flowable powders, allowing for the processing of micro- to sub-microscale particles for technical ceramics. The process begins with applying thin layers of slurry onto a build platform, with the slot nozzle guided similarly to slot-die coating. The layers are dried using infrared radiation, while subsequent layers are primarily dewatered by capillary action, resulting in a high density of the powder bed.

After drying, an organic binder, such as a curing resin, is applied with an inkjet print head and cured using UV light or infrared radiation. This cycle is repeated until all layers of the green body are created. The FFS printing allows for the processing of various powder materials, including oxide and non-oxide ceramics as well as metal powders, and can handle particle sizes of < 1 µm, leading to improved material properties.



The process is scalable and cost-effective, enabling the manufacturing of large-format, densely sintered components made from ceramics, glass, or metals. The slurry-based additive manufacturing offers flexible and customized solutions that minimize resource consumption, as unused material can be recycled. Additionally, the process contributes to demand-oriented production and avoids overproduction, which enhances resilience in manufacturing.

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InVECOF—Pilot Manufacturing of Oxide Ceramic Reinforcement Fibers

Since May 2022, the fiber group of the Fraunhofer Center for High Temperature Materials and Design (HTL) has been actively involved in the EU project InVECOF, focusing on the development and production of novel oxide ceramic reinforcement fibers. These fibers are characterized by improved thermomechanical properties and will be used in various high-tech applications in the future. The challenge of this project is to transfer the fiber processes from lab scale to a pilot facility established in Bayreuth.

Facility Development

The fiber pilot plant, planned and constructed in-house, is the centerpiece of this initiative. It consists of several highly specialized units that allow for the entire manufacturing process of oxide ceramic fibers to be conducted under controlled conditions:

1. Raw Material Preparation

The fiber production begins with the storage of raw materials for the spinning solutions. These are then processed in special mixing vessels into aqueous sol-gel precursors. The mixing vessels are designed to process up to 100 liters through vacuum distillation, ensuring efficient and uniform production of the spinning solutions.

2. Spinning Tower and Fiber Line

The spinning tower is equipped with four parallel spinning stations, each capable of producing up to 500 filaments simultaneously. This high capacity enables the manufacture of large quantities of oxide ceramic fibers in a short period. A four-meter-long spinning shaft allows for the drying of the spun fibers in a controlled gas flow, where both temperature and humidity can be regulated to ensure optimal drying conditions. The bundles of fibers are continuously withdrawn from the spinning tower, protected with a protective coating from damage in the subsequent processing steps, and deposited in special ceramic bins using a gas delivery nozzle for the next processing steps.



3. Heat Treatment

In two large chamber furnaces, the fibers are calcined. These furnaces can accommodate up to 30 baskets at the same time and reach temperatures of up to 1,200 °C. This is followed by continuous sintering in a six-meter-high vertical tube furnace. This furnace reaches temperatures of up to 1,750 °C, ensuring that the fibers achieve the necessary high strength and stiffness.

4. Sizing Application

At the end of the process, a sizing application is performed, which prepares the fibers for textile processing. After drying the sizing, the fiber bundles are wound onto spools at a total of 15 winding stations and shipped.

Future Developments

The facility is designed for the production of fibers with various oxide ceramic compositions. Fiber diameter and shape, as well as the number of filaments in the roving, can be customized within a wide range. As part of the InVECOF project, pure alumina fibers and fibers with high creep resistance are also being developed and produced at the facility. The pilot plant opens up new possibilities for the manufacturing of oxide ceramic fibers in various industrial applications, ranging from aerospace to high-temperature applications in energy generation.

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Project progress and initial successes

Since April 2024, the facility has been fully operational. As part of the InVECOF project, the first continuous fiber spools with lengths exceeding 100 meters and with 250 or 500 filaments have been successfully produced. Currently, the focus is on the development of mullite fibers ($3 \text{ Al}_2\text{O}_3 \cdot 2 \text{ SiO}_2$) for the InVECOF project partners. These fibers exhibit impressive mechanical properties: a tensile strength of about 1,600 MPa and a modulus of elasticity of 270 GPa with a fiber diameter of 10 – 12 μm .

<https://invecof.eu/>

Cascade Reactions for the Production of Fine Chemicals

The production of fine chemicals, such as those used in pharmaceuticals or agrochemicals, is usually complex and costly. It requires various synthesis steps in separate reactors. Intermediate products, by-products, or homogeneously distributed catalyst materials often have to be separated from one reactor to the next, which is time-consuming and costly.

An interdisciplinary team of Fraunhofer researchers has now jointly developed an innovative synthesis process for the production of fine chemicals based on cascade reactions. In the new process, the end product is produced in a continuous synthesis cascade, ideally in a single reactor. This method significantly improves process efficiency and makes production more sustainable by shortening changeover times and reducing energy requirements. These advantages not only directly reduce costs, but also the CO₂ emissions of the entire synthesis.

The process developed by the Fraunhofer researchers is based on an innovative combination of two catalytic steps that take place in a cascade. For example, light-activated photocatalysts are combined with enzymes that act as biocatalysts.

For this type of cascade reaction, known as photo-assisted biocatalysis, the individual catalysts must be positioned at the optimum distance from each other, as the product resulting from the photocatalytic step is the starting material for the biocatalytic step.

Fraunhofer ISC has developed hybrid catalyst particles for this purpose. These hybrid catalyst particles consist, for example, of photocatalytic building blocks and carrier particles on which enzymes have been immobilized, which represent the biocatalytic building block. With our spray drying technology at Fraunhofer ISC, the type and quantity of the building blocks can be easily varied depending on the desired cascade reaction and mixed to form hybrid catalyst particles. The catalyst particles can be used in flow reactors in suspended form and thus easily separated after use. Furthermore, the catalysts can be immobilized in microchannels using Fraunhofer ISC's selective dispensing technology. After the reaction fluid has flowed through, the channel-carrying components of the flow reactor can be easily replaced.

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cascade-reactions.de



Decarbonization

Fraunhofer ISC is actively working in various areas on decarbonization – specifically, the necessary reduction of the CO₂ footprint of materials and processes in light of climate change. This includes analyzing industrial heat treatment processes to improve their efficiency and thereby reduce energy consumption, enhancing the efficiency of energy conversion and storage processes, and developing materials that are significant for the hydrogen economy. Below are examples related to decarbonization from the field of hydrogen technologies:

H₂ Storage and Transport—Materials for Hydrogen Barriers

To store and transport hydrogen in existing natural gas infrastructure, materials and technologies must be adapted to the specific challenges posed by hydrogen. The significantly smaller hydrogen molecule, compared to fossil energy carriers, imposes higher requirements on diffusion barriers; in short, the walls of pipes and tanks have to be more dense. At Fraunhofer ISC, the coating technology department has extensive expertise in the development and design of ultra-barrier coatings.

ORMOCER®-based coatings combine various properties (adhesion, strength, corrosion protection, etc.) with gas barrier effects through their inorganic-organic network. Their synthesis allows for individual adjustment of flexibility, barrier performance, and enables the simplified incorporation of additives. The application of gas barrier coatings from liquid media allows for the use of various application techniques, making it possible to coat large areas and complex three-dimensional geometries.

Compared to gas-phase deposited gas barrier coatings, a customizable, rapid, and cost-effective application can be achieved. The combination of different ORMOCER® formulations, additive incorporation, and multiple coatings enables the setting of desired gas barrier values.

For use as hydrogen gas barriers, established gas barrier systems from the packaging and electronics sectors are being tested, further developed, and optimized at ISC. Flexible adaptation of the wet-chemical systems and the institute's own testing capabilities allow for rapid development of gas barrier systems.

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HySecunda—Green Hydrogen Materials

South Africa and its neighboring countries could establish themselves as reliable partners in the production and delivery of green hydrogen in the coming years, particularly in collaboration with Germany. However, challenges currently exist regarding the storage and distribution of this resource. This is where the Fraunhofer collaborative project HySecunda comes in, involving nine Fraunhofer institutes and the Fraunhofer Academy. The project aims to find optimized solutions for the production, storage, and certification of green hydrogen. In addition, the consortium supports capacity building in the region and in current projects.

Fraunhofer ISC leads the development of barrier layers based on ORMOCER® and fail-safe hydrogen sensors in HySecunda to make the production, storage, transport, and utilization of green hydrogen efficient and safe. For instance, ORMOCER® barrier layers are intended to extend the lifespan of components during water electrolysis. New material concepts for pressure tanks for hydrogen storage and the H₂/O₂ tight coating of pipelines are also among the tasks of Fraunhofer ISC. Furthermore, the simple, safe, and immediate detection of leaks will be necessary for the extraction, storage, transport, and utilization of hydrogen to ensure safety. To achieve this, non-powered sensors are being developed at Fraunhofer ISC that can immediately detect existing or previous hydrogen leaks through a simple color change without the need for additional tools.

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Funded by
the European Union



*Links to all ISC activities on
hydrogen technology*

**H₂AL—Industrial Heat Processes Using Hydrogen Instead of Natural Gas as Fuel –
How safe are Refractory Materials?**

For the european goal of decarbonizing key industrial sites, short-term, scalable solutions are necessary. One approach is to replace natural gas with hydrogen (H₂) in hard-to-decarbonize industries to reduce greenhouse gas emissions. The EU project H₂AL examines how natural gas can be replaced by hydrogen in furnace processes, using aluminum recycling as an example, to significantly reduce CO₂ emissions.

The replacement of natural gas with hydrogen alters combustion conditions, such as flame speed and the steam content in the furnace atmosphere, which can impact the refractory materials used in the furnace. The H₂AL project analyzes, whether current refractory materials can tolerate the new combustion conditions or whether adjustments are necessary. Additionally, burners, refractory materials, and sensors will be retrofitted in existing furnaces to enable the recycling process with up to 100 % H₂.

At the Fraunhofer Center for High-Temperature Materials and Design (HTL), the effects of the H₂ combustion atmosphere on various refractory materials have been investigated. The tests, conducted under controlled conditions in thermo-optical measuring devices (TOM), included steam contents of 35 % and 100 %, as well as temperatures ranging from 800 °C to 1250 °C. XRD, SEM, and CT were utilized to analyze microstructural changes and porosity. The results showed significant differences in corrosion effects, with certain commonly used material additives exacerbating corrosion. The findings also contribute to the development of new materials with improved corrosion resistance and durability under H₂ combustion conditions.

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<https://h2al.ulb.be>



Funded by
the European Union



HiQ-CARB—More Effective Carbon Additives for Batteries with a Lower CO₂ Footprint

The HiQ-CARB project, funded by the EU/EIT RawMaterials, aimed to develop sustainable, high-quality, conductive additives for lithium-ion batteries. Given the growing demand for rechargeable batteries, particularly in the field of e-mobility, the use of environmentally friendly materials is becoming increasingly important. By combining carbon nanotubes (CNT) with carbon in the form of acetylene black, derived from renewable raw materials, the goal is to reduce the carbon footprint of battery production. This also leads to cost savings and improves the electrochemical performance of the batteries. As part of the project, the composition of the additives was optimized, production was scaled up to an industrial level, and comprehensive material assessments were conducted. Collaborations with institutions such as the Fraunhofer ISC and Aalto University were crucial to this effort.

The new additives were successfully integrated into existing battery production processes, ultimately enabling the manufacture of lighter and more efficient batteries. A life cycle assessment (LCA) revealed that, compared to conventional additives, the production of acetylene black has a lower global warming potential. Overall, the HiQ-CARB project made significant progress in the field of sustainable production of lithium-ion batteries.

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greener-carbons.eu





Battery Research at Fraunhofer ISC

The Fraunhofer Research and Development Center for Electric Mobility in Bavaria (FZEB), based at Fraunhofer ISC, is one of the largest battery research groups in Germany, with approximately 35 employees. In addition to a wide range of national and international collaborative projects that drive developments strategically relevant to the European production hub, the FZEB carries out bilateral projects directly with industry partners to provide application-oriented support for technological challenges. FZEB is committed to a holistic research approach aimed at making the entire battery life cycle more efficient and sustainable, starting with the use of safer raw materials, through design for recycling, to reuse and direct recycling. The founding of the startup CellCircle, which originated at Fraunhofer ISC, can be seen as an indicator of the success of this research approach. CellCircle has already been awarded several startup prizes and is establishing itself in the market with the goal of separating and regenerating high-purity functional materials from lithium-ion batteries for direct reuse.

FZEB's central positioning within national and international networks is achieved through its deep understanding of materials and experience in the manufacturing and recycling of a wide variety of battery types. In collaboration with the European BATTERIE 2030+ initiative, the Batteries European Partnership Association (BEPA), and the industry association RECHARGE at European level, FZEB plays a key role in the European Battery Roadmap. At the national level, the R&D center contributes its material and technology expertise to the Fraunhofer Research Institution for Battery Cell Production FFB. In addition to lithium-ion and lithium solid-state batteries, material solutions and component development for sodium batteries are being advanced. Over the past two years, FZEB has also been involved in designing and implementing various continuing education programs in the field of battery-related topics to train urgently needed specialists for the industry.

In the fall of 2024, the first international Conference on Battery Direct Recycling was held in Würzburg with great success. With contributions from internationally recognized experts from the U.S., Canada, and Europe, the more than 180 participants were able to engage in intensive discussions on the latest developments and approaches to the direct recycling of functional battery materials. Due to the overwhelmingly positive feedback from participants, the conference will be held again in February 2026. The Conference on Battery Direct Recycling is thus the only conference focused on this topic, thereby filling a gap in the international conference calendar.

Selected projects related to the various FZEB activities are presented on the following pages.



Battery Research

Research Focus Solid State Battery (SSB)

ROBATT—Infrastructure Development for the Pilot Manufacturing of Solid-State Battery Cells

Solid-state batteries can overcome some of the limitations of current lithium-ion cell technology, offer improved safety, and enhance key performance parameters in battery technology. Polymer solid-state cells, in particular, hold great promise for a wide range of industries. The parallel development of the associated production technology in the subfields of material synthesis, electrode production, cell assembly, as well as formation and cell analysis is crucial for a rapid and economically successful market launch.

To support Bavarian industry in particular, the Fraunhofer Institutes ISC and IGCV have, as part of the High-Tech Agenda Bavaria, established infrastructure for critical process steps in battery cell production in Augsburg and Würzburg and expanded production expertise in the field of solid-state batteries. The focus here is on digitized and automated processes. These are intended to accelerate development cycles in the synthesis of battery materials, the laboratory and pilot production of solid-state cells, and the recovery of secondary battery materials, while also increasing production stability. Fraunhofer ISC is working on material and process development at the prototype scale, particularly for solid-state batteries and digitized material development. A prototype system for the automated production of solid-state cells for polymer-based solid-state batteries was set up for this purpose as part of the project at the Würzburg site.

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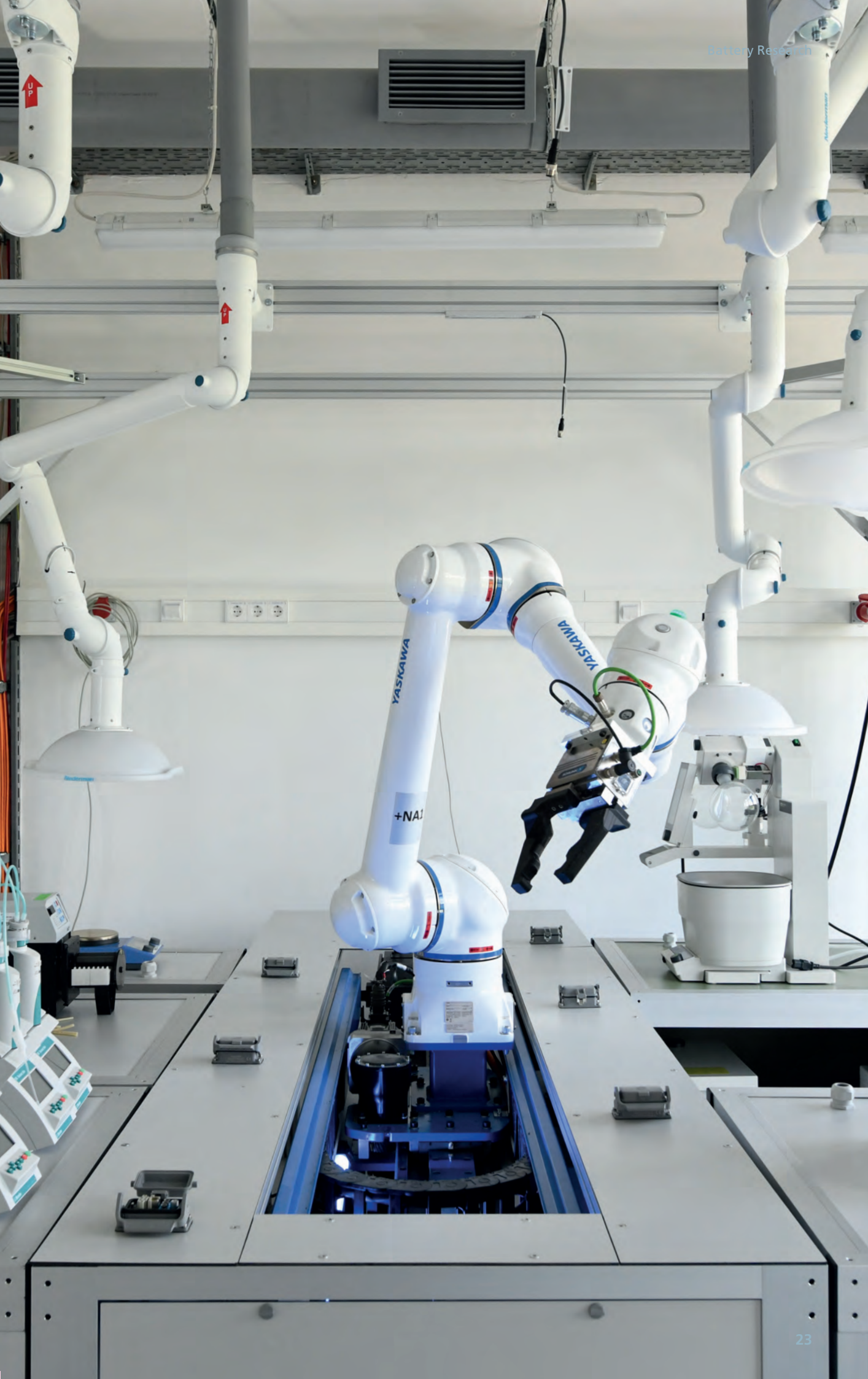


*funded by the
Free State of Bavaria*

"Advanced battery technologies, including solid-state batteries, are essential to decarbonize transport and integrate renewables efficiently."

Wopke Hoekstra, Commissioner for Climate, Net Zero and Clean Growth





ASTRABAT—Material Basis for Solid-State Batteries

As part of the European ASTRABAT project, researchers at Fraunhofer ISC have made significant progress in the development of solid-state batteries. Solid-state batteries offer advantages in terms of energy density and safety because they can be manufactured without the use of flammable electrolytes. A central component of the project was the development of a hybrid polymer electrolyte that exhibits high conductivity and elasticity. In combination with the use of silicon as the anode material (instead of graphite), the theoretically possible energy capacity can be quadrupled.

The use of silicon as an anode material offers significant advantages over lithium, including the prevention of dendrite formation and associated short circuits. The researchers are relying on a cost-effective doctor-blade process for manufacturing the silicon-polymer electrodes, which can be adapted to existing production lines. It has been promisingly demonstrated that elastic polymer electrolytes minimize cell aging, even though silicon undergoes significant volume changes during the charging and discharging process. The project's results could pave the way for the next generation of lithium-ion batteries, which not only offer higher energy density but are also safer. The scientific findings and developments from this project lay the foundation for future advances in the fields of electromobility and energy storage.

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astrabat.eu



**Funded by
the European Union**

SOLiDIFY—Scalable Solid-State Battery Concept

The SOLiDIFY project focused on developing a novel solid-state battery concept based on a nanocomposite-based solid electrolyte. This electrolyte offers solutions to many of the challenges associated with current solid-state batteries, particularly for large cells and high-performance applications such as traction batteries. The development goals included high energy density, fast charging capability, improved safety, competitive manufacturing costs, and sustainable production processes with lower cobalt content and reduced CO₂ emissions.

Fraunhofer ISC's contribution focused on developing a wet-chemically produced composite cathode, thereby playing a central role in the SOLiDIFY consortium. To facilitate future industrial implementation, aqueous processes were used from the outset. In addition, Fraunhofer ISC developed a new cell architecture and scaled up production to a continuous roll-to-roll process.

As part of SOLiDIFY, 14 European partners worked on the development of individual components for an initial cell prototype. The consortium set technical goals of an energy density of 900 Wh/L, a charging time of 40 minutes, and a lifespan of over 500 cycles. The components developed include advanced cathode architectures, a stable polymer-electrolyte separator, and new anodes featuring thin lithium-metal anodes. Prototypes of these cells were built and tested. The cell manufacturers and end users in the project consortium had developed specifications and test protocols for this purpose. In parallel, life-cycle and cost analyses were conducted for solid-state battery cells to evaluate the sustainability and cost-effectiveness of the developed technologies.

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solidify-h2020.eu



**Funded by
the European Union**

SPINMATE—Establishment of a Pilot Production Line

The SPINMATE project aims to establish a scalable, sustainable, safe, and cost-effective digital pilot production line with a Technology Readiness Level (TRL) of 6 and to demonstrate its functionality. This pilot production line serves as the foundation for the large-scale manufacturing of so-called Generation 4b (Gen 4b) solid-state batteries (SSBs) and modules, and is thus intended to support developments in the field of e-mobility. The development of new digital manufacturing technologies for the large-scale production of SSBs is of crucial importance. The BATTERY 2030+ roadmap considers the manufacturability of solid-state batteries to be a key factor for the success of sustainable batteries. Innovative and scalable manufacturing techniques are intended to reduce costs, save energy, and increase safety.

Initially, however, SPINMATE is focusing on material development for the highly conductive polymer-based electrolyte, the coated lithium metal, and the nickel-rich layered oxide cathodes. Based on this, both small SSB cells with a capacity of less than 1 Ah and large SSB cells with a capacity of 10 Ah are produced. New, solvent-free extrusion methods as well as roll-to-roll coating methods are used in electrode and electrolyte processing.

Within the SPINMATE project, Fraunhofer ISC is responsible for the critical surface cleaning of lithium metal foils as well as the production of polymer-based lithium solid-state batteries supported by digital processes. The electrochemical properties of these batteries are tested and evaluated at Fraunhofer ISC. SPINMATE's Generation 4b SSB cells will establish a new value chain in Europe and advance the commercialization of this technology. This new generation of batteries will enable improved energy densities, enhanced safety, sustainable, high-volume manufacturing processes, and an excellent carbon footprint.

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spinmate.eu



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Battery Research

Research Focus Direct Recycling

ReUse—Efficient Direct Recycling for Low-Value Lithium-Ion Battery Waste

The ReUse project receives funding of approximately 5 million euros under the EU's *Horizon Europe* program as part of the BATTERY 2030+ initiative. It aims to improve the circularity and sustainability of the European value chain for lithium-ion batteries (LiB), particularly for lithium iron phosphate batteries (LFP). This is achieved through the development of new direct recycling processes to enable optimal recovery of the materials used.

The consortium consists of 13 partners from 8 European countries. Initial work focused on defining the expected battery waste streams and developing a standard protocol for battery discharge. Initial work on the regeneration of anode materials has been successfully completed. At the same time, a life-cycle analysis was conducted to demonstrate the sustainability of the ReUse recycling concept, taking into account the recyclability of the raw materials used. ReUse has the potential to make a significant contribution to LiB recycling technologies by 2030.

Fraunhofer ISC coordinates the project and is responsible for the further development of recycling technologies. One focus is on the automated disassembly of batteries to enable efficient, environmentally friendly, and function-preserving recovery. ReUse supports the policy goals of the European Green Deal by addressing technological and environmental shortcomings in the recycling of end-of-life batteries.

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IDcycLIB—Project Success for Sustainable Battery Manufacturing

The BMBF-funded project IDcycLIB, successfully completed in December 2024, addressed the entire value chain of battery production with a budget of approximately 7 million euros and significantly contributed to the development of sustainable lithium-ion batteries. A central outcome of Fraunhofer ISC's work in the project is the transition of cathode production to a water-based process, which greatly enhances the environmental friendliness of manufacturing. Additionally, eco-friendly materials and processes were introduced in electrode production, including the use of cellulose as a binder instead of harmful substances like PVDF and NMP. The new water-based process not only provides advantages for battery production but also benefits subsequent recycling.

Another important aspect of the project is the development of a digital battery passport that enables unique identification and traceability of battery cells. This passport, supported by tamper-proof markers, allows for the digital recording and exchange of production data, increasing safety and efficiency in the recovery of battery materials.

Progress has been made in the area of direct recycling, allowing for the functional recovery of battery materials. New, water-based recycling processes have been successfully scaled up to a pilot level and have already proven to be more cost-effective than conventional methods at this early stage. Electrohydraulic disassembly enables clean separation of material fractions, while modern measurement technologies facilitate rapid analysis of material composition. Overall, the IDcycLIB project demonstrates significant progress toward sustainable and economical battery production and recycling.

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RecyLIB—Reducing Environmental Impact of Batteries, Conserving Resources and Energy

The RecyLIB project aimed to reduce the environmental impact of batteries and improve resource efficiency. Funded by ERA-MIN and national funding organizations, the project consortium developed innovative processes for battery electrode production and the direct recycling of lithium-ion batteries. The developed manufacturing process enabled the use of recycled material, allowing the active functional material to be recovered after the battery’s end of life with high yield and high quality and directly reintegrated into the electrode manufacturing process without compromising cell performance.

The RecyLIB team, coordinated by the Fraunhofer Institute for Silicate Research ISC, used water-based separation processes such as electrohydraulic fragmentation and centrifugation to gently recover battery materials. In addition, a melt-based and thus solvent- and PFAS¹-free electrode manufacturing process was further developed. The project also investigated the performance and aging behavior of battery cells manufactured either from primary raw materials or from recycled material.

A key objective of RecyLIB was to develop a process chain for reintegrating up to 25 wt% of recycled electrode material into new batteries. The results show that cells containing recycled material achieve over 90% of the capacity compared to cells made with 100% virgin material. The project also conducted a comprehensive sustainability assessment that took into account socio-ecological impacts, life cycle analysis, and circularity assessment. RecyLIB thus makes an important contribution to a sustainable, circular battery ecosystem in Europe. The project ended in July 2025.

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<https://recylib.eu>



**Co-funded by
the European Union**

REWIND—First Junior Research Group Established for the Competence Center for Direct Recycling

The REWIND project, launched in 2024, plays a central role in the development of environmentally friendly mobility and sustainable energy supply by improving the recyclability of lithium-ion batteries. As part of the *BattFutur* program of the BMFTR, REWIND aims to increase resource efficiency and reduce CO₂ emissions. A key component of the project is the promotion of young scientists to address the shortage of skilled workers in battery research.

REWIND follows a circular approach that develops a recycling-friendly lithium-ion battery, whose components can be almost completely recovered. This enables the direct re-use of recyclates in cell manufacturing. Despite the advantages of direct recycling, the use of conventional direct recycling methods resulted in a loss of functional materials, which prevented their industrial implementation. REWIND addresses these challenges through recycling-oriented material and cell design and by advancing markers for labeling cell contents to facilitate the separation of anode and cathode.

The project focuses on lithium iron phosphate and examines its applicability to sodium-ion batteries to expand potential applications. REWIND builds on existing projects and aims to establish a competence center for direct recycling that will serve as a platform for industrial contacts.

Overall, REWIND represents sustainable technological innovation that aims to fundamentally transform battery recycling and can make a significant contribution to a more sustainable mobile future.

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¹ PFAS: per- and polyfluoroalkyl substances



An absolute highlight for all stakeholders
in battery research:

**The 2nd Conference on Direct Battery Recycling
in February 2026 in Würzburg!**



Battery Research

Research Focus State of Health—State of Charge

SPARTACUS and PHOENIX—Two BATTERY 2030+ Projects on Battery Sensor Technology and Self-Healing

The SPARTACUS and PHOENIX projects, carried out as part of the BATTERY 2030+ initiative and funded by the EU, aim to develop sensor-based condition monitoring for batteries. SPARTACUS, coordinated by Fraunhofer ISC, concluded in spring 2024 and investigated various types of battery-integrated sensors for accurately determining the state of charge and health of battery cells. The results showed that dielectric elastomer sensors, which monitor the expansion of the cell, can detect critical cell conditions such as overcharging ten minutes earlier than conventional gas sensors. This additional time improves safety management during critical battery conditions. Furthermore, it was demonstrated that by controlling the charging process—supported by temperature sensors located near the cells—the charging time can be reduced by 13%.

The follow-up project PHOENIX builds on these findings and investigates self-healing mechanisms in lithium-ion batteries with the aim of extending battery lifespan. Different types of degradation and self-healing mechanisms are being investigated in various battery generations, including Generation 3b (lithium-ion) and 4a (solid-state electrolytes). The goal is to increase the cycle stability of the self-healing polymers to over 1,200 cycles and to boost the specific capacity of the silicon anodes by 20% compared to the state of the art. Fraunhofer ISC is further developing the elastomer sensors tested in SPARTACUS to precisely measure the expansion of self-healing battery cells. Innovative triggering mechanisms for self-healing, such as HASEL (HASEL = Hydraulic Actuator by Electrostatic Locking) actuators and self-regulating resistive heaters, are being implemented to enable targeted activation of self-healing via pressure and temperature. This will sustainably improve the efficiency, service life, and safety of batteries.

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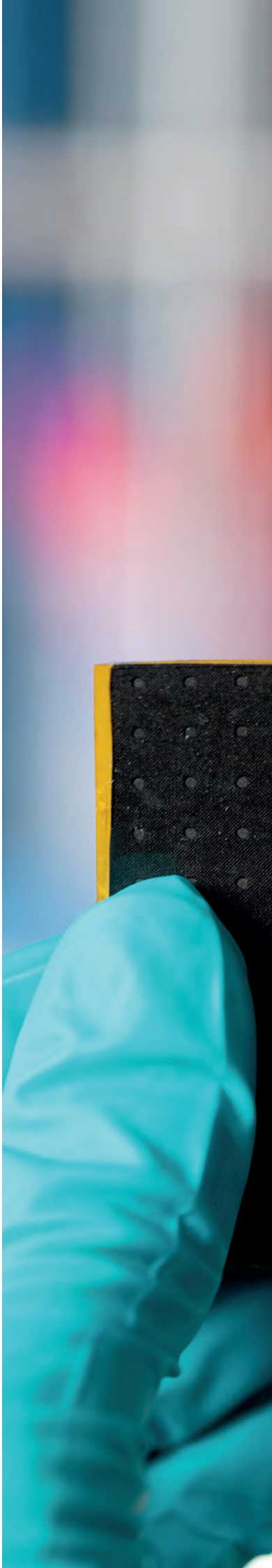
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More information



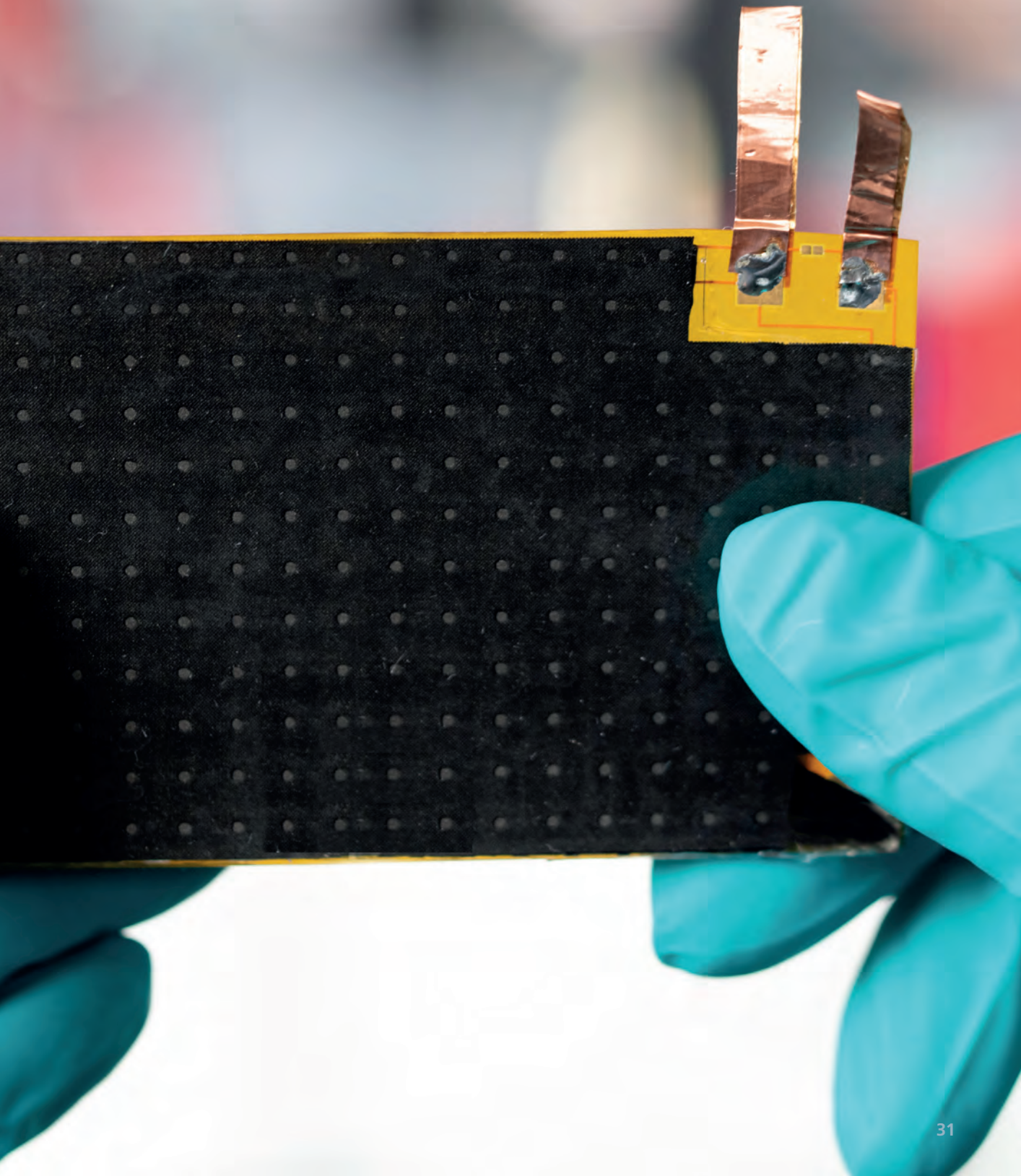
spartacus-battery.eu

phoenix-smartbatteries.eu



"We re-invent the way of
inventing battery materials"

Kristina Edström | BATTERY 2030+



MADAM4Life—Mechanical Aging Diagnostics for Lifespan Prediction with Strain Gauges, Dilation, Pressure, Acoustics, and Modal Analysis

The MADAM4Life project aimed to optimize the lifespan of lithium-ion battery cells (LIBs) through non-invasive mechanical aging diagnostics. Various mechanical measurement methods were employed, and their suitability for real-time condition monitoring of battery cells was analyzed, including strain measurement, dilation, pressure, acoustics, and modal analysis.

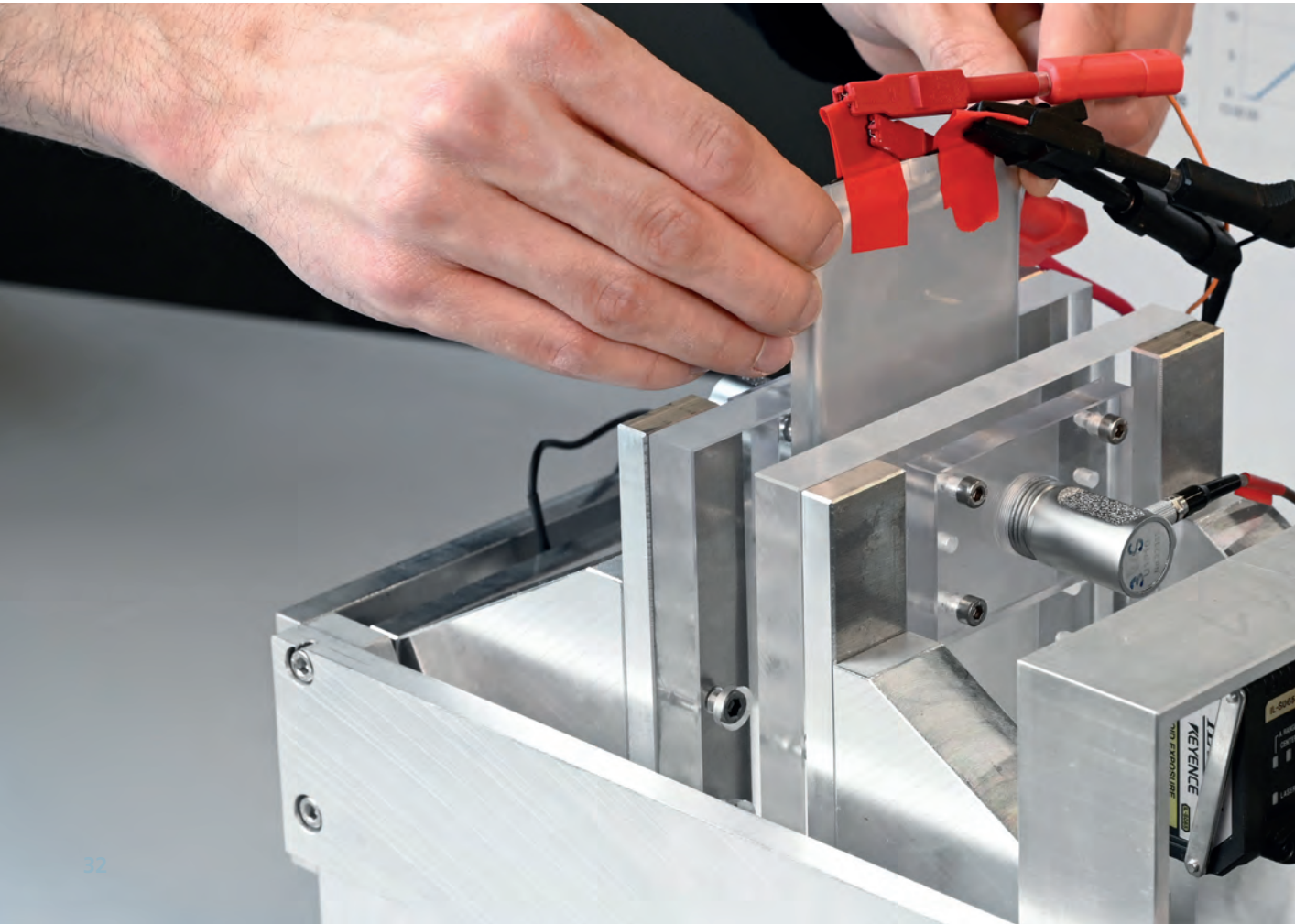
Another focus was the development of a measurement method to monitor the internal pressure of the cells, with the goal of correlating the results with strain data. By combining these methods, a deeper understanding of the mechanical changes in the cells during charging and discharging was achieved. This approach lays the groundwork for a better understanding of aging processes in the cells.

The creation of a comprehensive digital database of tailored aging tests was also addressed in the project. Detailed models supported the analysis of ultrasound signal propagation in relation to aging phenomena and allowed for a physical description of pressure and temperature changes.

The ultrasound investigations, data collection during aging to estimate state of charge (SoC) and state of health (SoH), as well as the creation of a mechanical state-of-charge map that can serve as a basis for predicting the remaining useful life (RUL) of lithium-ion battery cells, were carried out by Fraunhofer ISC.

The mechanical measurement methods supported the development of innovative diagnostic procedures for battery management systems, enabling a more accurate determination of the state of health. Combined with an empirical aging model, the strain data is used to predict the service life of the battery cells and, by establishing more precise criteria for the end of their service life, to extend battery operation or qualify the batteries for further use in less demanding applications (2nd-life).

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HealthBatt—Improved Battery Management Through Comprehensive Data Collection and Analysis

The HealthBatt project aims to improve the efficiency and safety of battery systems through an innovative multi-sensor approach. In this research project, which is funded by the Federal Ministry for Economic Affairs and Climate Action as part of the Research in the Priority Funding Area of Battery Cell Manufacturing initiative, the partners are working to develop a comprehensive sensor concept.

Current battery management systems in electric vehicles primarily collect thermal and electrical data. HealthBatt expands this approach by taking additional stresses such as mechanical shocks, vibrations, and humidity into account. By combining damage analyses with intelligent data evaluation, the aim is to estimate the service life of battery storage systems more precisely. This helps prevent unexpected battery failures and enables the possibility of subsequent use in stationary energy storage systems.

The project implements an innovative sensor integration that can be used in both new and existing battery designs. Fraunhofer ISC is working on the testing methodology for assessing the condition of the cells and conducting post-mortem analyses. A digital model that analyzes the load histories and the condition of the battery storage units enables a precise estimation of remaining service life. HealthBatt represents a significant advance in the sustainable use of batteries and contributes to resource conservation as well as to extending the value chain in the material cycle.

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by the German Bundestag



Battery Research

Focus on Skilled Workforce Training

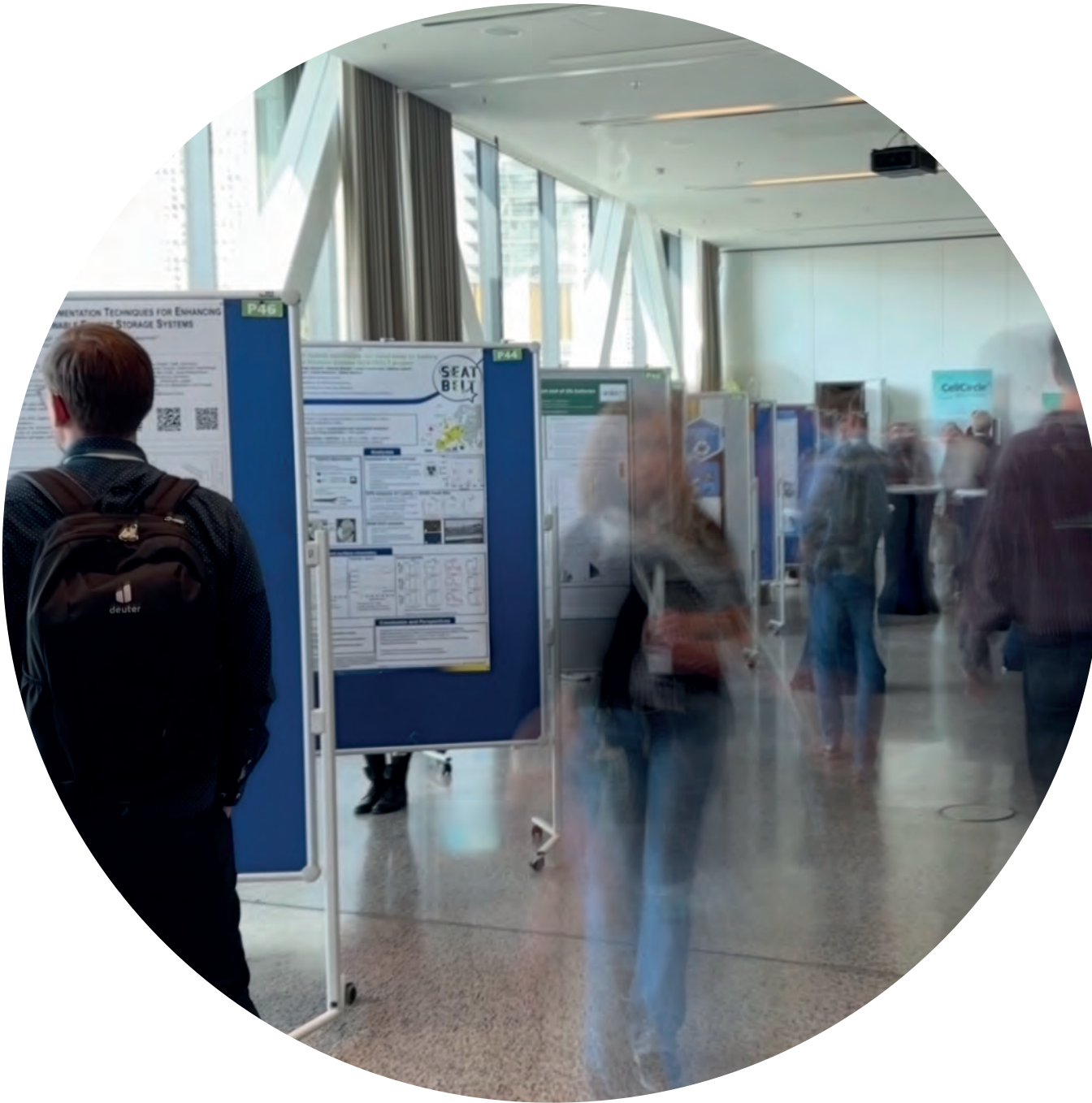
The FZEB at Fraunhofer ISC is committed to training skilled workers in the fields of electromobility and battery technology at both the national and European levels. In addition to foundational knowledge, Fraunhofer ISC researchers focus on topics developed in various public research projects, such as battery recycling, automation, battery testing, and the evaluation of future battery generations. Through these activities, the FZEB aims to make an active contribution to strengthening the German and European economies and improving competitiveness. FZEB researchers contribute their expertise to various educational initiatives in this area.

The B³ Battery Education Network Bavaria (B3) makes a substantial contribution through tailored qualification concepts for industry, small and medium-sized companies, and their employees in Bavaria, offering training programs with a strong practical focus. As part of this network, FZEB provides introductory courses such as *Lithium-Ion Batteries* and advanced courses like *Battery Materials for Lithium-Ion Batteries*, *Recycling of Lithium-Ion Batteries—Current Status and Future Perspectives* as well as *Occupational, Health, and Environmental Protection in Lithium-Ion Batteries—Fundamentals and Safety Strategies*.

The European Battery Business Club (EBBC) is an important initiative to meet the growing demand for qualified professionals in the European battery sector. Funded by EIT Raw Materials and the European Union, the project is carried out by a renowned international consortium led by the Fraunhofer Gesellschaft. Other consortium members include Uppsala University, the University of Ljubljana, and industry partners such as ACC, Northern Graphite, and Orano. Together, an innovative learning program was developed, tailored to needs of the European battery market. The trainings cover various topics such as battery economics and market, digitalization and data analysis, materials science and cell production, recycling, and circular economy. Fraunhofer ISC participates in both the conceptualization and the course offerings. EBBC primarily targets professionals from the battery industry who wish to engage with the economic, technological, and digital aspects of the value chain.

The European Learning Lab Battery Cells, abbreviated as ELLB, is affiliated with the Fraunhofer Research Institution for Battery Cell Production FFB. The project team, composed of members from the Fraunhofer Academy, FFB, Fraunhofer experts from numerous Fraunhofer institutes, as well as university and industry partners, is building a continuously expanded training program with a modern, comprehensive curriculum focused on battery technology. ELLB addresses a broader audience, from students and trainees to professionals and managers from various industries who wish to further their education or retrain in battery cell manufacturing. FZEB also contributes its expertise and participates in the training modules.

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*European Battery
Business Club*



*ELLB European
Learning Lab
Battery Cells*

Digitalization

Linking AI and Digitalization for Sustainable Material Development

The development of materials and processes is firmly embedded in the research DNA of Fraunhofer ISC. The institute is increasingly integrating digital technologies, artificial intelligence (AI), and machine learning to accelerate the often lengthy development process. One example is the high-throughput facility for the development of specialty glass, which is utilized in its expanded form for the MAPz@BAM of the Federal Institute for Materials Research and Testing (BAM) to advance the digitized development of glass formulations. However, the solutions now go far beyond this.

BIG-MAP—Accelerated Materials Development

Rising global energy demand and gas shortages in Europe underscore the urgency of developing sustainable materials for energy production and storage to combat the climate crisis. Advanced materials—that is, highly developed and application-optimized material solutions—are crucial for strategies to mitigate the effects of climate change, as 20% of the industrial base and 70% of technical innovations rely on them. The *Green Deal Industrial Plan* in Europe supports the transition to climate neutrality and promotes industrial competitiveness, while the *Materials 2030 Manifesto* calls for systemic collaboration to solve challenges in the field of these advanced materials.

Material Acceleration Platforms (MAPs) combine computer-aided and experimental approaches with digital and AI-based tools to make the research and development of innovative materials faster and more cost-effective. MAPs automate laboratory experiments and handle repetitive tasks, allowing researchers to focus on scientific questions.

A MAP comprises hardware, software, and the research community: the hardware automates experiments, while the software stores data and supports AI-driven planning. The BIG-MAP project, a key component of the European BATTERY 2030+ initiative, aimed to increase the discovery rate for battery materials by a factor of 5 to 10 over the next five to ten years. To this end, an EU network was established for the exchange, standardized collection, and ontologization of battery data. As a project partner, Fraunhofer ISC played a key role in this important innovation and established an infrastructure in Würzburg featuring artificial intelligence and autonomous synthesis robotics. This enables the independent, iterative adaptation of synthesis protocols until the desired material properties are achieved.

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Funded by
the European Union

MaRA-Print—Market Flexibility and Enhanced Resilience Through Robotic Printing Technology Platforms

The MaRA-Print project aimed to develop industrial-grade application modules for additive manufacturing technologies and integrate them into an integrated production platform. These modules are designed to interact flexibly with one another to enable a needs-based platform for the manufacture of various products. This allows functional elements, such as sensors, actuators, optics, or indicator lights, to be produced quickly and with minimal effort, integrated into a wide variety of products, and enables the flexible production of customized prototypes made of metal and plastic. As part of the MaRA-Print project funded by the Fraunhofer Gesellschaft, the Center for Smart Materials and Adaptive Systems (CeSMA) of Fraunhofer ISC has developed a modular robotic system for the automated serial production of smart material components, designed to independently evaluate and optimize process parameters.



For example, this system manufactures smart actuators for soft robotic grippers or elastomer sensors using inkjet and dispensing processes, including printed circuit tracks, in small batches. The innovative design of the modular platform minimizes time-consuming tool changes and efficiently automates the production steps. A simple production change-over is possible, as only the functional modules need to be swapped out. The robot controller also allows for work on 3D-shaped surfaces. The system is continuously optimized and expanded, e.g. through an intuitive device control or for controlled sealing in the manufacture of actuators. It is used in current research projects for manufacturing and prototyping, for example for the HASEL actuators (HASEL = Hydraulic Actuator by Electrostatic Locking) mentioned in the following project report on *SoMaRo – Soft Materials Robotics*.

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Sensor Technology

Innovative Technologies to Enhance Interaction and Quality of Life Through Adaptive Materials

SoMaRo—Soft Materials Robotics

Robot-assisted automation is on the rise in many industries. However, current rigid gripping tools cannot handle soft and delicate objects like fruits and vegetables without causing damage. Initial developments of soft robotic grippers have struggled due to a lack of fine sensing and control, resulting in many agricultural products still being handled manually.

Fraunhofer ISC and its Center for Smart Materials and Adaptive Systems (CeSMA) are working on innovative gripping technology in the SoMaRo project. This technology is based on soft, adaptively controllable soft kinematics with integrated soft actuators, sensors, and electronics. The developed materials can be deliberately deformed and controlled in their stiffness. By combining these components, sensitive grippers are created that can envelop and hold objects similarly to the human hand.

At the core of the technology are the so-called HASEL actuators (HASEL = Hydraulic Actuator by Electrostatic Locking), which combine electrostatic and hydraulic forces. The project has laid the foundation for a technology platform for adaptive soft grippers that can be integrated into existing robotic systems. Two modular robotic gripper tools have been developed as demonstrators for the automated handling of delicate food items. The technology is also of interest for production processes in other areas involving sensitive goods.

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HILDE—Haptical Interfaces for Vivid Experiences

In 2018, one-third of people over the age of 65 in Germany lived alone, and among those over 90, the figure was nearly 70%. Social participation among older adults is steadily declining, with a preliminary peak during the COVID-19 pandemic. This has highlighted the need for strategies to bridge social distances. Social networks improve quality of life in old age, and friendly relationships protect against loneliness. A friendly touch, a hug, or gestures play a central role in social interaction. In the HILDE project, everyday objects such as blankets, stuffed animals, or other items are enhanced with interactive haptic features, thereby making video calls and communication tangible. The interactive objects facilitate contact with friends and relatives and enable shared activities such as games over long distances. They combine everyday objects with digital information and make the technology less conspicuous and more acceptable to older adults with mental or motor impairments. Fraunhofer ISC's CeSMA is working on the further development of adaptive materials for the haptic components and, together with its cooperation partners—Dresden University of Applied Sciences, Charité, and Awesome Technologies—aims to improve communication through tactile user interfaces and combat loneliness.

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With funding from the:



Federal Ministry
of Research, Technology
and Space





SoMaRo Funding:
Fraunhofer-Gesellschaft PREPARE
Duration: 04/2021—03/2024

NewSpace

Strategic Research for Pioneering Developments in Space Exploration

VLEO—Manufacturing Small Satellites Faster and More Cost-Effectively

The project VLEO aims to make the production of small satellites for Very Low Earth Orbits (VLEOs) more efficient and cost-effective. Three Fraunhofer institutes and the Center for Telematics e.V. in Würzburg are researching innovative materials, manufacturing processes, and automated qualification tests to reduce production costs and increase manufacturing speed.

With approximately 2 million euros in funding from the Bavarian Ministry of Economic Affairs, the foundation is being laid for series-capable manufacturing processes. This approach promotes the possibility of highly scalable mass production, particularly in the fields of satellite communication and Earth observation.

This is intended to enable lower production costs, allowing even smaller companies to participate in space missions with minimal risk. Given the forecast that over 90 percent of newly launched satellites will be small satellites by 2030, the project strengthens the competitiveness of the German *NewSpace* market and opens up long-term prospects for the industry in Bavaria and beyond.

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funded by the Free State of Bavaria

NeT pioneer—Testing Capabilities for Small Satellite Components

In the framework of the NeT pioneer project, the Fraunhofer Gesellschaft is pooling its testing expertise to cover the entire satellite lifecycle. Through digital technologies, standardization, and automation, the goal is to establish a digital *NewSpace* test line, thereby providing the necessary testing capabilities for typical qualification and verification steps in Germany. In light of the growing development of the *NewSpace* sector, this project addresses a critical gap in existing testing capabilities and capacities. By optimizing test environments and adapting to new market requirements, the project aims not only to improve the quality and reliability of future *NewSpace* satellites but also to lay the foundation for Germany to play a leading role in the future space industry. In NeT pioneer, Fraunhofer ISC contributes its expertise in the development of robot-assisted and digitized technology platforms. The project is coordinated by the Fraunhofer Aviation & Space Alliance.

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NewSpace at
Fraunhofer ISC



StellarHeal—Advanced Wound Care

In space, microgravity and increased radiation exposure often lead to fibrotic processes during injury healing, resulting in delayed recovery and increased scarring, which adversely affects the health of astronauts. The StellarHeal project, conducted by Fraunhofer ISC along with its Translational Center for Regenerative Therapies, Fraunhofer ITEM, and the ILK Dresden (Institut für Luft- und Kältetechnik gemeinnützige Gesellschaft mbH), is developing an innovative, cryo-preserveable cell-based solution for wound healing in space that can also be applied to chronic diseases on Earth.

StellarHeal combines a hemostatic material with a cryopreserveable hydrogel and cells derived from astronaut stem cells. This solution aims to reduce fibrotic processes and accelerate regeneration.

The benefits for space are significant: easy self-care, faster recovery, reduced infection risk, fibrosis-free wound healing and complete biodegradability. Additionally, patients with chronic wounds on Earth will benefit from this innovation; over four million people in Germany are affected, resulting in annual costs of approximately eight billion euros.

The project team was the winner of the InnoSpace Masters 2024 German Space Agency at DLR Challenge – congratulations!

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ExPFAS—Semi-Automated Decision Making for PFAS Substitution

PFAS (per- and polyfluoroalkyl substances) are widely used in numerous technical applications, particularly in aerospace, due to their high chemical stability. However, their extreme persistence poses significant risks to the environment and health. In this context, the European Chemicals Agency (ECHA) has proposed a comprehensive PFAS ban, significantly increasing regulatory pressure. Additionally, the withdrawal of major manufacturers such as 3M is exacerbating availability risks for PFAS-based components in the aerospace sector.

At the same time, the growing *NewSpace* market is creating opportunities for PFAS-free alternatives, as there is increasing demand for cost-efficient systems with shorter deployment and service lifetimes. However, PFAS substitution is complex and requires interdisciplinary approaches that integrate regulatory, materials science, and technological aspects.

The exPFAS research project addresses this challenge with the goal of developing an experimental, partially automated decision-making tool for PFAS substitution in aerospace. The approach is based on data science methods and responds flexibly to changing regulatory frameworks. The long-term vision is to create an AI-supported system that assesses impact, conducts structured problem analysis, and systematically derives suitable alternatives, with continuous validation together with partners.

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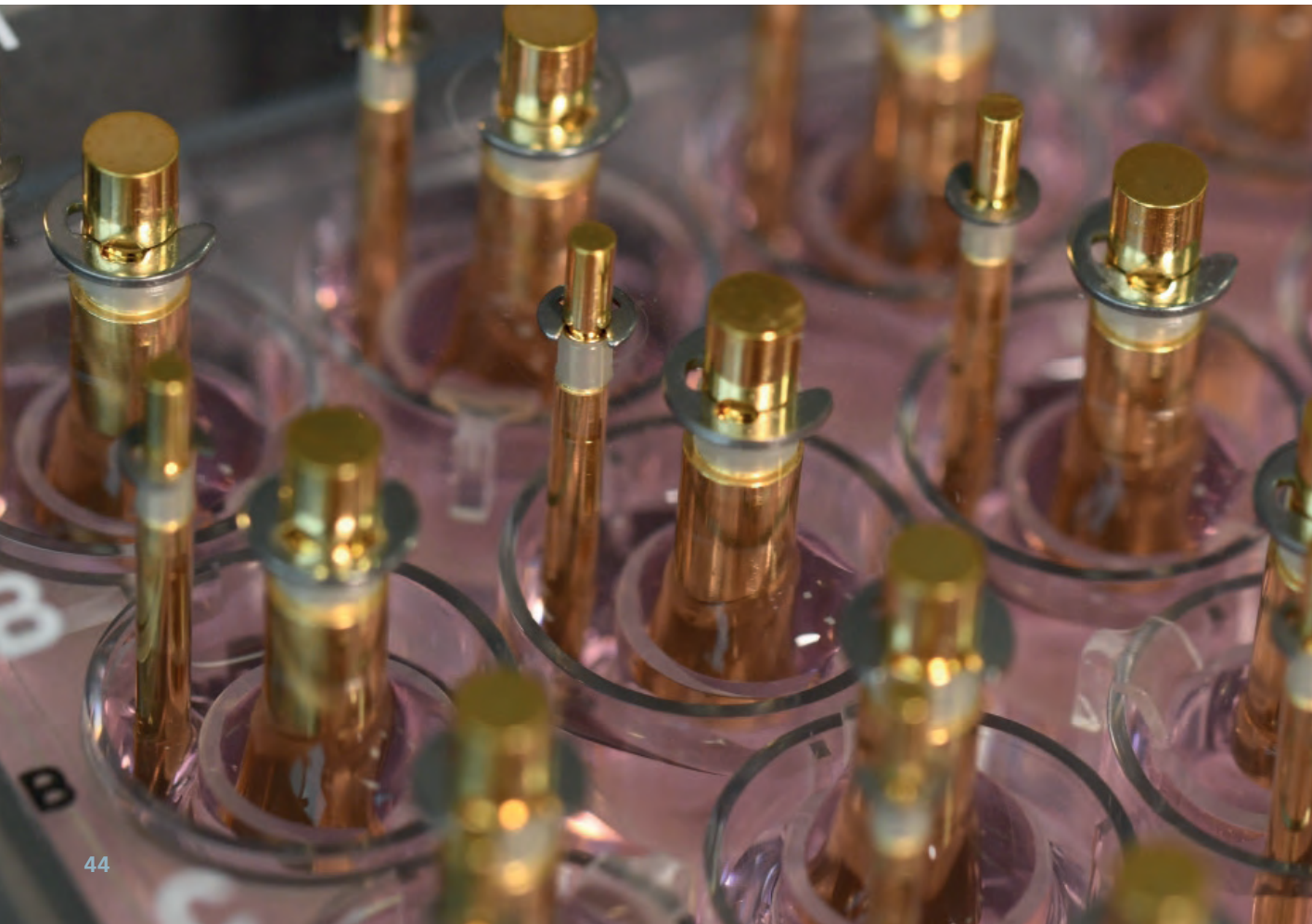


Biomedicine

The recent initiatives of the U.S. Food and Drug Administration (FDA) to phase out animal testing in drug development mark an important step forward for the recognition and implementation of alternative methods. Similarly, the European Parliament is advocating for a faster transition, reflecting the public preference for animal-free research practices.

In-vitro tissue models are increasingly gaining importance as valuable tools for regulatory assessments prior to clinical studies, in alignment with the 3R principles (Replace, Reduce, Refine). Despite their potential, barriers such as the need for standardization, availability, and cost stand in the way of broader acceptance. The Fraunhofer Translational Center for Regenerative Therapies (TLC-RT) at Fraunhofer ISC has dedicated itself to advancing this field.

With the establishment of the WI3R (Wuerzburg Initiative 3 R) network and the eponymous symposium, which was held for the first time in 2024, TLC-RT has established itself as an important competence provider in this promising scientific field. The projects presented below illustrate various research approaches currently being pursued at TLC-RT.



BioCor—Advancements in the Storage of Corneas

Approximately 9,000 corneal transplants are performed annually in Germany, making this the most commonly conducted organ transplant. The demand is even higher, but the number of usable donor corneas is insufficient to meet the needs of all patients. In addition to the low willingness to donate, the sensitivity of corneas during storage is also a reason for this shortage. Conventional storage methods in so-called tissue banks lead to quality loss and a high rejection rate. As a result, many corneas are no longer suitable for transplantation. The BioCor project aims to change this by validating and making available a new storage method.

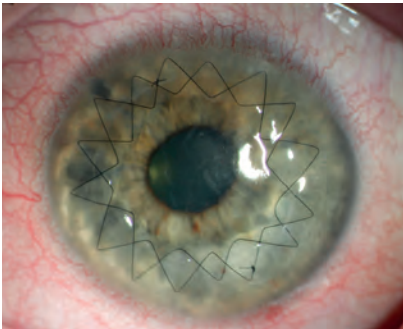
The centerpiece of the innovative method is a novel bioreactor that mimics the natural conditions of the eye, ensuring optimal nourishment of the cornea. In addition to the dynamic cell culture with continuous supply of nutrients and oxygen, an integrated sensor and microscopy system allows for the monitoring of the corneas.

The patented bioreactor was developed by the Fraunhofer Translational Center for Regenerative Therapies at Fraunhofer ISC. In the BioCor project, the bioreactor will be tested in collaboration with the University Hospital of Würzburg as part of biological tests and validation studies. In addition to improving the availability of donor corneas, the project team expects advancements in medical research, for example, in testing active substances on tissue cultures instead of in animal testing.

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With funding from the:
 Federal Ministry
of Research, Technology
and Space

Due to a scar, the central cornea was replaced here with a transplant that was secured with fine sutures. © Zdenek Jilek / UKW



SUSI—Automated Cell Cultivation

Human induced pluripotent stem cells (hiPSCs) are considered an innovative tool in medicine. They hold great promise for cell therapies and research into diseases—in the future, they are expected to enable the treatment of many conditions, such as neurodegenerative diseases. However, the production of large quantities of hiPSCs remains a challenge, as this cell type requires specific culture conditions to maintain its stem cell properties.

Researchers at the Fraunhofer Translational Center for Regenerative Therapies (TLC-RT) have developed an innovative bioreactor that enables automated hiPSC suspension culture without the use of additional micro-scaffolds. The bioreactor provides optimal conditions such as 37 °C and 5% CO₂ to support cell cultivation.

A key component is the impeller, which performs mixing, aeration, and heat and mass transfer functions to ensure a homogeneous cell suspension. Software simulations were used to determine optimal operating parameters. The bioreactor enables the cultivation of human iPSCs without micro-scaffolds in suspension in a volume range up to 100 ml. The integration of a microscope into the cultivation unit enables online monitoring of the culture in real time and thus automatic monitoring of key culture parameters for quality assurance. The modular system is flexible and customizable. It also enables various cell differentiations and has the potential to produce large quantities of hiPSCs.

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With funding from the:



Federal Ministry
of Research, Technology
and Space

ORINTHERA—Organoids as Innovative Tools for the Development of New Therapies

Clinical and pharmaceutical researchers are constantly working to develop new and improved treatments for diseases. However, before a new drug or therapy can be deemed safe and effective, hundreds of tests and trials are often required—a time-consuming and costly process.

The ORINTHERA research project aims to pave the way for the automated and standardized production of complex cell-based test systems. The scientific focus is on the development and validation of stem cell-derived organoids and the in vitro test systems based on them for preclinical research, e.g., for toxicological risk assessment and/or the development of new active ingredients. This includes, among other things, smart automation solutions, as well as methods for the long-term stabilization of the models and the precise design of biomaterials that serve as biomimetic scaffolds or as novel bio-inks in 3D printing.

An important task in this context is the standardization of processes and protocols. This applies not only to scientific methods in development or production but also to organizational procedures regarding the storage and availability of hiPS cell-derived organoids for industrial applications. Standardized protocols and work instructions help ensure that research results are reproducible and reliable; this is a particularly pressing issue for complex and multicellular systems such as hiPS cell-derived organoids.

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Biomedicine

PhysioINK—Development of Sustainable Bio-Inks for the Production of Physiological Human Organ Structures

3D bioprinting is a technology that could enable the automated production of living organs or at least parts of them at the push of a button in the future. This method could allow for patient-specific organ implants as well as the multiple provision of identical pathological—diseased—tissue models for disease research and therapy derivation. However, replicating the physiological composition and structure of tissues has been an insurmountable hurdle until now. Through preliminary work by the Fraunhofer Institutes ISC and IAP, this hurdle may now be overcome.

The current project PhysioINK coordinated by the TLC-RT of Fraunhofer ISC, builds on the preliminary work of the sister institutes. The project team aims to develop inks made from the most common tissue proteins that can replicate physiological tissue structures without chemical modification. Through targeted macromolecular interactions, the print-ability of the structural proteins under cell-compatible conditions will be achieved, and physiological tissue formation processes will be triggered easily. Innovative companies such as AbbVie, GfN-Selco/KBM, and Blackdrop Bioprinter are supporting the project team as advisors.

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ReBiA—Robotic Enabled Biological Automation: 3D Epithelial Tissue Production

The production of in vitro tissue models—tissue engineering—is extremely sensitive to minimal variations in factors such as incubation times, isolation of human primary cells, composition of prepared cell culture media, and individual practices of operators. Therefore, an appropriate degree of standardization is required to ensure the reproducibility of in vitro tissues and analytical evaluations. To address these challenges, the Robotic Enabled Biological Automation (ReBiA) system has been developed. This system utilizes a dual-arm robot capable of standardizing laboratory processes within a closed automated environment and converting manual processes into automated ones. This reduces the need for process-specific developments, making in vitro tissue models more consistent and cost-effective.

The performance of ReBiA is demonstrated through the production of human reconstructed epithelium, human airway epithelial models, and human intestinal organoids. Analyses confirm that these models correspond to the morphology and protein expression of manually prepared and native tissues, with similar cell viability. These successes highlight the potential of ReBiA to break down barriers to broader acceptance of in vitro tissue models and support a shift towards more ethical and advanced research methods.

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Funding:
PhysiolINK
Fraunhofer-Gesellschaft e. V.
PREPARE-Project

ReBiA
Deutsche Forschungsgemeinschaft DFG

Outlook Industry

QUALITY ASSURANCE

Analytics and Characterization at Fraunhofer ISC

In-depth material expertise across various fields, modern testing and analytical methods, high-quality laboratory equipment, and tailored solutions for a wide range of questions: The Center for Applied Analytics (ZAA) offers customers from research and industry a broad array of testing and analytical methods, including analytical support in the development of new products and ideas, as well as the development of new testing and analytical methods customized to individual requirements, in close collaboration with clients.

The core competencies of the ZAA encompass all relevant areas of sample preparation, analytics of nanomaterials, chemical, physical, and thermal analytics, as well as surface and materials analysis.

The ZAA provides a comprehensive portfolio of advanced chemical and physical analytical methods for determining material properties. These include, for example, the chemical analysis of glass and glass products, contamination analysis on surfaces, the investigation of material damage, or the thermal behavior of materials under various temperature conditions, as well as specific testing methods, e.g., for particle characterization or hydrolytic resistance according to EP/USP.

The Center for Applied Analytics is also a RAL and EUCEB testing laboratory for mineral wool and has been accredited for testing in the following areas according to DIN EN ISO/IEC 17025:2018: chemical analytics, chemical surface analytics, electron microscopy. The accreditation applies to the scope defined in certificate annex D-PL-11140-12-00.

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Nanomaterials | Damage Analysis | Thermal Analytics | Materials Analysis
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QUALITY ASSURANCE

Accreditation of the Mechanical Testing Laboratory at HTL According to DIN EN ISO/IEC 17025

Since January 2024, the mechanical testing laboratory at the HTL Center has been accredited by DAkkS for various testing procedures according to DIN EN ISO/IEC 17025. The accreditation is a significant milestone for our laboratory and confirms an extraordinary level of quality, but it also brings new challenges and opportunities.

Reliable characterization of material properties and the determination of key parameters are critical factors that must meet high standards, both in the development of new materials and in their application. The mechanical testing laboratory at the HTL Center has been successfully providing reliable material properties for various projects and partners from research and industry for years.

In contrast to the certification according to ISO 9001, which has been valid for the entire HTL since 2013, accreditation according to DIN EN ISO/IEC 17025 is granted specifically for certain areas of activity. The certification served as a baseline from which we were able to build successfully to achieve the necessary quality level for accreditation.

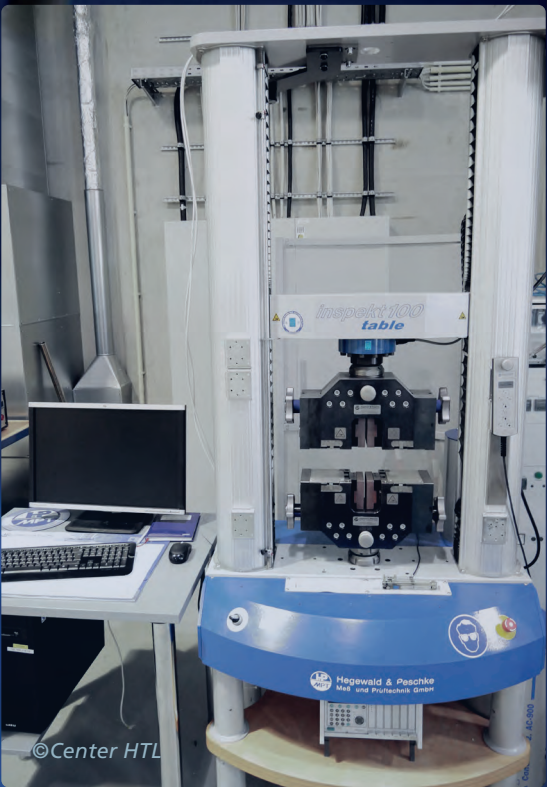
The accreditation introduces new processes and an expanded field of activity for quality assurance. In addition to the annual calibration of all equipment and measuring instruments already conducted, regular reference measurements on appropriate sample materials will now also be

performed. Additionally, regular laboratory comparison tests with external testing laboratories will be conducted.

The accreditation was carried out in close cooperation with our existing quality management. Regular training for laboratory staff and internal audits have contributed to maintaining standards and increasing efficiency. The testing standards included in the accreditation will be gradually expanded.

The mechanical testing laboratory at the HTL Center is accredited for the following testing methods according to DIN EN ISO/IEC 17025: bending tests according to ASTM C1341, DIN EN 843-1, and DIN EN 658-3; tensile tests according to ASTM C1359 and DIN EN 658-1; shear tests according to DIN EN 658-5

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QUALITY ASSURANCE

CeDeD—Certified Special Equipment Construction at Fraunhofer ISC

For the development, design, and manufacturing of scientific special equipment and research facilities, the Center of Device Development at Fraunhofer ISC, abbreviated as CeDeD, serves as a central point of contact for internal and external research groups, as well as for industry.

The researchers at CeDeD design and produce prototypes, demonstrators, and pilot plants for the production and processing of innovative materials, covering the entire development process from 3D modeling to computer-aided component production.

Key tasks include the development and construction of thermo-optical measuring devices for in-situ characterization of materials during heat treatment, such as during melting or sintering. Depending on the equipment, the method allows measurements under controlled atmospheres and temperature conditions ranging from -70 °C to +2400 °C.

CeDeD's research encompasses various development tasks to support the material and process development of Fraunhofer ISC. This includes, for example, automation in glass development, quality testing of ceramic balls for ball bearings, and semi-automated calibration of laboratory glassware with high precision. The services offered by CeDeD are in high demand, particularly in the specialty glass and high-tech ceramics industry. By integrating online analytics, vacuum technology, laser processes, and robotics, CeDeD enhances conventional methods and creates optimal conditions for digitized material development and quality assurance in production. CeDeD is certified according to ISO 9001:2015, ensuring complete reproducibility of the process chain.

<https://www.ceded.de>

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PILOT PLANTS

Synthesis and Coating

The EU project INN-PRESSME (see page 13) aimed to develop a Europe-wide ecosystem for the development and upscaling/pilot manufacturing of plant-based, recyclable, and biodegradable materials. For the INN-PRESSME pilot plants, Fraunhofer ISC expanded its synthesis lines for biobased coating materials and particle-based additives.

At Fraunhofer ISC, pilot lines are available for the upscaling of the synthesis of biobased functional and barrier layers up to 100 liters per day. This quantity can coat up to 10,000 m² of film area. The coating materials can then be processed at ISC using a roll-to-roll pilot coating system with a roll width of up to 500 mm.

Advantages for customers and project partners include the extensive material and process expertise of Fraunhofer ISC and the associated flexibility in synthesizing and adapting formulations to the various requirements of customer-specific applications. These range from paper packaging to plastic films to consumer goods and sports articles. The functional layers can repel fat, water, moisture, or oxygen, can be equipped to be antimicrobial or antistatic, increase abrasion resistance, or prevent the migration of odors or monomers, depending on the desired formulation.

Furthermore, the INN-PRESSME Open Innovation Test Bed includes a wide range of additional pilot plants and services distributed across Europe, from raw material transformation and material development to bioplastics and corresponding analytics.

<https://www.inn-pressme.eu>



**Funded by
the European Union**

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PILOT PLANTS

Particle Synthesis

Global economic growth continues to be accompanied by a strong increase in resource consumption. However, since the resources of our planet are limited and cannot withstand the current consumption in the long term, the new motto of modern economics should be: *Less is more*.

As part of the EU project OASIS, production capacities of 12 pilot lines for the synthesis and production of innovative nanomaterials for lightweight construction were established. At Fraunhofer ISC, a synthesis facility for the semi-continuous production of nanoparticles was expanded. The goal of OASIS was to sustain the pilot lines beyond the showcases conducted in the project. For this purpose, infrastructure was provided for small, medium-sized, and large companies, enabling them to access unique facilities and comprehensive knowledge without high capital investments. During two open calls, companies were able to submit their project ideas.

Fraunhofer ISC made an important contribution with its material research and process development to give its customers and development partners the opportunity to produce more sustainable products with fair value creation using fewer resources. In both open calls, the halogen-free, flame-retardant particles from ISC were utilized for interesting industrial projects. In both cases, a more environmentally friendly and resource-saving industrial production was enabled with comparatively low material usage.

The pilot line for the semi-continuous production of nanoparticles established at Fraunhofer ISC as part of OASIS has since been further expanded and used for various customer-specific particle syntheses. It continues to be available for test production and development to interested parties from research and industry.

<https://s.fhg.de/partikelsynthese>



**Funded by
the European Union**

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NETWORKING AND SPIN-OFFS

FIP-FM@KU = Fraunhofer Innovation Platform for Functional Passive Materials at Korea University

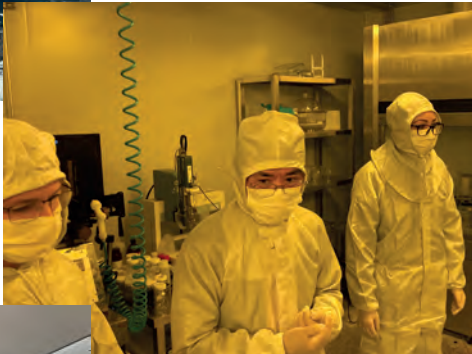
Scientific progress thrives on mutual exchange. With the Fraunhofer Innovation Platform FIP-FPM@KU, Fraunhofer ISC, in collaboration with Korea University, has launched a research and development platform to promote cooperation between German and Korean research institutes as well as industry in both countries. At FIP-FPM@KU, innovative solutions for advanced technologies in the fields of displays, semiconductors, telecommunications, and energy systems are created through the joint development of materials and processes and adapted to future challenges. The Fraunhofer Innovation Platform (FIP) serves as a technology-oriented networking platform in close collaboration with Korean and European companies, research institutions, and various institutes of the Fraunhofer Society.

The goal of the funding program is to validate, transfer, and commercialize research results by strategically combining the complementary expertise of various institutions. In cooperation with German and Korean partners, FIP-FM@KU aims to advance research projects from feasibility studies through to development contracts, thereby making a sustainable, economic, and social contribution. At the same time, FIP-FM@KU represents a significant contribution to the internationalization of Fraunhofer ISC.

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"Of course, with innovation comes challenges, and our research teams are working tirelessly to meet them."

Prof. Miriam Unterlass | Fraunhofer ISC



© Gerhard Domann



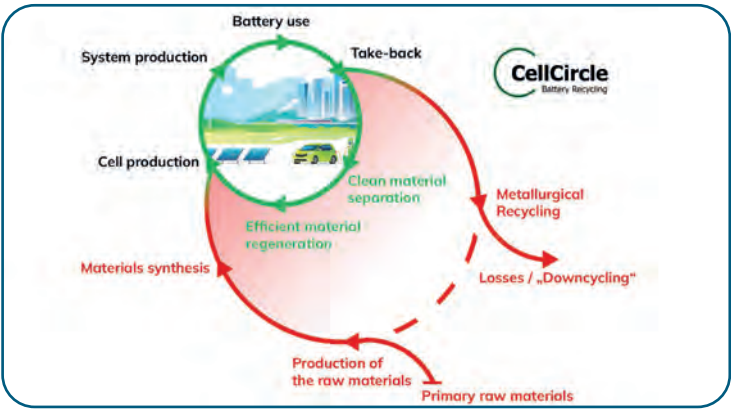
NETWORKING AND SPIN-OFFS
Start-Up CellCircle—Green Solutions "Made in Germany"

Efficiency, innovation, sustainability—this is the mission of the start-up company CellCircle founded in 2022 as a spin-off of Fraunhofer ISC. Following the concept of a circular economy, the company aims to commercialize an innovative recycling process for batteries that separates and regenerates lithium-ion batteries with high purity for direct reuse. This saves energy- and chemical-intensive intermediate steps, making the recovered materials directly reusable for the production of new materials.

The result is an efficient closed-loop material cycle through the recovery of functional materials. The method is more efficient, faster, and reduces CO₂ emissions by up to 50 % compared to previous methods. This innovative approach has garnered significant attention, leading the start-up to secure the first place in the *Energy Start-Up Bayern Founder Competition* organized by the Bavarian State Ministry for Economic Affairs, Regional Development, and Energy in 2024.

In addition to battery recycling, the company also sells battery materials and facilitates their recovery from battery waste. Furthermore, CellCircle offers consulting services to companies regarding suitable recycling solutions, assesses recycling processes, and provides recommendations for recycling-friendly product design and the creation of life cycle assessments for recycling options.

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©CellCircle.de

"The efficient recovery and regeneration of functional battery materials must become a matter of course in the future."

Dr. Andreas Bittner | CellCircle



cellcircle.de

WWW and Social Media



Our Websites

www.isc.fraunhofer.de

www.fzeb.fraunhofer.de

www.htl.fraunhofer.de

www.regenerative-therapien.fraunhofer.de

www.ceded.de

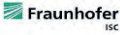
www.glas-dienstleistungen.de

www.analytik-dienstleistungen.de



The complete annual report of Fraunhofer ISC online

<https://www.isc.fraunhofer.de/en/publications/annual-reports.html>



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ABOUT FRAUNHOFER ISC

FIELDS OF ACTIVITY

SUSTAINABILITY

FOCUS AND EVENTS

PUBLICATIONS



Materials Enabling Innovation

Materials with precisely tailored properties are the foundation of technological progress. The performance, functionality, and cost-effectiveness of a product are largely determined during the development and selection of the right material.

This is where the Fraunhofer Institute for Silicate Research ISC in Würzburg applies its extensive expertise: With outstanding materials science capabilities and many years of experience in the processing, application, and analysis of materials, the institute supports companies in successfully transferring innovative materials and technologies into practical applications.



WARNING: This video contains rapid changes in lighting and strobe effects.

Scarcity of raw materials, competitive pressure, and a shortage of skilled workers are just some of the many challenges facing the manufacturing industry. Researchers at the ISC focus on industrially applicable solutions, including affordable healthcare and regenerative therapies, resource and energy efficiency, as well as sustainability and the circular economy.

Particular emphasis is placed on the use of bio-based and economically viable raw materials, reducing the use of critical raw materials, and developing intelligent and sustainable processing technologies.

Looking for the right material solution for your application?

We look forward to discussing your requirements and finding the right approach together.

SEND REQUEST



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NEWSLETTER

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