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LBF

Fraunhofer Institute for Structural Durability and System Reliability LBF

# Safe. Digital. Sustainable.

**Annual Report 2022**

1938 – 2023
**85 Years – Safe. Digital. Sustainable.**

**Environment, safety, "Smart Services" – we at Fraunhofer LBF are also working on solutions to these global issues."**

**Editorial notes.**
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# 2022 at a glance



**The annual report 2022 – digital**
www.lbf.fraunhofer.de/annual-report

1938 – 2023
**85 Years – Safe. Digital. Sustainable.**

"Sustainability, digitalization and lightweight design are key challenges of our time. We provide smart solutions in technical applications."

**Prof. Dr. Tobias Melz,**
Institute Director





# Safe. Digital. Sustainable.

**Dear customers and partners of Fraunhofer LBF,**

Safe. Digital. Sustainable. This is the motto that defines our institute's agenda for the future. In 2022, we once again aligned our key research topics according to that motto: from the development of digital models for components and systems, through development methods and simulation strategies for designing, analyzing and safeguarding critical products, right up to creating concrete, circular material and system solutions. In our numerous research projects, we are expanding our scientific and technological market offerings for polymer materials, durable and intelligent lightweight design, structural dynamics and experimental, digital and cyber-physical simulations. What matters most to us is providing our customers and partners with optimal support as they increase resource and energy efficiency, sustainability and innovation in all product life cycle phases and value chain stages.

Highlights of our work in the area of **safety and reliability** in 2022 included establishing the **Smart Lab for Future Mobility Chassis Systems**. In this modular system, our institute now has a cutting-edge laboratory environment for simulating operating loads for complex and even active component assemblies in automotive engineering systems. The smart lab was set up as an expertise and application center, but it will also promote the transfer of research results to industry.

Vibroacoustic metamaterials (VAMM) have been a core area of research at Fraunhofer LBF for many years, forming the focus of numerous **smart and digital** technology projects in the fields of mobility and infrastructure engineering. Our most recent achievement in this domain saw our researchers develop a prototype for noise-insulating walls as part of their investigations on how to better protect residents affected by road traffic noise. Using metamaterials significantly improved transmission values in comparison to the conventional method of increasing insulation wall thickness. ASFINAG, the Austrian public corporation that manages the country's highways, is currently planning to implement the materials in practice.

In the last year, our scientists have also worked to drive sustainability in multiple projects on **clean, eco-friendly** technology. These projects include efforts to develop biobased, biodegradable plastic solutions with a high technical quality level from recycled materials. In 2022, we also expanded our expertise in the field of recyclable plastics. In addition, we launched and implemented multiple new projects in two of our key research fields: smart, durable lightweight design and resource efficiency.

## 2022 – digital

With this annual report, we are using the digital channels in a new and closely interlinked way. You will find a lot of attractively prepared content within our online presence

**www.lbf.fraunhofer.de/annual-report**

Follow us

Electromobility had its own part to play at Fraunhofer LBF in 2022, as our teams began working on a new application focus with **CyPhy-FuelCell**, a unique validation environment for reliability testing and design in fuel cell systems for electric vehicles.

One particularly notable highlight of the year gone by was the founding of Altosens GmbH with the support of the CoLab and AHEAD incubator programs. Building on the foundations of the institute's **DELTA-C®** technology, Altosens is developing a cloud-based monitoring system with force sensors that can be used in applications such as monitoring wind farms. Other collaborative initiatives focusing on sensors saw the development of a technology that is now being tested in technical applications for bolt monitoring.

These are just a few of the research activities that we will present in this Annual Report, which is available in entirely digital form for the first time, in line with our efforts to increase digitalization and sustainability. We hope you enjoy reading this report.

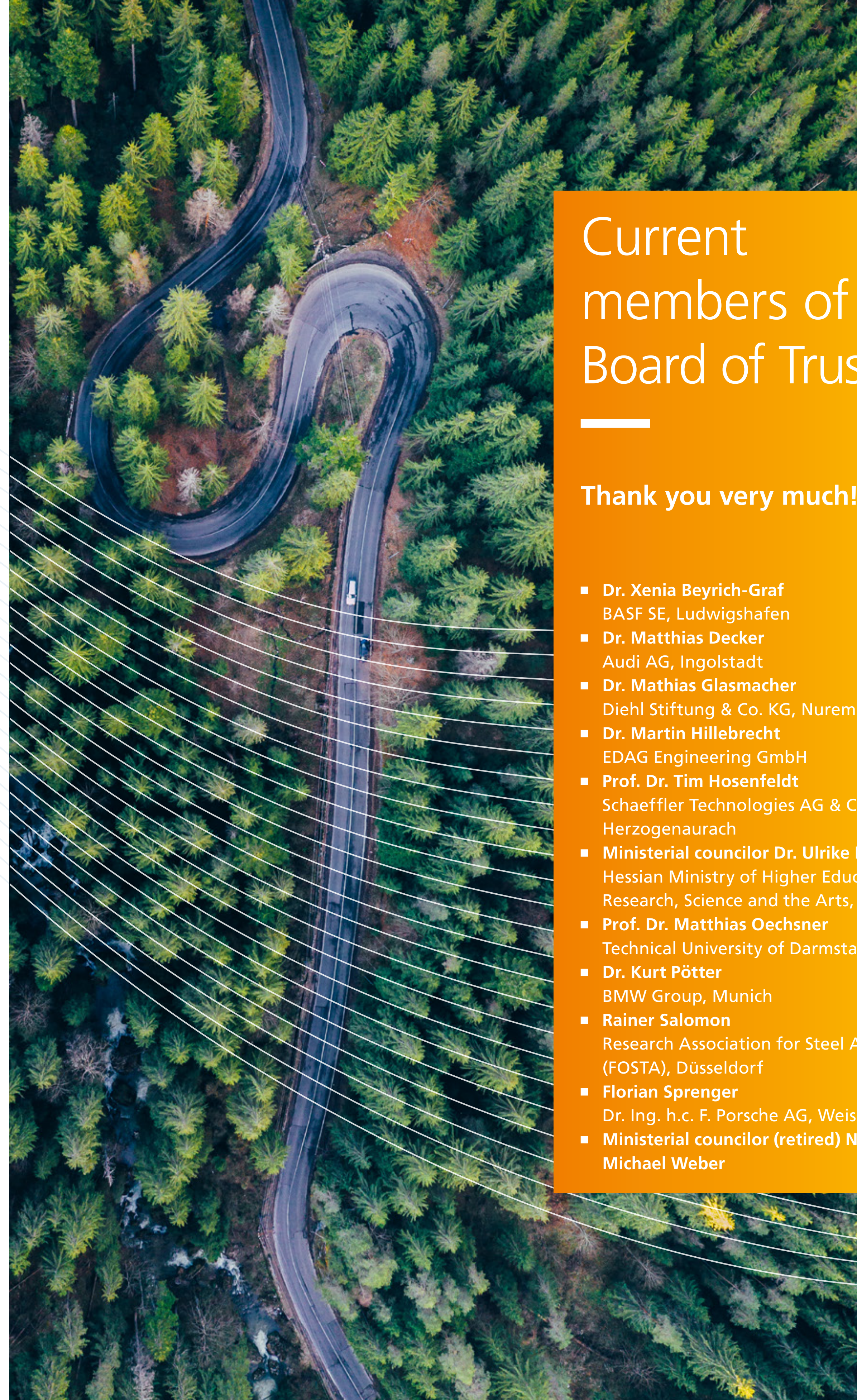
The Fraunhofer LBF team would like to thank you for your trust and collaboration over the past year. In 2023, the year of our 85th anniversary, we would be delighted to continue this relationship and develop customized solutions for the challenges ahead of you.

You are most welcome to contact us and we look forward to collaborating with you.

Prof. Dr. Tobias Melz,
Institute Director

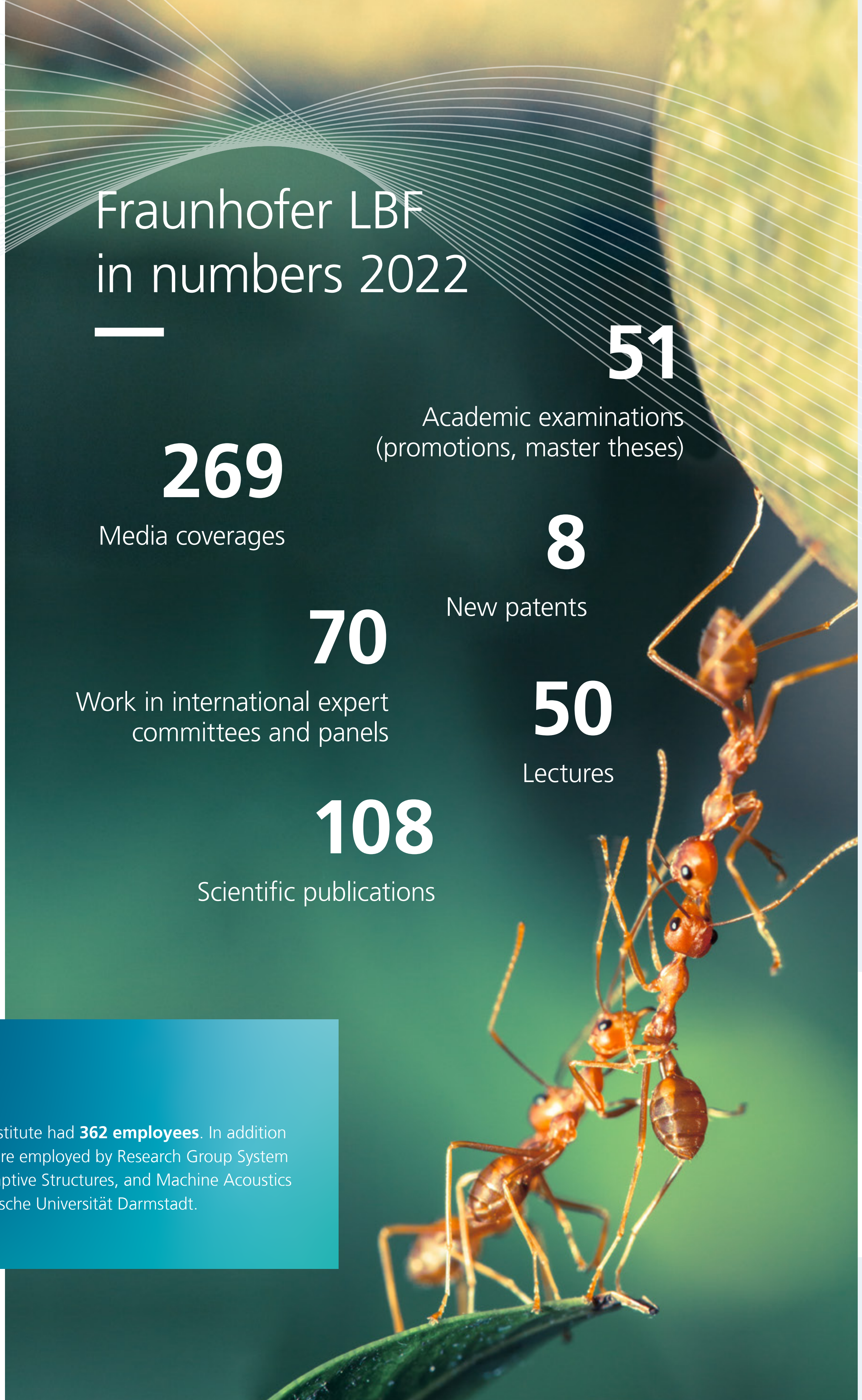




# Current members of the Board of Trustees

**Thank you very much!**



# Fraunhofer LBF in numbers 2022

**51**
Academic examinations (promotions, master theses)

**269**
Media coverages

**8**
New patents

**70**
Work in international expert committees and panels

**50**
Lectures

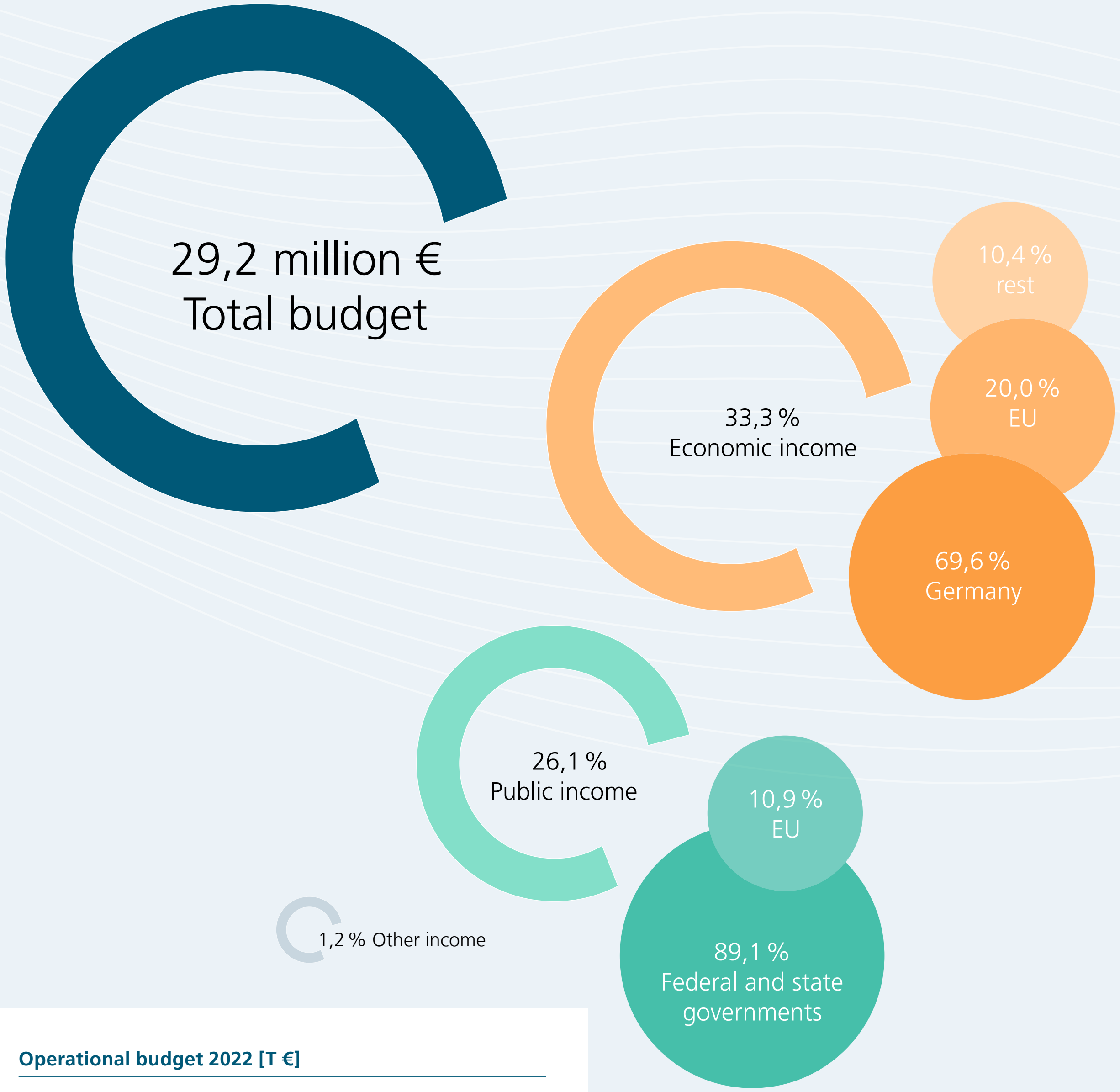
**108**
Scientific publications

**Personnel**

In 2022 the institute had **362 employees**. In addition 27 persons were employed by Research Group System Reliability, Adaptive Structures, and Machine Acoustics SAM at Technische Universität Darmstadt.








**Operational budget 2022 [T €]**

| | |
|---|---|
| Economic income | 9.780 |
| Public income | 7.629 |
| Other income | 365 |
| Internal programs | 4.333 |
| Institutional funding (Grufi) | 7.179 |
| **Total** | **29.226** |

Status: April 2023

# Digital Engineering

## Area of Expertise

The product development of the future is fast, efficient, flexible and digital. In Fraunhofer LBF, we develop innovative modeling and simulation solutions from product creation and use to the end of life. In conjunction with new cyber-physical methods and tools, it is also possible to implement end-to-end validation of products and product functions at the component level throughout the development process. Increasingly scarce development capacities can be utilized efficient by supplementing and replacing specific experimental analyses, as well as through numerical methods and validation processes.

**www.lbf.fraunhofer.de/digital-engineering-en**





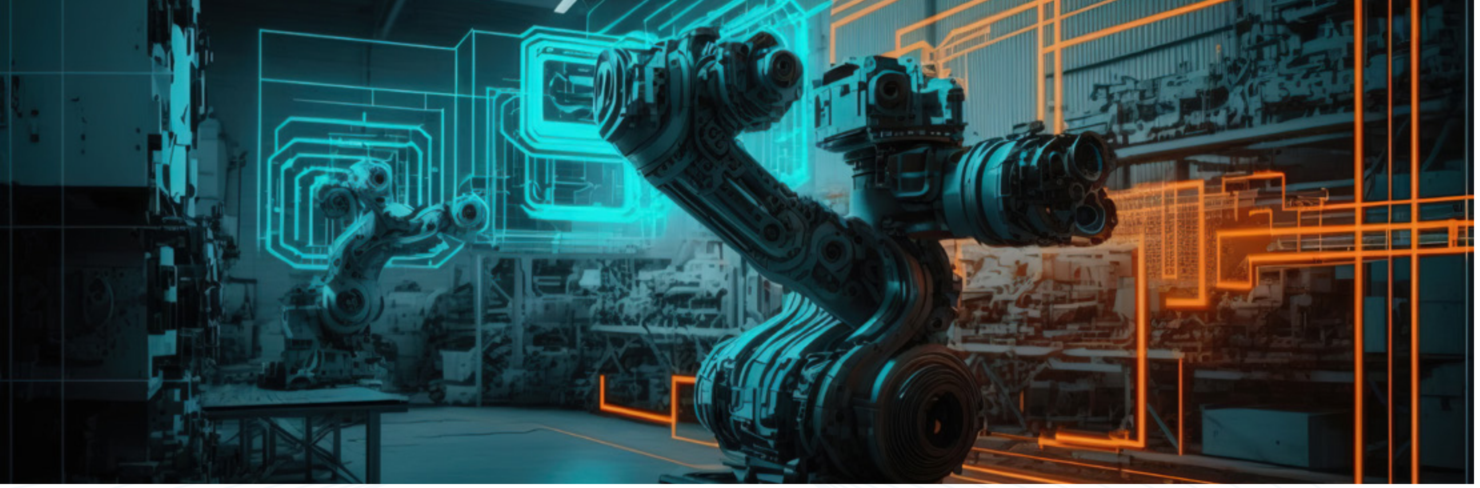
### Using resources wisely for secure, stable and efficient processes

Industrial value creation is characterized by ever shorter product life cycles and, at the same time, increasing product diversity – sometimes with individually tailored properties – as well as the distributed development, realization and use of products. In addition, there are increasing requirements for sustainability and resource efficiency, as well as increased functional complexity of systems in different operating and usage scenarios.

**"We develop the tools to make your digital product development efficient."**

Against this background, product development processes are coming under increasing pressure in terms of efficiency, costs and flexibility, e.g. due to the reduction of available prototype systems or the increasing need for early decision-making and safeguarding processes to accompany development. Alternative development tools and realistic digital models are therefore needed to ensure that the requirements for quality, safety and reliability of the products can still be met. The aim here is to increase the predictive quality of the actual component and system behavior through suitable modeling in such a way that, among other things, the number of prototype systems can be reduced and physical validations can be supplemented and optimized by virtual analyses.

In the **Digital Engineering** area of expertise, researchers are developing new methods and, where necessary, customized tools that aim to virtually map development, safeguarding and validation processes. For instance, innovative modeling and simulation solutions allow for extended functional properties in plastic components and in mechanical systems to be considered in the early design and realization process already. At the same time, usage data from practice, production and operation are integrated for validated modeling and simulation. This allows influences, stresses or damage at the material, component and overall system level to be realistically digitally reproduced. In this way, the number of possible variants for the later realization of a product can be reduced to a minimum at an early stage of the design and development process.



*Fraunhofer LBF helps SMEs conduct rapid feasibility studies to assess new technologies.*

# Agile dynamic systems – AgiDyS

**Rapidly adapting mechanical systems to meet changing requirements**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**Fraunhofer project Generally, when developing a technical system, researchers have to ensure that any vibrations that occur in that system do not damage it, cause inefficiencies in production processes or put people in danger. This is a particular challenge in the case of systems with structural dynamic properties that change during operation, for example, due to shifting loads or varying projection lengths of individual components. Fraunhofer LBF is developing technologies that allow machines or their components to adjust their structural dynamic properties to changing requirements.**

These technologies include devices that make it possible to configure the translational or torsional stiffness of components. If operators also need to configure the damping of a component independently, this can be done through adjustable elastomers. Not only do all the solutions allow for stepless adjustment, but they are also scalable to a great extent ("mm to m", "N to kN") and very easy to implement – no actuators or energy supply required. These technologies were developed by Fraunhofer LBF and can be integrated into customer products or form the basis of new products for our customers.

In our internal research project AgiDyS, we are developing a largely automated design process to facilitate rapid feasibility studies for SMEs; this process makes it possible to quickly adapt the technologies involved to different application scenarios. This results in an efficient assessment of the technology's performance in a concrete use case, which is particularly helpful for SMEs.

TECHNOLOGY TRANSFER, VIBRATIONS, STRUCTURAL DYNAMICS

**Further information online**

www.lbf.fraunhofer.de/agidys-en





# DNAguss: Multicriteria optimization of casting components

**Optimizing castability, lightweight design, structural durability and validation**

**Future project In German, DNAguss draws its name from the notion of fully digital design of casting components along the entire process chain. This research project is focused on optimizing the development process of casting components, based on the example of the material EN-GJS-400-18-LT. The goal is to combine all the software tools used during the construction process for casting components within one software chain, with a view to optimizing castability, lightweight design and non-destructive testing while simultaneously ensuring structural durability.**

The development and design process for casting components usually consists of multiple steps in which different software solutions are used for a range of issues and optimization stages. The DNAguss team is taking an interdisciplinary approach, combining topology and forming optimization, casting process simulation, structural mechanics and structural durability in order to optimize the lightweight design of casting components.

This sequence of interlinked software tools opens up entirely new possibilities for the design of casting components. By integrating all the software tools used in the design process into a single software chain, developers can optimize castability, lightweight design, structural durability and non-destructive testing of components and adjust these parameters to suit each other. This enables improved structural design, reduced component weight and lower manufacturing costs, while simultaneously ensuring structural durability.

SOFTWARE CHAIN, LIGHTWEIGHT DESIGN, OPTIMIZATION

**Further information online**

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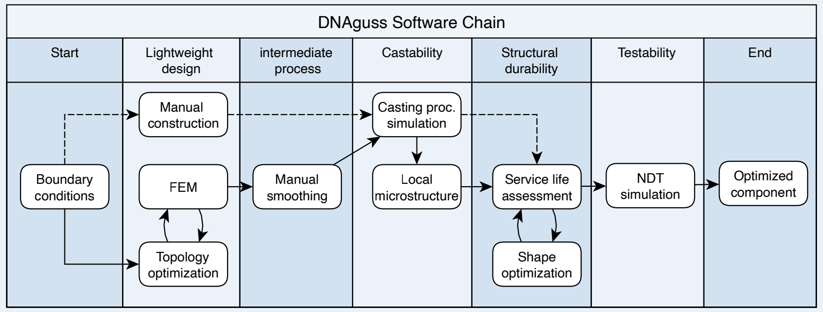



*The DNAguss software chain represents an innovative approach to improving the lightweight design potential of cast components.*

# Which way up? Direction-dependent material properties in 3D printing

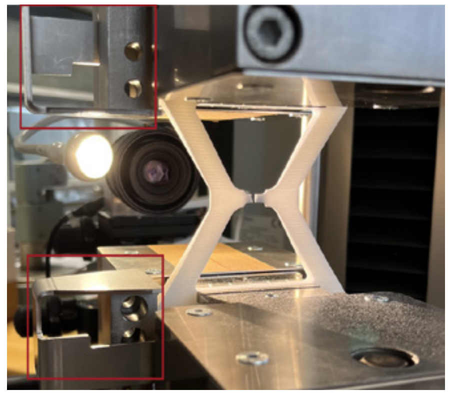
**Project AddiSim focuses on the design of 3D-printed plastic components**

**Further information online**

www.lbf.fraunhofer.de/addisim-en

**Industry project** **If components are structurally identical but printed with a different orientation in the build chamber, they will have very different mechanical properties. Understanding this anisotropy (direction dependence) is an important factor in producing a reliable simulation of a component. In the project AddiSim, scientists at Fraunhofer LBF studied the mechanical properties of SLS printed plastic components and developed a suitable simulation method for the given design.**

The AddiSim team developed a simplified method for the structural simulation of SLS-manufactured plastic components based on their investigations of the components' mechanical properties. Using this procedure, extensive results on the behavior of the printed material are determined based on differently located and oriented specimens in the build chamber. The method generated at Fraunhofer LBF includes important findings for the safe and lightweight dimensioning of SLS-produced components. Although most manufacturers of printed components do not have fully equipped mechanical laboratories at their disposal, they still are expected to develop reliable lightweight components. Fraunhofer LBF can provide assistance here, based on its experimental findings and simplified design methodology.



*The quality of the simulations is tested using validation components. This image shows a tensile test.*

The new material modeling method was developed in the FEA program ANSYS through parameterization of an orthotropic approach based on a linear elastic initial deformation. A Hill yield criterion describes the transition to the plastic stage, which is modeled based on a non-linear solidification curve. The print direction is aligned with the FEA simulation grid via a local component coordinate system.

3D PRINTING, SELECTIVE LASER SINTERING, TENSILE TESTING/MECHANICAL INVESTIGATION, SIMULATION

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**Further information online**

www.lbf.fraunhofer.de/ai-damage-analysis

*Efficiently analyzing elastomer failure – with AI.*

# AI failure analysis of technical elastomers

**Developing an automated detection process for elastomer failure**

**Fraunhofer project** **Elastomer failure needs to be detected quickly and easily – but how? Due the variety of failure patterns that occur on elastomer components, it is not always easy to establish the exact cause of a failure. In the internal Fraunhofer project, AI Failure Analysis of Technical Elastomers, researchers are exploring the possibility of objectively analyzing elastomer failures through artificial intelligence. The resulting process will be transferred to customer-specific applications at a later stage.**

The standard VDI 3822 can be used as a basis for analyzing component failure. However, in this process, experience, expertise and the occurrence of similar failure patterns with differing failure causes can lead to a subjective assessment of the failure. In this project, Fraunhofer researchers hope to automate this time-consuming and cost-intensive process and make it more objective. They also hope to explore the conditions (i.e., input parameters, training data base, extrapolation potential, etc.) that would be required for practical implementation.

To begin with, the researchers are working on a process chain that covers every step from image capturing to reliable analysis of varying forms of component damage; the chain will also include additional material and process parameters. Once the detection, analysis and matching of failure causes and failure patterns are achieved successfully, the team will conduct a detailed analysis of the model's scope of application by varying the component or type of failure. In the process, they will study factors such as the influence of scaling effects or the position and shape of the damage, so that they can draw conclusions regarding any generalization errors the model makes. They will use these findings as a basis for investigating whether the process can be transferred to other use cases.

ELASTOMERS, FAILURE CAUSE, FAILURE ANALYSIS, AI, MULTIPLE INPUT VARIABLES

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# Smart Solutions

## Area of Expertise

In an environment in which value chains, production flows, as well as materials and components are being optimized as much as possible, our researchers are developing smart monitoring systems to prevent damage, limit the need for maintenance and minimize unplanned failures. The targeted influence of vibrational properties of structures in mobile systems, machine learning and promising metamaterials play a major role here.

**www.lbf.fraunhofer.de/smart-solutions-en**

### Everything in view and everything under control to increase technical availabilities

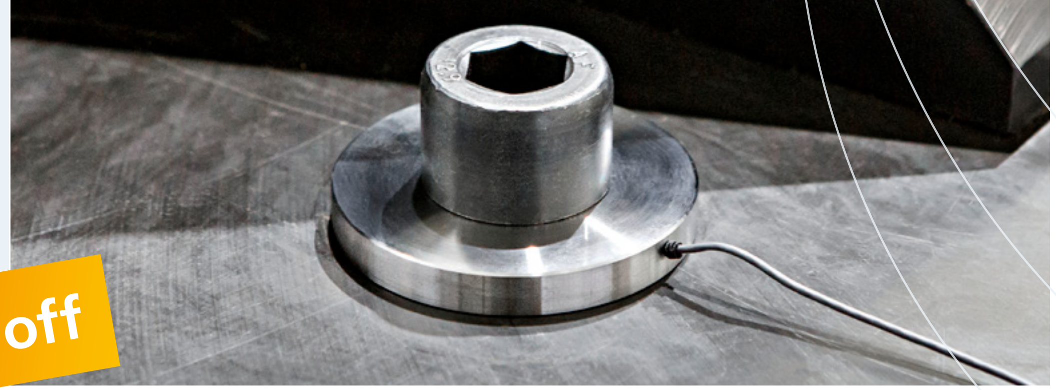
Intelligent sensor technology for the targeted collection and assessment of large amounts of data, increasing networking, function distribution and real-time, cross-system data communication, as well as function enhancement and mechatronization, are all drivers of digitization in modern products. Artificial intelligence and data-based services not only enable process chains in production to be analyzed, simplified and optimized. In fact, they also allow for structural monitoring that is adapted to current environmental and operating conditions, as well as actively influencing factors such as the vibration characteristics of machines and vehicles.

**"Innovative materials and AI-based solutions for intelligent condition monitoring and noise control."**

In the **Smart Solutions** area of expertise, scientists are researching and developing hardware and software solutions, based, among other things, on digital engineering modeling approaches, for smart maintenance applications, for predicting and preventing unplanned machine and system failures, and for increasing technical availability. Another topic is the targeted influencing of the vibration-related properties of structures in mobile systems such as vehicles and in machines and systems. In both cases, machine learning methods are used for the advanced analysis of growing volumes of data, in conjunction with intelligent sensors and sensor networks, as well as integrated actuator technology. In this context, work with so-called metamaterials is going even further. These have high potential for the structurally-integrated influencing and adjustment of qualities such as acoustic or structural dynamic properties for the purpose of the reduction or alternative adjustment undesirable or harmful vibrations and sound radiation. The linking of methods established in relation to reliability as well as in vibration and materials engineering with new data-driven, digital approaches that the work aims to achieve is moreover an important building block for the development and realization of intelligent lightweight structures.

"By partnering with Altosens, we can develop technology further and provide even better support to our customers."
*William Kaal*

Spin-off



*Force sensors for monitoring bolt preload force.*

# Technology transfer through a spin-off – Altosens GmbH

**From sensor technology development to market-ready sensors**

**Further information online**

www.lbf.fraunhofer.de/altosens-en

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**Highlight project** **Dielectric elastomers are smart materials that can act as actuators, sensors and generators and can be used in a highly varied range of applications. DELTA-C® is a sensor technology based on these materials. Altosens GmbH was founded as a spin-off with the vision to translate this technology into market-ready force sensors and providing services based on the technology.**

The digital transformation, industry 4.0 and smart services are creating enormous challenges for the industry sector. Machine learning and artificial intelligence methods are opening up new value creation opportunities based on data-driven business models. One thing that all these applications and business models have in common is that they use multiphysics sensor data. In the internet of things (IoT), sensors are connected to form networks, thus making industrial systems even more complex.

To facilitate access to data without additional effort, machine elements with integrated sensors are being developed, such as connecting elements or storage facilities with an inbuilt measurement functionality.

The current managing director of Altosens GmbH was convinced that the DELTA-C® technology could be a success, so he approached Fraunhofer LBF to discuss the possibility of founding a start-up based on it. The Fraunhofer programs CoLab and AHEAD supported the team on the journey from the initial idea to actually founding the start-up. CoLab brings Fraunhofer technologies and researchers together with existing start-ups and external entrepreneurs interested in founding a company. Meanwhile, the AHEAD incubator program supports start-ups over the course of their journey from formulating the idea to founding the company.

TECHNOLOGY TRANSFER, DELTA-C®, SPIN-OFF





# HyMon: intelligent tanks for hydrogen vehicles

**Sensor-based condition monitoring for vehicular pressurized hydrogen containers made from FRP**

*Automated metrological monitoring of pressurized fiber-reinforced plastics containers makes them safer.*

**Future project** **Fraunhofer researchers have developed technologies for automated condition monitoring in high-pressure storage systems. These technologies can distinguish between critical and non-critical events during operation, meaning that simply replacing the containers at scheduled intervals is no longer necessary. This reduces the costs involved without impacting safety. As such, this development may help fulfill yet more of the requirements for establishing hydrogen technologies on a broad scale.**

Pressurized containers for storing gaseous fuels are a core element of $H_2$ propulsion systems for motor vehicles; however, as safety components, they are also under high levels of stress. Containers made from fiber-reinforced plastics have far less mass than metal tanks and can operate at the same pressure. This makes them an attractive option for the mobility and transportation sector. They are designed for a service life of up to 20 years, at operating pressures of 200 to 1,000 bar.

At present, containers in automotive applications have to undergo a visual inspection every two years. However, this a purely external assessment does not allow the inspector to come to any conclusions regarding the internal state of the thick, fiber-reinforced composite material. If pressurized containers had a built-in structural monitoring system based on suitable sensors and analysis electronics, structural health monitoring data (SHM data) could be used to make the assessment more objective. In the future, a system like this could enable continuous monitoring in $H_2$ fuel cell vehicles ($H_2$ FCEV). Going forward, in addition to supporting repairs and servicing, SHM data may also be used to help suggest targeted measures for safe vehicle recovery during rescue missions in the event of vehicular accidents or misuse.

HYDROGEN, $H_2$, TANKS, PRESSURIZED CONTAINERS, FIBER-REINFORCED PLASTIC, FIBER-REINFORCED COMPOSITE

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funded by:
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**Further information online**

www.lbf.fraunhofer.de/hymon-en

Supported by:

Federal Ministry
for Economic Affairs
and Climate Action

The “Meerwind Süd/Ost” wind farm operated by WindMW GmbH.

# InsituWIND – structural monitoring at offshore wind farms

## Combining radar and reference sensors to detect failures

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**Future project** **Expanding wind energy and reliably feeding renewable energy into the electricity grid are indispensable factors for the energy transition. In project InsituWIND, researchers are developing combined methods for structural monitoring of the grouting in turbines at offshore wind farms, to increase the safety and durability of this element. The team’s solution is a groundbreaking combination of radar and reference sensor technologies, which can automatically identify grouting failures that were previously impossible to detect.**

Grouting structures in offshore wind farms are exposed to harsh weather conditions and high dynamic loads caused by wind and waves. This can lead to wear and failures, which reduces the turbines’ service lives.

In this project, the novel radar and reference sensor technology is being used to conduct extensive, direct qualitative and quantitative analyses of a wide range of real influencing factors (environmental and operating conditions) for a 3.6 MW offshore wind turbine in the “Meerwind Süd/Ost” wind park over a number of years. These parameters will be taken into account in the analysis algorithms. At the same time, researchers at Fraunhofer LBF are conducting laboratory tests on the grouting’s properties under defined loads and without any environmental factors. In these tests, the team applies axial and radial forces to the grouting by means of three hydraulic cylinders, so that the grouting is subjected to a sequence of loads until it finally fails. The experimentation also includes dynamic testing using an electrodynamic shaker, which is applied at certain defined points in the load sequence. In this way, the referenced radar technology can track the failure mechanisms even as they occur and analyze their impact on structural dynamics and integrity.

STRUCTURAL MONITORING, WIND FARMS, RADAR STRUCTURAL HEALTH MONITORING, WIND TURBINES, RADAR

**Further information online**

www.lbf.fraunhofer.de/insituwind-en





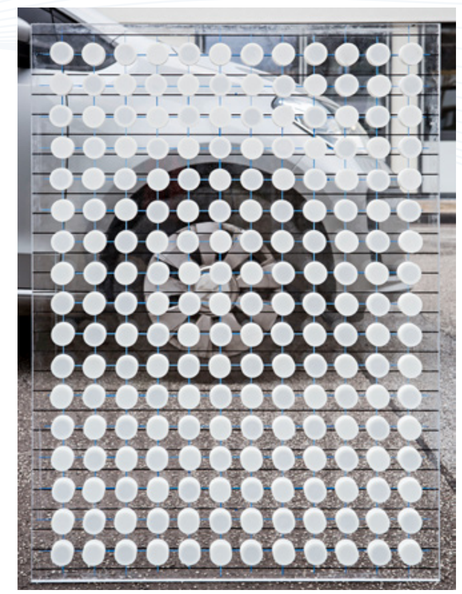
# Noise-insulating walls with vibroacoustic metamaterials

## More peace and quiet for people and animals

**Industry project** **ASFINAG, the Austrian public corporation that manages the country’s highways, has commissioned Fraunhofer LBF to develop a prototype of a noise-insulating wall based on vibroacoustic metamaterials (VAMM). Vibroacoustic metamaterials are a novel technology for dampening vibrations and noise. By adding vibroacoustic metamaterials to a section of an acrylic noise-insulating wall, scientists achieved a significant reduction in the transmission of the typical frequency range for road traffic noise.**

To identify innovative solutions for noise insulation on autobahns, ASFiNAG and the IÖB (the Austrian public procurement body for promoting innovation) launched a competition calling for technologies for reducing autobahn and highway noise. Fraunhofer LBF won out over the many other submissions with its solution for improving the transmission properties of noise-insulating walls using vibroacoustic metamaterials.

The institute went on to conduct a joint research and development project with ASFiNAG, whereby an acrylic noise-insulating wall was equipped with a resonator array so that its sound transmission properties could be investigated. For the resonators, the team used 3D-printed plastic membrane resonators with a steel cylinder inside to serve as a mass element. Measurements conducted at Fraunhofer LBF’s acoustics laboratory have shown that the VAMM principle can reduce transmission through the noise-insulating wall much more effectively than other measures, such as doubling the wall’s thickness. VAMMs can also be used for absorbent noise-insulating walls in cassette construction or wooden noise-insulating walls. The VAMM technology could also offer benefits for other sectors.



*Developing a noise-insulating wall with vibroacoustic metamaterials.*

NOISE INSULATION, VIBROACOUSTIC METAMATERIALS, SOUNDPROOFING

**Further information online**

www.lbf.fraunhofer.de/noise-control

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# Reliability Design

## Area of Expertise

Reliable functioning has always been a key requirement for products. We continuously develop new methods and tools for the reliable design of materials, components and systems. The research and development activities in this area of expertise are aimed at understanding and describing all phases of product development, use and application along with their interactions, in an increasingly comprehensive manner, so that validation and assurance processes can be continuously moved forward into the early design process.

**www.lbf.fraunhofer.de/reliability-design-en**

### Achieving more with less in terms of complexity, stability and reliability

Ever lighter material solutions and structures on the one hand and ever more complex products and systems on the other are shaping product development in many industrial sectors. At the same time, however, the requirements regarding the reliability of such systems are increasing. After all, malfunctions and failures in this context can quickly have critical economic, ecological or health effects.

> **"Our research makes reliable products possible by using reliable processes."**

The **Reliability Design** area of expertise represents a key scientific focus of Fraunhofer LBF. This is not just a matter of ensuring the service life of materials, components and products. Rather, the research and development activities in this area of expertise are aimed at understanding and describing all phases of product development, use and application along with their interactions, in an increasingly comprehensive manner, so that validation and assurance processes can be continuously moved forward into the early design process. In the spirit of "design to reliability", digital engineering solutions are linked with new design and simulation methods. Based on realistic application data in relation to typical mechanical, climatic, electrical and combined multiphysical loads, tools and processes are being developed that take into account the reliable design of structures as early as the design stage. In this way, "safety margins", which, in many cases, are still common today, can be reduced further and further in the future while maintaining or increasing the reliability of materials, components and products, thus enabling modern solutions that push the limits of what is feasible.

The new laboratory facilities were obtained as part of the European Regional Development Fund (ERDF) program, **Smart Lab for Future Mobility Chassis Systems – SmartLab4Chassis**, in conjunction with the Hessian Ministry of Higher Education, Research, Science and the Arts and Hesse WIBank.

**New laboratory facilities**

*Lab facility for validating active suspension/damper systems and air suspension systems.*

funded by:
EUROPÄISCHE UNION:
Investition in Ihre Zukunft
Europäischer Fonds für regionale Entwicklung





# SmartLab4Chassis – Smart Lab for Future Mobility Chassis Systems

## Investigating chassis systems in current and future vehicle designs

**Future project The European automotive industry is changing. The integration of electronic components and expansion of electromobility is making vehicles highly complex and – largely due to the high mass of high-voltage energy storage systems – increasingly heavy. This means that traditional processes for testing structural durability are no longer suitable for reliable development of such vehicles, nor for validating a service life of at least 15 years or 300,000 km. In addition, the future customer requirements will give rise to entirely new vehicle and chassis types.**

At its Kranichstein location, Fraunhofer LBF has established a smart lab for the development, functional verification and validation of the frame and chassis systems that will be used in future vehicles with alternative propulsion systems. As an expertise and application center, the **Smart Lab for Future Mobility Chassis Systems** aims to promote faster transfer of research findings into industrial application, and to make a substantial contribution to the development of low-emission mobility vehicles.

When combined with the vehicle road simulator, which has been operating successfully since 2012, this constitutes a cutting-edge laboratory environment for simulating operating loads in complex assemblies and systems. Specifically, the team behind the smart lab has procured and put into operation a road simulator for vehicles weighing up to a maximum allowable weight of 4.5 tons, and a servo-hydraulic laboratory facility for active suspension/damper and air suspension systems with the capacity to superimpose a simulated environment (temperature, humidity). Real-time hardware is available that allows both systems to be controlled "in the loop" to test out new control requirements, or model the behavior of an entire system, for example.

*Road simulator for validating entire vehicle frames.*

VEHICLE FRAME, AIR SUSPENSION, ACTIVE DAMPERS, STRUCTURAL DURABILITY VERIFICATION, FUNCTIONAL VERIFICATION, HIL

**Further information online**

www.lbf.fraunhofer.de/smartlab4chassis-en

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# Sports car prototype: Endurance test in Darmstadt laboratory

## Chassis testing in new multi-axle testing environment

**Further information online**

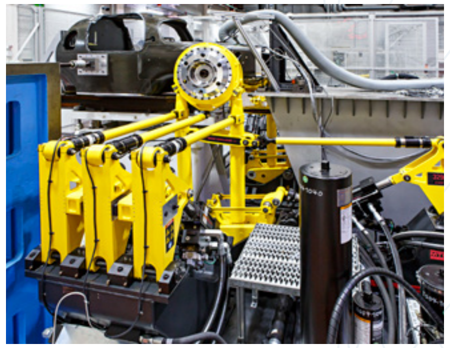
www.lbf.fraunhofer.de/sportscar-prototyp

**Industry project** **Road vehicles must be guaranteed to operate safely and reliably. Their chassis in particular are under close investigation during the development phase to ensure the safety of the vehicle's occupants throughout its entire useful life. Experiments are carried out in the laboratory or during a test run to provide conclusive evidence of structural durability.**

This method for ensuring structural durability is also used for sports and racing cars, which are subjected to considerably higher and more frequent lateral and longitudinal acceleration than normal passenger cars. Fraunhofer LBF has carried out a structural durability test on the chassis, monocoque, and other safety-related structural components of the Porsche 963 sports car prototype for the Motor Sports Department at Porsche AG. The racing car's 4.6-liter V8 bi-turbo engine can run on renewable fuels and is able to reach a system performance level of around 680 hp with a maximum speed of about 340 km/h. Fraunhofer LBF worked closely with those responsible for structural durability at Porsche's Motor Sports Department (Mr. Rieser) and for operating the chassis test benches at Porsche AG (Mr. Ruder).

### Fast and efficient verdict on structural durability

Sophisticated laboratory technology was required to simulate the forces exerted during operation on a one-to-one basis in the laboratory. This facility is offered by the new 12-channel axle test bench used at Fraunhofer LBF. It was acquired as part of the European Regional Development Fund (ERDF) "Smart Lab for Future Mobility Chassis Systems – SmartLab-4Chassis" initiative, and has been designed with testing powerful and electrified vehicle concepts in mind.



*Flexible and efficient: New "SmartLab-4Chassis" laboratory technology.*

CHASSIS, STRUCTURAL DURABILITY TEST, SERVO-HYDRAULIC LAB EQUIPMENT, OPERATING LOADS

funded by:
EUROPÄISCHE UNION:
Investition in Ihre Zukunft
Europäischer Fonds für regionale Entwicklung

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# Plastics all charged up

## Materials for electrifying and decarbonizing the economy

**Industry project** **It is impossible to imagine the electrical and electronics sectors without the use of plastics. Their easy malleability and outstanding insulation properties have absolutely revolutionized these sectors. For instance, elastomers are used in cable insulation, thermoplastics in housings or equipment cabinets, along with thermoset polymers in circuit board materials or high-voltage insulators. It is vital in every case to describe the plastic or compound in terms of its electrical properties to ensure that it can be used in the relevant application.**

While with some applications, such as the material on the reverse side of solar cells, it is vitally important to have a very small amount of electrical conductivity to help prevent current leaks and long-term corrosion, this can cause problems in other cases, e.g., due to electrostatic discharge. Occasionally, good electrical conductivity is required, for instance, for bipolar plates in fuel cells or conductive textile fibers.

With the wide range of applications, materials and shapes of components involved (plates, tubes, coatings, etc.), adapted measurement and description methods are often required. The scientists at Fraunhofer LBF apply their extensive expertise in a host of projects that involve both adapting and developing methods for characterizing electrical properties, such as electric strength, surface conductivity or permittivity of elastomers, thermoplastics, and thermoset polymers. Fraunhofer LBF has a comprehensive range of state-of-the-art laboratory equipment available for these projects. Researchers are also developing specific measurement devices for customers.

*Measuring cell for measuring volume conductivity and surface conductivity of plastic films and plates.*

SUSTAINABILITY, ELECTRICAL MEASUREMENT, EFFICIENT PRODUCT DEVELOPMENT

**Further information online**

www.lbf.fraunhofer.de/plastics-under-electricity

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The latest information is available on the High-Performance Center's website:

**www.leistungszentrum-wasserstoff-hessen.de/en.html**

**Future technology Hydrogen**

Green Mat 4 $H_2$ Leistungszentrum


# High-performance center GreenMat4$H_2$

### Hydrogen ($H_2$) is a hot topic


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**Future project Hydrogen is the first element on the periodic table, meaning that it is also the smallest, with a radius of around 25 pm. It has one proton, contained in its nucleus, and one electron. In its aggregate state, it is gaseous and highly reactive. Hydrogen is of increasing importance to society, industry and politics, as it represents a future energy carrier that is seen as an important stepping stone toward achieving the Paris climate goals. As an energy carrier that is sustainable and can be used flexibly, hydrogen will be capable of replacing fossil fuels in the future.**

For some years, Fraunhofer LBF has been researching topics related to reliability engineering in materials and components that come into contact with hydrogen. We are currently working with partners at the GreenMat4$H_2$ high-performance center, which has set itself the goal of driving technologies for generating, storing and transporting and utilizing hydrogen in the widest possible range of applications. With this in mind, Fraunhofer IWKS and LBF are further developing their range of technologies in the areas of fatigue, system reliability, special testing technologies, analytics, numerical and experimental simulation, material development and recycling, and component optimization, with the aim of working with partners from research and industry to ensure safer application of these future technologies.

To encourage dialogue between the partners, the high-performance center has also hosted regular $H_2$ meet-ups since 2022. These meet-ups involve inspiring talks, technology presentations and tours, all aimed at intensifying expert dialogue and, in particular, fostering new regional partnerships.

HYDROGEN, RELIABILITY, MATERIALS DEVELOPMENT

**Further information online**

www.lbf.fraunhofer.de/greenmat4h2-en

# Plastics in hydrogen applications

### Innovative design, safe design, reliable testing

**Future project Hydrogen and its associated technologies play a significant role in achieving decarbonization goals and securing energy supplies. The reliability of materials in corresponding systems is crucial to their implementation. Research at Fraunhofer LBF focuses not only on metals, but also on materials made from plastics.**

Plastics are a key factor in the design of sustainable, weight-optimized lightweight structures. They are used in housings and bipolar plates for fuel cells, in pressure tanks, and in component seals or pipelines. In the future, a multitude of existing plastic-based systems will be used in the hydrogen field (e.g., in the natural gas network). For the majority of these materials, however, only a very limited amount of knowledge is available regarding their behavior in the hydrogen context, particularly in the long term. The primary focus here is on influences on their mechanical properties, chemical and physical aging, sorption or diffusion characteristics, and swelling properties during media absorption.

At Fraunhofer LBF, in the course of our work on publicly funded research and bilateral customer projects, our unique combination of interdisciplinary expertise in the areas of materials development, analytics, materials testing and design methods allows us to devise solutions for reliable plastic components for hydrogen technologies. Structural simulations allow researchers to incorporate these results when developing methods for component design.

HYDROGEN, PLASTICS, MATERIAL VALIDATION

**Further information online**

www.lbf.fraunhofer.de/hydrogen-applications


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* These activities are embedded in the hydrogen high-performance center GreenMat4$H_2$.

*The improved formula reduces oxidation of the cable formulation as a result of weathering, increasing long-term stability.*

# Analysis of the interactions between additives and fillers using the example of flame-retardant cable sheaths


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**Further information online**

www.lbf.fraunhofer.de/nanoflame-en

**Industry project Plastics used in cable sheaths must meet high requirements over a long period. The properties that are required, like flame retardancy, are specifically adjusted using additives. As a result of standard EN 50575:2017 coming into force, the more stringent fire requirements can only be met by adding phyllosilicates depending on the composition of the cable formulation. However, doing so would significantly reduce the cable sheath's long-term stability, an issue that the researchers at Fraunhofer LBF have taken a closer look at as part of the "NanoFlame" project.**

The cable sheaths being analyzed are made not only from the polymers polyethylene (PE) and ethylene-vinyl acetate (EVA), but also from a high proportion of the filler aluminum trihydrate (ATH) and nano-scale phyllosilicates that have been modified with an intermediate layer.

Various additives, such as antioxidants and compatibilizers are used to complete these formulations. The project identified additive-filler interactions that are responsible for the lack of sufficient long-term stability. The damage analysis was carried out using ATR-IR spectroscopy, with the data being evaluated using non-negative matrix factorization (NMF).

A method was also developed to allow failure behavior under the influencing factors mentioned to be recognized at an early stage. This can be incorporated into the development of new materials which need to be both flame-retardant and possess suitable long-term properties. The new tool can be used to accelerate the development of cable sheath formulations and can be adapted to other systems.

ADDITIVES, RECYCLING, FLAME RETARDANCY

# Model for testing service life under combined mechanical and hydraulic stress conditions

## Investigating service life in elastomer components

**Industry project When investigating component service life, the value of a test is determined by its ability to realistically simulate all relevant stresses under real-life operating conditions. Pump components are subject to both mechanical and hydraulic stresses. The local elongation maxima of the respective elastomer components are established by superposing both types of stress. These elongation maxima play a crucial role in determining service life. Synchronous application of both stresses serves to establish service life and improve product quality.**

Pressure transducers can be used to great effect to generate hydraulic stresses on components. These typically use hydraulic oil as a medium for directing stresses and building pressure. Elastomer components should only come into contact with media actually used during operation, or other media that are compatible with the former. Unless explicitly intended, direct contact with hydraulic oils must be prevented. As such, particular attention must be paid to hydraulic oils' excellent lubrication properties when it comes to generating pressure to prevent wear in piston cylinder pairs and the elastomer samples compatibility with the media.

Fraunhofer LBF and Robert Bosch GmbH have taken an approach to applying mechanical-hydraulic stresses that involves media separation. The central element in this approach is the use of a flat membrane for the separation. This new experimental assembly allows realistic operating load signals to be applied to elastomer pump components in order to verify service life. The experimental assembly enables the transfer of comparable load mechanisms from the field into the laboratory environment, thus improving product quality.

ELASTOMERS, WÖHLER EXPERIMENTS, MECHANICAL AND HYDRAULIC LOADS

**Further information online**

www.lbf.fraunhofer.de/evaluation-concept


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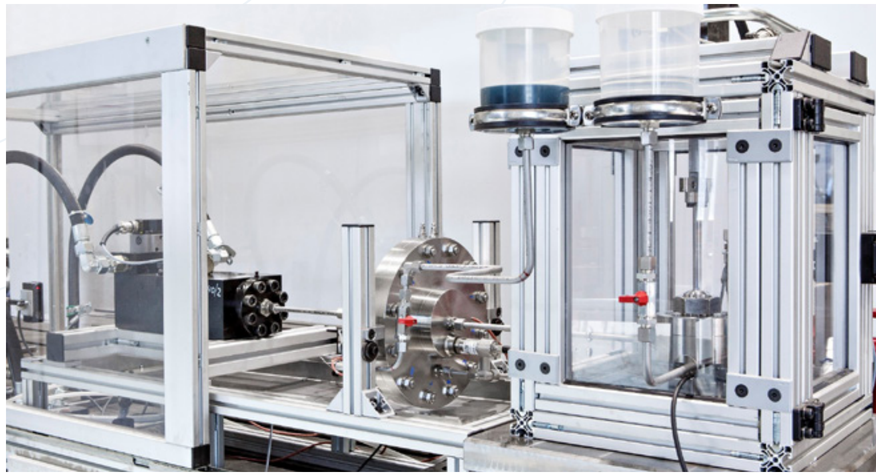
*Experimental service life verification methods at Fraunhofer LBF bring improved product quality.*



# Repair welding of spheroidal graphite cast iron

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**Further information online**

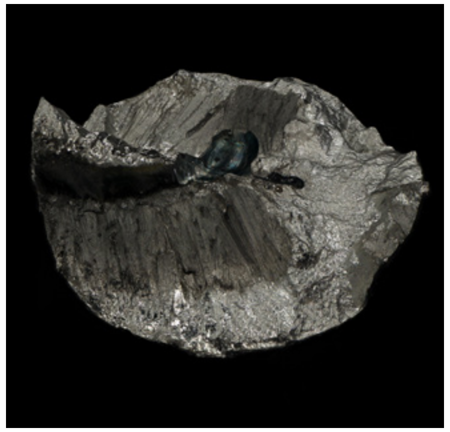
www.lbf.fraunhofer.de/nodularweld-en

**Future project** Components made from spheroidal graphite cast iron (GJS) are used in many areas of mechanical and plant engineering, as well as automotive and energy technologies. The casting process allows for freedom of design, high durability and manufacturing of larger components. Very large, high-mass components that are put under high levels of stress have to fulfill special requirements in terms of fatigue strength and rupture safety. In addition, calls to increase power-to-weight ratios and reduce weight are bringing more complexity to the manufacturing process. This increases the likelihood of mold filling and shrinkage faults, as well as structural irregularities. New repair processes such as repair welding are set to help avoid the high costs associated with eliminating and recasting faulty large-scale cast components.

In the nodularWeld research project, Fraunhofer experts have been investigating both the welding process and how it affects the fatigue strength of three different cast iron alloys that are commonly used in the large-scale casting industry. A comparison of the S-N curves shows that welding reduces fatigue strength, particularly in the high-cycle fatigue range, and therefore decreases load-bearing capacity.

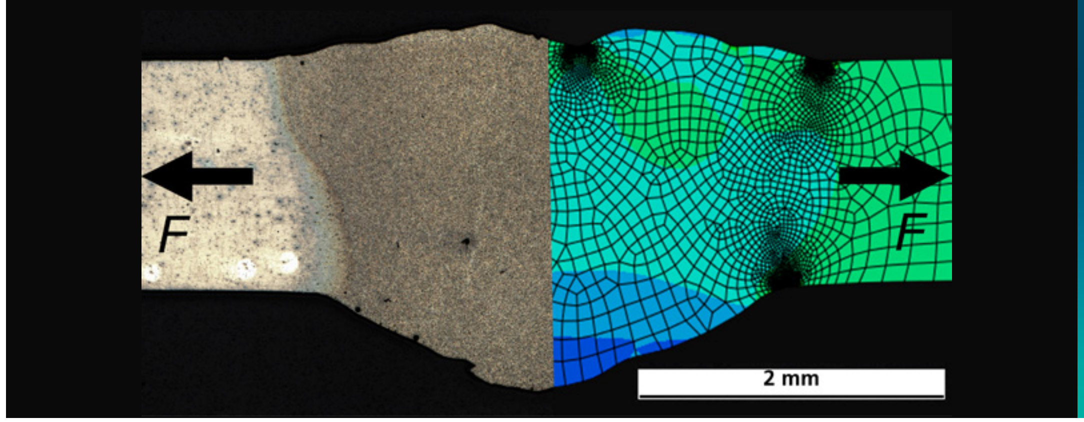
In addition, the test results have a larger scatter and the allowable nominal stress amplitude of materials such as EN-GJS-400-18LT, for example, is reduced by around 38 percent under alternating load conditions and for a service life of $5 \cdot 10^6$ cycles. This must be taken into account when estimating the service life of a potential repair weld, in order to ensure the components reliability. This process is particularly suitable for repairing material sections of the cast components that experience lower amounts of stress.

WELDING, CAST IRON, SPHEROIDAL GRAPHITE, FATIGUE STRENGTH



*Fracture pattern showing typical failure in the area of the weld seam due to defects, as-welded, integral probe A-10, base material EN-GJS-400-18-LT.*






*Cross-section of a laser-welded seam in EN AW-7075 metal sheet with a superimposed finite element mesh.*

**You can find more information online**

www.lbf.fraunhofer.de/allegro-en

# Exploiting the potential of high-strength wrought aluminum alloys in lightweight design

## Assessment of unconventional process technologies for wrought aluminum alloys in the 7xxx series

**Future project** The demand for increased ranges of electric vehicles makes it necessary to further exploit the potential of lightweight materials. Al-Zn-Mg-Cu alloys of the 7xxx series exhibit high lightweight potential due to their high static strengths at low mass density. Due to the challenges of forming and joining these alloys, process-related fatigue strength assumes a key role for their future use in lightweight design applications.

In the LOEWE focus area “ALLEGRO”, forming and welding processes were developed to realize high-quality joints consisting of the high-strength alloy EN AW-7075. In this process, the Fraunhofer LBF carried out fatigue strength investigations using specially developed electro-mechanical and piezo-actuator small-load test rigs. These enable energy-efficient tests on miniaturized and locally removed specimens with a minimum length of 35 mm.

Through “reverse engineering” and based on 3D laser scans as well as metallographic cross-sections of the joining area, finite element models were created. The alloy EN AW-7075 is considered to be weldable only to a limited extent. According to the current state of research, dissimilar joints with additively manufactured structures often lead to defects in the joining area. Nevertheless, it was possible to demonstrate a fatigue strength in a range of welded 5xxx and 6xxx wrought aluminum alloys on the basis of the local notch stress approach for butt-welded and overlapping magnetic pulse welded joints with additively manufactured AlSi10Mg.

PROCESS-RELATED STRUCTURAL DURABILITY, FATIGUE LIFE APPROACHES, CYCLIC MATERIAL BEHAVIOR

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# "We develop sustainable, recyclable and bio-based plastic solutions for a green future!"

## Circular Economy

### Area of Expertise

Plastic materials have a large amount of untapped potential applications. We are intensively working on solutions for resource-efficient, sustainable and bio-based plastics so that they can be used in an environmentally friendly way. Our particular strength is profound expertise in the additivation of plastics in order to adapt highly-specific material properties. Thus, biopolymers made from renewable raw materials can also be adjusted and upgraded for demanding technical applications in terms of their service life, degradation or performance. On the other hand, innovative additive systems allow for enhanced processability and improved end properties for recycled material.

**www.lbf.fraunhofer.de/circular-economy-en**





### Renewable and upcyclable raw materials also for demanding technical applications

Plastics are an integral part of our everyday lives. They offer the widest range of options in material technology solutions for a large number of applications. A wide range of properties can be imprinted in a targeted manner: Foodstuffs are hygienically packaged in a safe and durable way using plastics. As insulating and sealing materials with special fire protection properties, they are a modern building material. As engineering plastics, they offer effective and efficient functional features and lightweight design potential in primary and secondary components – often being shaped in a highly complex manner with defined insulating, vibration damping, sensory or actuator functions.

Yet while their extraordinarily positive technical properties cannot be denied, plastics are increasingly the subject of critical discussion. They are emblematic of modern environmental problems, in the form of microplastics or the pollution of the oceans, which we help to reduce through our research work.

In the **Circular Economy** area of expertise, Fraunhofer LBF scientists are working on sustainable, durable and environmentally compatible plastics solutions, from the molecule, formulation and chemical-physical characterization to synthesis and validation, from use to the "end of life" and recycling – thereby transforming linear processes into circular ones. The particular strength of LBF is the profound expertise in additivation of plastics in order to adapt highly-specific material properties. Thus, biopolymers made from renewable raw materials can also be adjusted and upgraded for demanding technical applications in terms of their service life, degradation or performance.

Beyond that, innovative additive systems allow for enhanced processability and improved end properties for recycled material. Additive systems can significantly expand the possibilities for material recycling of conventional polymers in terms of upcycling. Another field of research involves the development of bioadditives as substitutes for commercial systems which, in terms of quality and performance, achieve comparable properties to conventional additives and in some cases significantly surpass them, e.g. for the weather resistance or flame retardancy of polymers.

# Circular reusable transport solution with integrated air padding

**Sustainable transportation using an adaptable mono-material concept for B2B and B2C**

**Further information online**

www.lbf.fraunhofer.de/reusable-transportbox

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**Fraunhofer project** **Packaging materials are becoming increasingly scarce and are often not environmentally friendly. Conventional transportation packaging is designed to be disposed after a single use, and is often made from corrugated cardboard. At Fraunhofer LBF, researchers have collaborated with Berges GbR to develop an alternative solution to single-use packaging and submitted a patent application. This fully recyclable, reusable transportation solution for fragile goods protects the environment and enables companies to improve their carbon footprint.**

*Upcycling also makes sustainable packaging viable for end users.*

Padding and filler materials are often used to protect goods during transportation; from a purely financial perspective, these materials are currently not worth recycling.

There is considerable potential here for improving sustainability, and this is going untapped.

The fully recyclable, reusable transportation box developed by Berges in collaboration with Fraunhofer LBF offers an alternative solution (registered utility model DE202017106455). To contribute to circular value creation, all the box's components are made from the same class of plastic.

### Functional, flexibly adaptable and individually adjustable

The box contains a reversible inflatable air cushion that can be wrapped around the packaged goods, providing a high degree of protection during transportation. Once the air is let out, the cushion can be folded up. The transportation box can be adapted for specific mechanical stresses, refrigerated transportation and ESD equipment for electronics. Regulatory requirements can also be accounted for. It could also be possible to use sensors to track the box and monitor its status, or fit it with a secure locking system.

The box's individual components are commercially available, which means the whole system can quickly be adapted according to the needs of the respective end user.

CIRCULAR ECONOMY, REUSABLE TRANSPORTATION SOLUTION, MATERIAL RECYCLING





*Sorted and washed post-consumer polyethylene waste broken down into flakes.*

# Recyclate analytics: developing a modern analytics process for post-consumer waste

**Analyzing sorted PE and PP waste**

**Industry project** **Plastic products from recycled materials are becoming ever more important commercially, and support the circular economy. Fraunhofer LBF has created a cutting-edge, high-performance analytics system for sorted post-consumer PE and PP waste. The system allows the sorted objects to be characterized in detail, providing information on whether they contain foreign polymers, additives, volatile organic compounds (VOC) and metallic impurities. This information is essential for evaluating material properties that may affect their possible applications. This opens up new possibilities for developing innovative recyclates in a targeted way.**

### Plastics get a second chance at life

After polyethylene terephthalate (PET), polyethylene (PE) and polypropylene (PP) are the most common commercially used plastics with the widest range of possible applications. A key challenge in developing plastic recyclates from this material flow lies in analyzing the different chemical compositions of the sorted PE and PP waste in detail and finding a representative way of displaying the analysis results for the entire waste load. For this reason, Fraunhofer LBF researchers are developing customized sampling and preparation processes that take statistics into account so as to ensure optimal representation.

This analytical range is suitable for a broad spectrum of waste streams. As these processes cover the analysis of non-polymer impurities, they also address regulatory concerns and issues in processing. This opens up new material and process development opportunities for recyclate developers and processors.

CIRCULAR ECONOMY, RECYCLATES, ANALYTICS

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**Further information online**

www.lbf.fraunhofer.de/recyclates-analytics

# Plastic additives make a significant contribution to improving the quality of recycled materials

**Further information online**

www.lbf.fraunhofer.de/plastic-additives

**Future project** **Post-consumer plastic generally cannot be recycled in the form that it had at the time of production or collection. It will usually be sorted (where necessary), cleaned and reprocessed. The plastic must be treated with special additives in post-stabilization in order for the recycled material to meet the level of quality required for the specific application and be stable enough for processing and long-term use. Stabilizers, compatibilizers and reactive additives can enable recycled materials to reach comparable properties to virgin materials.**

Although stabilizer residue from the plastic's first use can help with the recycling process and further stabilizing the recycled material, it is generally insufficient, especially if the post-consumer plastic was originally used for a short-term application (e.g., packaging) and it is intended for long-term application in its new form. The post-stabilization of recycled materials using suitable additives is an essential step toward improving the quality of recycled materials. The stabilizers used can protect the recycled material from further oxidative and/or photo-oxidative damage, just as with virgin material.

## Additive formula improves film made from recycled plastic film

At Fraunhofer LBF, researchers have succeeded in carrying out post-stabilization on polyethylene films, which can now be produced from recycled film materials. For these films to be reliable and durable, flaws cannot occur during the manufacturing process. By treating the material with a suitable additive formula, the researchers have significantly improved the film's quality. They have also made the production process more efficient and cost-effective.

ADDITIVES, MATERIAL RECYCLING, CIRCULAR ECONOMY

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*Using the right additives produces flawless film.*



*Improved management of fluctuating material flows.*



Supported by:
Federal Ministry of Education and Research

# PET secondary materials from different post-consumer sources

**Influence of the characteristics and formulation of recycled materials on material properties**

**Future project** **Fraunhofer LBF has collaborated with EASICOMP GmbH to lay the foundations for producing long glass fiber-reinforced thermoplastics (LFT) from post-consumer recycled materials outside of the conventional bottle recycling cycle based on polyethylene terephthalate (PET). Identifying suitable material flows presented a significant challenge for the researchers; what's more, the flows in question fluctuate more intensively in terms of material composition, aging and delivery form when compared to virgin plastics or PET from bottles.**

In the UpcyclePET project, a new LFT material has been developed based on used PET drinks bottles. In UpcyclePET-Plus, the research team worked to develop secondary raw material sources that cannot yet be used in high-quality recycling processes. They are planning obtain to new sources of post-consumer raw materials for the LFT material from PET tray fractions from household recycling collections and PET from commercial and industrial waste flows. To identify the most suitable additive strategy for the respective material flow, the researchers need to know the exact composition of input material flow, and must identify and evaluate critical contaminants. They can then determine the type and content of suitable additives and adapt the formula. The LFTs that the Fraunhofer researchers were able to develop from the new material flows have comparable properties to those developed in a previous project. In comparison to LFTs based on PET bottles, which, according to the life cycle assessment by the Öko-Institut, produce 5.1 $CO_2$ equivalent/kg, the new LFT has a reduced $CO_2$ footprint of 3.8–4.4 $CO_2$ equivalent/kg.

PLASTIC ADDITIVES, UPCYCLING, SUSTAINABILITY, SECONDARY RAW MATERIALS

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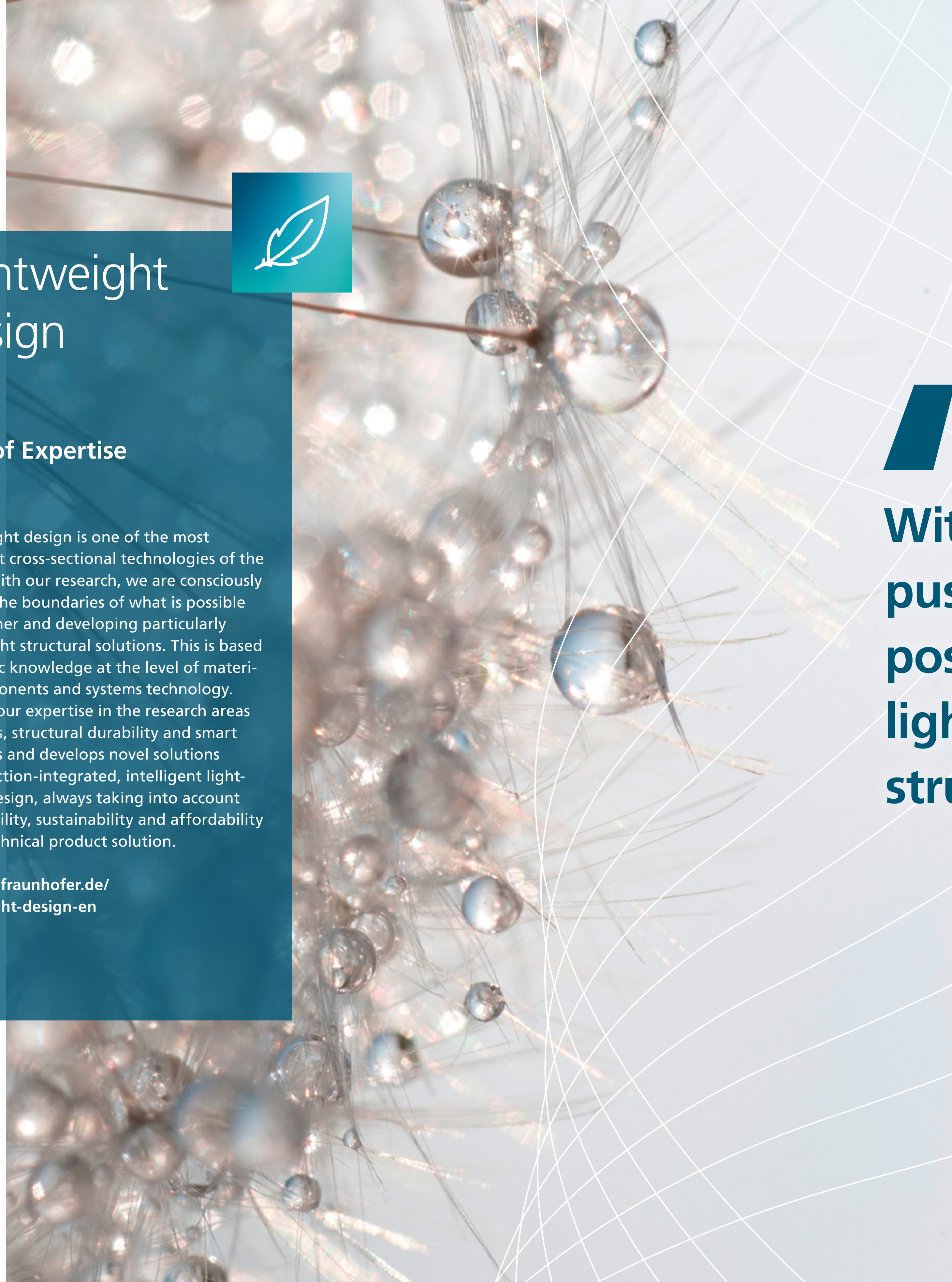


# Lightweight Design

## Area of Expertise

Lightweight design is one of the most important cross-sectional technologies of the future. With our research, we are consciously pushing the boundaries of what is possible ever further and developing particularly lightweight structural solutions. This is based on holistic knowledge at the level of materials, components and systems technology. We pool our expertise in the research areas of plastics, structural durability and smart structures and develops novel solutions from function-integrated, intelligent lightweight design, always taking into account the reliability, sustainability and affordability of the technical product solution.

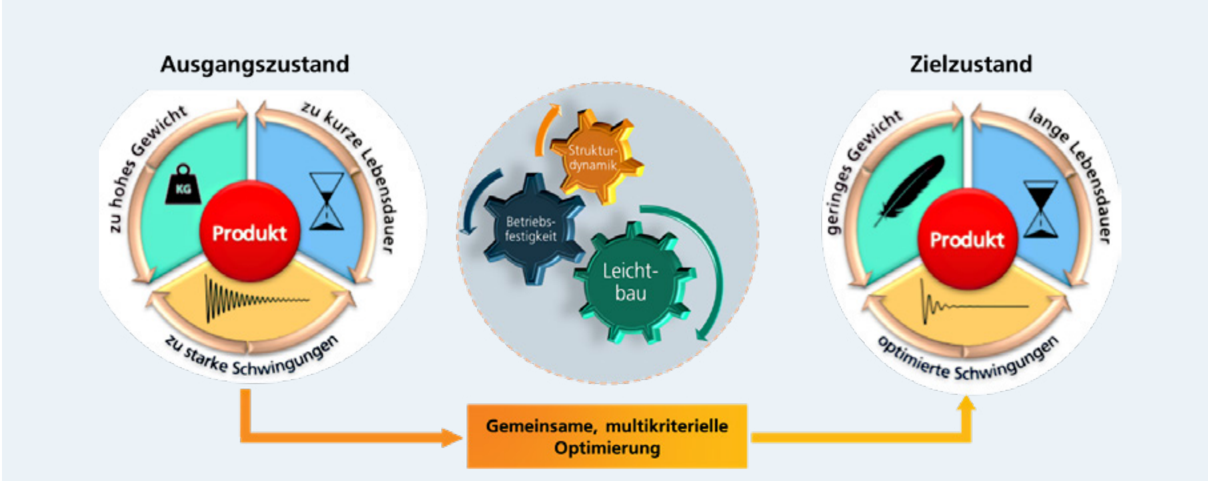
**www.lbf.fraunhofer.de/lightweight-design-en**

### More efficiency for commercially successful products thanks to lightweight technology

Lightweighting has long since ceased to be a “technical niche solution” for aircraft and innovative sports vehicles. Rather, affordable lightweight solutions for the best possible mass and energy efficiency in all mobile systems – such as in the production and operation of products – are key to achieving climate policy goals in vehicle manufacturing, mechanical and plant engineering, energy and the construction industry. Without lightweight design, the possibility of commercially successful products, such as those in electromobility, would become less and less, perhaps rendering them impossible. What is more, successful, safe lightweight design requires comprehensive expertise in reliability and structural durability.

In the **Lightweight Design** area of expertise, LBF is pushing the limits of what is possible even further. This is based on holistic knowledge at the level of materials, components and system technologies. In addition, methods of material construction as well as those of constructive and systemic lightweight design are combined. Fraunhofer LBF pools its expertise in the research areas of plastics, structural durability and smart structures and develops novel solutions from function-integrated, intelligent lightweight design, always taking into account the reliability, sustainability and affordability of the technical product solution. Scientists conduct interdisciplinary research and develop solutions, for example, for functionalized polymers, functionally integrated fiber composite systems, mono and multi-material systems, numeric al and experimental methods of reliability and durability assessment of lightweight solutions, and the use of integrated sensors and actuators for the monitoring and property optimization of structures.

> **“With our research, we are pushing the boundaries of what is possible and developing radically lightweight, property optimized structural solutions.”**




*SMEs benefit from new methodology developed by Fraunhofer LBF*

# Optimizing dynamically loaded lightweight structures

**Further information online**

www.lbf.fraunhofer.de/duradyn-en

**Research project** **Every branch of machinery and plant engineering and the mobility sectors are seeing a growth in requirements in terms of the vibration behavior of components and structures. At the same time, products need to be made as lightweight as possible, while still guaranteeing a sufficiently long service life. The tasks of optimizing structural dynamics, on the one hand, and assessing service life, on the other, are generally considered separately. As part of the "DyraDyn" research project, Fraunhofer LBF is developing a methodology for digitally optimizing lightweight structures, while taking structural dynamics and service life into account. This should benefit medium-sized companies in particular.**

At the heart of this project is the development of a digital method for simultaneously optimizing structural dynamics and the service life of components and systems in a calculation process. With this in mind, a parametric model reduction is being expanded by taking into account modal stresses at critical points, resulting in a service life assessment.

The methods applied for optimizing dynamic systems with passive and active measures, such as using reinforcements, vibration absorbers or inertial mass actuators, are then expanded by assessing the service life so that, for instance, required minimum service lives can be specified as an additional influencing factor for optimization.

The methodology is validated and demonstrated using industry-related application scenarios where particular consideration is given to structures from the agricultural machinery sector.

LIGHTWEIGHT DESIGN, STRUCTURAL DURABILITY, STRUCTURAL DYNAMICS

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# MetaVib – Vibro-acoustic metamaterials for reducing noise and vibration

**New potential lightweight structure for vehicles and machines**

**Fraunhofer project** **To enable machinery and mobility devices to become more economical and sustainable, the components used in them need to be manufactured more efficiently and designed with a more lightweight structure. However, these structures often encounter vibration problems. As part of the "MetaVib" project, vibro-acoustic metamaterials have been researched and developed as an innovative approach to reducing noise and vibration. They offer new freedom when it comes to designing components with targeted vibro-acoustic improvements, while also taking into account criteria for a lightweight structure.**

Currently, vibro-acoustic metamaterials are a topic being researched across the globe in the area of noise and vibration reduction. They can be used to reduce the amplitudes of harmful structure vibrations and noise to such a low level and across such a wide range that would not be possible using conventional measures. They are applied to passive or active local resonators usually arranged periodically on the component to be influenced. The local resonators are tuned into the natural frequency in question and are placed on the basic structure at distances smaller than half the wavelength of the frequency to be influenced. "Stop bands", which are areas where no wave propagation is possible, occur in this frequency range during the transfer function.

*Fraunhofer has developed new concepts and manufacturing technologies for VAMM.*

During the "MetaVib" project, Fraunhofer researchers managed to achieve an effective structure-borne noise reduction of up to 20 dB in defined frequency ranges. This knowledge is provided in a toolbox that facilitates the task of designing and optimizing structures as vibro-acoustic metamaterials at different levels of detail. The design process varies according to the application and supports efficient prototype development in industrial follow-up projects.

VIBRO-ACOUSTIC METAMATERIALS, PASSIVE VIBRATION REDUCTION MEASURES, STRUCTURAL DYNAMICS

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**Further information online**

www.lbf.fraunhofer.de/metavib-en

# Hybrid lightweight wheels

**Secure adhesive joints in highly stressed hybrid structural components**

**Further information online**

www.lbf.fraunhofer.de/gohybrid-en

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**Future project** **The past few years have seen an increased focus on lightweight development processes for components and systems – particularly in the mobility sector, where there is huge potential for the use of mixed construction methods using light metals and fiber-reinforced plastic. However, the process of designing hybrid structures that are exposed to high levels of stress presents particular challenges, because the varying degrees of thermal expansion in the materials must be taken into account throughout the construction process and the hybrid joints must be designed safely.**

Hybrid wheels that consist of alloyed aluminum spokes and a wheel rim made of carbon fiber composite are already well-established on the market. These two joints are connected via a highly complex screw arrangement, which runs counter to the principle of consistently lightweight design.

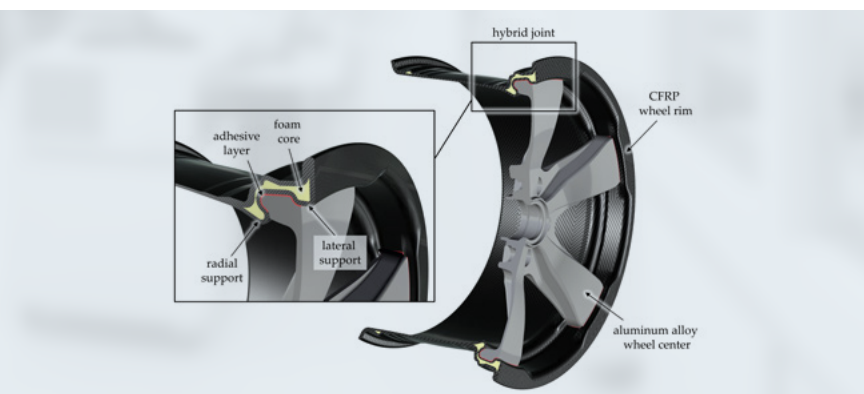
As such, researchers in the GOHybrid project developed an adhesive joint for hybrid wheels of this type. Since the wheels are a safety component, they must be able to reliably resist the high structural stresses that occur during various loading conditions. The individual materials used in the hybrid adhesive joint must be able to withstand both low and elevated temperatures and compensate for the varying degrees of thermal expansion.

Researchers at Fraunhofer LBF have combined this firmly bonded adhesive joint with a form-fit geometry and developed a joining process for the spoke wheel center that can follow the direction of rotation. By adapting the fiber structure in the wheel rim, the team succeeded in significantly reducing the thermal residual stresses affecting the joint. Test results show that the bonded joint exhibits sufficient strength and that the new, form-fit joint is an improvement when compared to simpler bonded joints.

ADHESIVE JOINT, HYBRID JOINT, LIGHTWEIGHT WHEEL

**Supported by:**

Federal Ministry of Education and Research




*New fiber design in the wheel rim area significantly reduces thermal residual stresses.*

*Better life cycle assessment (LCA) and greater sustainability in product development.*

**Further information online**

www.lbf.fraunhofer.de/cooperate-en

# Strong low $CO_2$ components from fiber-reinforced biopolymers

**Development of sustainable, durable components for challenging operating conditions**

**Future project** **Plastic components offer great potential for reducing emissions. As part of the "COOPERATE" project, Fraunhofer LBF is working with partners to develop methods for fundamentally improving the product design in terms of LCA and sustainability. Combining the replacement of petroleum-based plastics with bio-based alternatives and the development of improved methods for designing components favoring a more economical use of materials will cut the $CO_2$ requirement of plastic components by up to 75 % in challenging industrial applications and consumer goods.**

Improving design processes will boost the potential for a lightweight structure as well as the resource efficiency arising from this downstream. The project partners will then jointly develop design methods that favor a more economical use of materials and bio-based composites to produce durable, heavy-duty components. Specific use cases from the automotive engineering sector are being used as a benchmark.

Given that bio-based materials achieve a different performance level than traditional materials, the climate-neutral substitutes will be developed further in this project, while practical analyses will be conducted on the material properties in light of the structurally important characteristic values. One of the upshots from the project has been new calculation methods that consider the influences of manufacturing on the quasi-static and dynamic behavior of the materials.

The new methods developed and the improved material properties will pave the way for new plastics to be deployed in other technology sectors.

SUSTAINABLE, POLYMER, LIGHTWEIGHT DESIGN

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# Future Mobility

## Area of Expertise

Sustainable, networked and autonomous – these features are the hallmarks of future mobility. With our core competencies in Lightweight design, Reliability Design and Digital Engineering tools, we design innovative vehicle concepts. Here, we combine the work of the other areas of expertise in relation to their application in mobility solutions, e.g. cyber-physical methods for the validation of new mobility technologies that accompany the development of alternative drive concepts, component-integrated battery systems or innovative ultra-lightweight design solutions. One focus of the work is electromobility, using both battery-electric and fuel cell systems.

**www.lbf.fraunhofer.de/future-mobility-en**

> **"With our methods, we are also supporting and shaping the implementation of future innovative vehicle concepts."**





### Pooling expertise for sustainable, connected and autonomous mobility

Mobility is undergoing a sustainable transformation process. It is increasingly understood as a networked system of different mobility solutions and operator models. The demands on mobile resource efficiency have once again massively increased, not least due to criticism regarding increasing pressures in relation to climate change and the decarbonization required. They make it necessary to develop new drive technologies, lighter construction methods and alternative mobility concepts.

The progressive electrification of mobile systems, the intermodality of modes of transport and the introduction of increasingly automated driving functions are an essential building block in the movement toward future mobility, from a technical and organizational perspective. The same applies to the increased use and development of new small and micro vehicles in the field of private transport, such as pedelecs, cargo bikes, e-scooters – or increasingly drones.

The topic of shared mobility also offers technical challenges ranging from smart digital solutions, app developments, and distributed functions to material technology – especially because, in this context, it is necessary to master entirely new usage scenarios. New future mobility solutions whether on land, by road or rail; on water or in the air – must function safely and reliably, while, at the same time, being cost-effective and efficient to implement and operate. Yet they must also meet the ever-increasing requirements in terms of the number of mobility carriers, individualization and sustainability in the passenger vehicle, commercial vehicle and special vehicle sectors. The consistent focus on a thermoplastic and thermoplastic-based approach has led to questions being asked about suitable lightweight solutions, reliable system design, intelligent structural and monitoring functions, sustainable materials and even the use of biomaterials.

In this context, the **Future Mobility** area of expertise at Fraunhofer LBF combines the work of the other areas of expertise in relation to their application in mobility solutions, e.g. cyber-physical methods for the validation of new mobility technologies that accompany the development of alternative drive concepts, component-integrated battery systems or innovative ultra-lightweight design solutions. One focus of the work is electromobility, using both battery-electric and fuel cell systems.

# Minimizing friction losses

**New star-shaped polymers reduce friction when used as a lubricant additive**

**Further information online**

www.lbf.fraunhofer.de/prometheus-en

*The star polymer in the form of a highly viscous liquid.*

**Future project** **Lubricants are used to reduce friction and wear in moving machine parts. Reducing friction can significantly contribute to energy savings and lower $CO_2$ emissions. Selecting suitable base oils and using additives to assist with lubrication are both essential measures for minimizing friction losses. These friction modifiers (FM) include surface-active polymers that form a protective polymer layer on the surface.**

Researchers tasked with creating the formula for a lubricant must confront a conflict of objectives: Low-viscosity oils result in low friction losses in the hydrodynamic range (i.e., when there are low loads, but high speeds). However, at higher loads or low speeds, this leads to greater wear. Polymers on the surface can help counteract this wear. On the other hand, when polymers dissolve into the lubricant, this causes an increase in viscosity, which in turn leads to higher friction loss at low loads and high speeds.

Researchers in the laboratory at Fraunhofer LBF have synthesized a new type of star-shaped polymers that can interact with the surface in a promising way. This synthesis was scaled up to the kilogram mark to facilitate tests by the LBF's project partner Fuchs Lubricants Germany GmbH, who examined its potential to reduce friction in lubricants. The results were impressive: The tests found significantly lower coefficients of friction both in lubricant model formulations and in fully formulated engine oils that contained the new star-shaped polymer.

POLYMER SYNTHESIS, LUBRICANT ADDITIVES, TRIBOLOGY

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*Design freeze in place for the eVTOL autonomous freight transport drone.*

**Lighthouse project**

# ALBACOPTER®: The Fraunhofer-Gesellschaft's eVTOL lighthouse project

**Highlight project** **Fraunhofer is making an important contribution to achieving emission-neutral Urban Air Mobility (UAM) with their development of eVTOL drones for autonomous freight transport.**

Fraunhofer LBF is one of the six Fraunhofer institutes involved. The core tasks at the institute are battery development, aerodynamic design and the construction of the aircraft. In developing a method for designing the structure, the researchers are taking a mission-oriented approach, accounting for requirements in terms of aerodynamics and strength, among other things, during different phases of the flight and for an array of overarching conditions associated with the design and manufacturing processes. The fuselage is designed and constructed to integrate with and adapt to various system components – this includes the battery and emergency rescue systems, electronics, junction boxes, sensor systems in the fuselage and wingtips, and the connection of the engines to the wings via motor support arms. Fraunhofer LBF is leading a subproject on materials and aerodynamic structures, combining its own design methods with the manufacturing technologies produced by Fraunhofer ICT. The results of this subject include the creation of a skeletal hull structure made of pultruded tubular profiles and sustainable, scalable and easily recyclable transport boxes. As part of a subproject on engines, Fraunhofer LBF is developing an energy storage system, thereby contributing significantly to the goal of making the Albacopter fully electric.

With this development, the consortium led by the Fraunhofer IVI aims to make a major contribution to an environmentally friendly, flexible and safe future transportation culture.

AUTONOMOUS FLYING, LIGHTWEIGHT DESIGN, TRANSPORTATION, THERMOPLASTICS

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**Further information online**

www.lbf.fraunhofer.de/albacopter-en

# CIRCULUS – Sustainable battery systems for the energy transition

**Developing a sustainable energy storage system for mobile and, subsequently, stationary use**

**Further information online**

www.lbf.fraunhofer.de/circulus-en

**Future project** **In terms of design, traction batteries are generally not developed for further use as stationary storage systems once they are no longer used in vehicles. However, as they still retain their electrical power values, traction batteries would be suitable for storing energy from photovoltaic systems and, subsequently, for stationary use. Purchasing new cells is expensive, and as a result, stationary storage is often not financially viable – in this context, the use of existing batteries would represent a very sustainable approach. From a systems perspective, however, it presents a challenge.**

Basically, there are three main aspects to be considered in the secondary use of lithium-ion cells or lithium-ion battery systems: the current condition of the cell, the evaluation the battery's continuing safety in view of its age and the design of the battery system as a whole.

As part of the CIRCULUS research project, researchers are developing a battery system designed specifically for a second use phase. The main focus of their work is on creating reliable joints that are reversible, but lightweight at the cell level throughout the entire process, from module fastening to system housing. They are investigating practicable methods for evaluating cells and implementing their plans for quickly and efficiently converting batteries from mobile to stationary applications; they are also exploring financially viable methods of separating and recovering the plastics.

This would result in a sustainable mobile battery system and a real stationary storage system made of aged lithium-ion vehicle batteries that will be installed in a residential area.

LITHIUM-ION BATTERY, SUSTAINABILITY, EMISSION REDUCTION, MATERIAL EFFICIENCY

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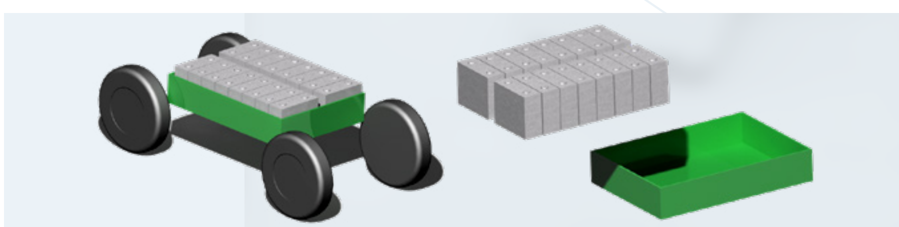
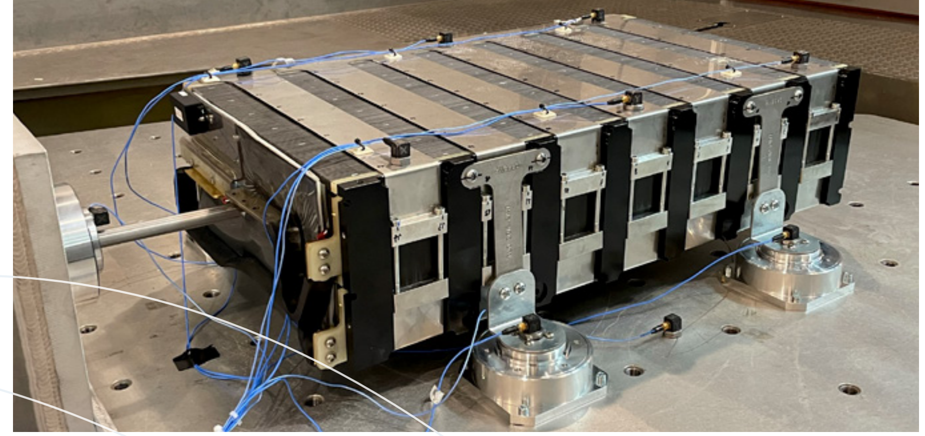


*Symbolic representation of vehicle use and recycling.*







*The cyber-physical validation of fuel cell systems at Fraunhofer LBF.*

# Electromobility: Assessing the reliability of hydrogen fuel cells

**Unique experimental validation environments for hydrogen fuel cell systems**

**Future project** **Experts expect that hydrogen fuel cell systems will quickly enter widespread use. For this, they must need a reliable and efficient design. The systems' materials and components, as well as the system itself, must be validated as early as possible during the development process, in a cost-efficient way that takes operational conditions into account. Further more, it must be possible to conduct the validation without having the entire system manufactured or available. Cyber-physical testing and validation methods could provide the solution here.**

The establishment of an electrochemical energy supply using hydrogen fuel cells would represent an important system solution for commercial vehicles in the context of transitioning to climate-neutral mobility. At the same time, the fact that these cells are used on a non-stationary basis and thus subjected to multiphysical and chemical stresses means that creating a reliable design presents some special challenges.

Fraunhofer LBF is expanding its research facilities to include a hydrogen infrastructure that will supply fuel cell stacks of up to 200 kW; moreover, they will install shakers that work in combination with climate chambers to facilitate vibration studies under environmental conditions, as well as analysis environments for metallic and polymeric materials and components that come into contact with hydrogen. Cyber-physical validation scenarios could provide cost-effective and flexible analysis processes for fuel cell systems and their components in the future, thanks their sophisticated combination of experimental test environments, model-based simulations and cutting-edge information technology with operational stresses.

With the CyPhyFuelCell platform, which involves the cyber-physical validation of fuel cell systems for future mobility applications, the Darmstadt site has gained a unique area of experience and an application focus that represents an important step toward sustainable mobility.

FUEL CELL, HYDROGEN, RELIABILITY AND SAFETY

funded by:

EUROPÄISCHE UNION:
Investition in Ihre Zukunft
Europäischer Fonds für regionale Entwicklung

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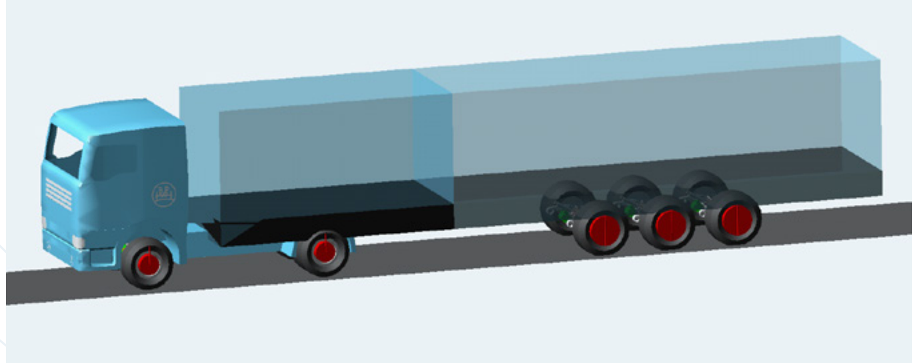

*Multibody simulation model of the entire vehicle (traction unit and trailer) in MSC.Adams.*

# State identification of trailers connected to automated trucks

## Identifying dynamic- and safety-related states using digital twins

**Further information online**

www.lbf.fraunhofer.de/ident-en

**Future project** Self-driving trucks will be on our roads in the future. The question is how the conditions of the trailer can be verified to see that it has no technical faults before setting off if there is no longer a driver. This relates in particular to the components that are responsible for traffic safety and driving stability. Even the driving characteristics of the combined unit that drivers usually sense while driving the vehicle and to which they are able to adjust their driving need to be recorded automatically in the future and considered by the autopilot. Solutions have been devised for these issues as part of the "IdenT" project.

At the heart of the solution is an EDGE device on the trailer, which records, with the help of a network of sensors, metrics such as acceleration and pressure or images from a camera. There is an online digital twin that runs on the computer and processes the data in real time via a vehicle dynamics model of the trailer.

Specific driving situations that require further analysis are identified and automatically transmitted to a cloud-based offline twin for a more detailed assessment.

A vital metric for modeling the digital twin are the coupling forces on the kingpin, which is used to connect the trailer to the traction unit. The forces and moments are recorded at this point and compared with the measurement data so that these interface forces can be reliably determined using models.

A sensor module forms part of the sensor network, which is installed as a hub cap on the trailer's wheel. The small generator, which is powered while the wheel rotates, supplies enough energy to operate the sensors, a powerful controller and various wireless interfaces such as Bluetooth or LoRaWAN. The hub cap sensor can also be used as a standalone device to record, assess and send sensor data.

DIGITAL TWIN, CONDITION MONITORING, KINGPIN, HUB CAP SENSOR

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# The "Forum Plastic Recyclates" discusses how recycled materials are turned into high-performance raw materials.

**Prof. Rudolf Pfaendner,**
Chairman Forum Plastic Recyclates

# 2022 event highlights

We can finally meet in person again. Our research teams attended 15 trade shows, and we organized "public discussion panels" and workshops devoted to specific topics on site in Darmstadt. We have also continued with our virtual event formats.

# Hands-on research

## K trade fair: Efficient manufacturing process for natural fiber reinforced plastics

**Trade show** Lightweight design ensures competitive and sustainable products; however, safety and reliable functioning must still be guaranteed. Researchers from Fraunhofer LBF presented their promising new approaches for sustainable and efficient manufacturing processes with natural fiber reinforced materials. With our project on sustainable battery housing for e-bikes, we are demonstrating the potential for batch production. At Fraunhofer LBF, the quality of products made from plastic recyclates can be efficiently investigated in the early development process, i.e., before batch production. Our exhibit on reliably estimating service life for plastic recyclates was well received (see image left).

## Vibroacoustic metamaterials for the international aerospace industry

**Trade show** At trade shows such as the Space Tech Expo and the ILA, experts from the worlds of industry, research and politics exchange ideas and discuss innovations and developments on topics pertaining to lightweight design. Lightweight design solutions often present problems relating to vibrations. Vibroacoustic metamaterials (VAMM) represent an innovative approach to reducing vibrations; moreover, when it comes to influencing vibration behavior, they offer advantages over conventional measures.

A team from Fraunhofer LBF demonstrated how VAMMs are used to reduce micro-vibrations on optical devices for satellites, before showcasing a sandwich panel for that can bear sensitive satellite components while keeping vibrations to a low level.

## Close to customers

*VAMMs offer structural dynamic solutions for a variety of applications.*



## On site at Fraunhofer LBF

*One highlight of the event showed plastics' fun side*

## Plastic – is it all garbage? Residents of Darmstadt were invited to an open lab event at Fraunhofer LBF

**On site** The visitors learned a lot of new information about "good" plastics. Highlights included the guided tours, short lectures, exhibits and astounding experiments related to recycling and the circular economy. One tangible project result featured at the event was a shopping cart chip made from grass fibers and produced live in the pilot plant. The amount of incorrect or heavily soiled waste in plastic recycling collections means that very little of the plastic inside can be separated by type and go through further processing. As a result, a lot of plastic waste ends up in waste incineration plants or is recycled as a substitute fuel.

**Recycle more plastics, separate waste properly – both young and old participated in activities that produced some valuable tips.**

25 JAHRE WISSENSCHAFTSSTADT DARMSTADT

With this event, we participated in activities celebrating the 25th anniversary of Darmstadt's title as a **city of science** – Darmstadt was the first city in Germany to receive this honorary title.

## Flying the $H_2$ flag

**On site** As part of the GreenMat4$H_2$ high-performance center, Fraunhofer LBF organized regular **$H_2$ meet-ups** and an **OpenLab Day**. The aim is to develop new partnerships, particularly within the region, through inspiring lectures, technology presentations and guided tours. More than 300 people took part.

## Forum Plastic Recyclates

**Online event** The 2022 Plastic Recyclates Forum, which took place virtually, included its first-ever session dedicated entirely to creating recyclates equivalent to virgin plastics in quality. In order to realize the full potential of recyclates, it is necessary to analyze recyclate streams; Fraunhofer LBF addressed the question of whether analytical fingerprinting could advance the cause of a circular plastics economy. Plastics producers and processors, as well as recyclers and interested parties from the automotive, white goods, construction and packaging user industries, took advantage of this excellent opportunity to update their knowledge.

**By the way…**
The 2023 Forum Plastic Recyclates brought together more than 100 in-person participants; planning will soon begin for the March 2024 event in Darmstadt.

# Systematic Research!

We apply our core competences of structural durability, system reliability, smart structures and plastics across divisions and achieve optimal benefits for our customers with innovative system solutions.





# Structural Durability

Structural durability is one of the most powerful means of assessing components and structures in terms of lifetime; as such, it has formed the foundation of our research activities at Fraunhofer LBF since the founding of the institute.

**"We create lightweight design. Reliable."**

The mobility industry, as well as mechanical and plant engineering and energy technology, all benefit from products that are both light and designed to be safe and reliable for the entire operating and usage phase. Our research and work focuses on designing safe components, assemblies and systems for road and vehicle construction, shipping, aviation, crane construction and wind turbines with a strong focus on practical application and ensuring a long lifetime. Our eight-step block program, developed by Ernst Gaßner, ensures our place in the history of structural durability innovations. Today, we combine cutting-edge numerical, metrological and experimental methods of ensuring structural durability to achieve solutions that meet our high standards of quality and actively incorporate related material science and engineering disciplines. Our core areas of expertise involve developing methods and procedures for designing structures with a view towards long lifetimes and provable safety and structural integrity. You will find these in successful products, in material and component innovations as well as in processes, such as in additive manufacturing, for example. Over the course of the digital transformation, these core areas of expertise will be expanded to include powerful tools for cyber-physical simulation and a comprehensive description of cyclic material properties from the LCF to the VHCF regime.

From materials to complete structures: the departments Materials and Components and Assemblies and Systems specialize in issues pertaining to structural durability, providing you with the answers you need to questions around assessing structural durability of metal materials and components, developing numerical methods, describing complex kinematics by means of multibody simulation (MBS), constructing and verifying suitable models for both components and complete vehicles, and formulating time-accelerated test procedures for laboratory testing.

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smart-structures

In addition to function and performance characteristics, sustainability and comfort properties will play an important role in the success of new products and systems in the future. In complex systems with multiple external influencing factors acting simultaneously, the process of designing these properties often leads to conflicting goals, thereby limiting the number of scenarios in which the product or system can operate.

In our research, we concentrate on the dynamic behavior of mechanical components and structures, taking into account how they interact with various electrical or thermal behaviors, for example – areas where conventional development methods often come up short. Our focus is on analyzing, evaluating and optimizing the above-mentioned properties and ensuring system reliability. To this end, we research, develop, validate and apply new forms of passive, active and adaptive structural measures.

We provide support for problem and feasibility analyses, design optimized solutions for our customers and implement them on a prototype basis. The customized tools for multiphysical system design that we have developed at our institute support the transfer of the latest scientific findings into commercial applications. For this purpose, our researchers develop, link and flexibly apply methods from fields such as numerical and experimental structural and reliability analysis, structural dynamics and signal processing. We

**"We design reliable systems with a high degree of autonomy so that they can function optimally in operation."**

use these methods to create reliable, networked and increasingly autonomous structural and system solutions that make use of smart sensor and actuator systems linked by intelligent signal processing.

Our three departments for Experimental Analysis and Electromechanics, Structural Dynamics and Vibration Technology and System Reliability will support you in your research and development process, from the first stroke of the pen to conducting tests in the field. To this end, we provide a comprehensive design chain for reliable, circular and smart solutions for making your product innovations a reality, using building blocks that we adapt on a customer-specific basis.





# Plastics

Only cutting-edge products with reliable and rapid access to innovative and high-performance materials can be offered competitively on the world market today. Tailored plastics, plastic additives, plastic composites and plastic processing technologies play a central role in meeting high global demands in the areas of mobility, energy, environment, communication, health, nutrition and safety. **Plastics** enable tremendous savings in resources and energy as well as a wide variety of options in lightweight design. Particularly when they are fiber-reinforced, particle-filled, foamed or integrated into sandwich structures, plastics can withstand the highest degree of loading and absorb a great deal of energy. They can be supplemented with an additional range of functions such as protection from UV rays and the affects of weathering, reduced fire behavior, functions for the development of special optical properties, electric and thermal conductivity and with sensor and actuator functions. At the same time, increasing demands on sustainability require new solutions in terms of a circular economy and recycling or the development of bioplastics.

All components relevant for the implementation of sophisticated plastic applications, running the scope from basic natural science disciplines such as chemistry and physics, material sciences and material technology in processing to expertise in analytics, testing and modeling, are united at a high level under one roof.

This is what the following four departments – complementary in their disciplines and methods – "Polymer Processing and Component Design", "Material Analytics and Characterization", "Additivation and Durability" and also "Synthesis and Formulation", stand for.

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plastics

**"We develop long-lasting and safe plastics with improved recyclability as well as new technologies for an efficient circular economy."**

# LBF Management Team

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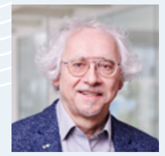

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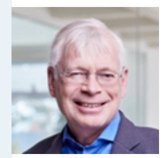

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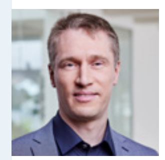

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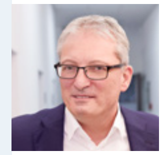

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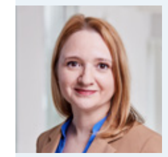

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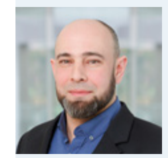

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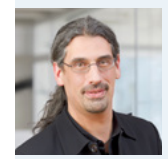

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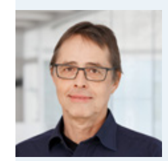

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# Networks

With our involvement in alliances and market-oriented networks both within and outside of the Fraunhofer-Gesellschaft, we expand your and our possibilities in technical and economic terms. LBF is firmly anchored in the Fraunhofer Group for Materials and Components, which has been pooling the expertise of the materials science-oriented institutes of the Fraunhofer-Gesellschaft for more than 20 years. In addition, the close, interdisciplinary cooperation with our specialized sister institutes in lead-market-oriented alliances creates excellent conditions for the development of our system services and reinforces our innovative strength for the design of your product developments. Since 2019, we have also been involved in the Group for Defense and Security (VVS).

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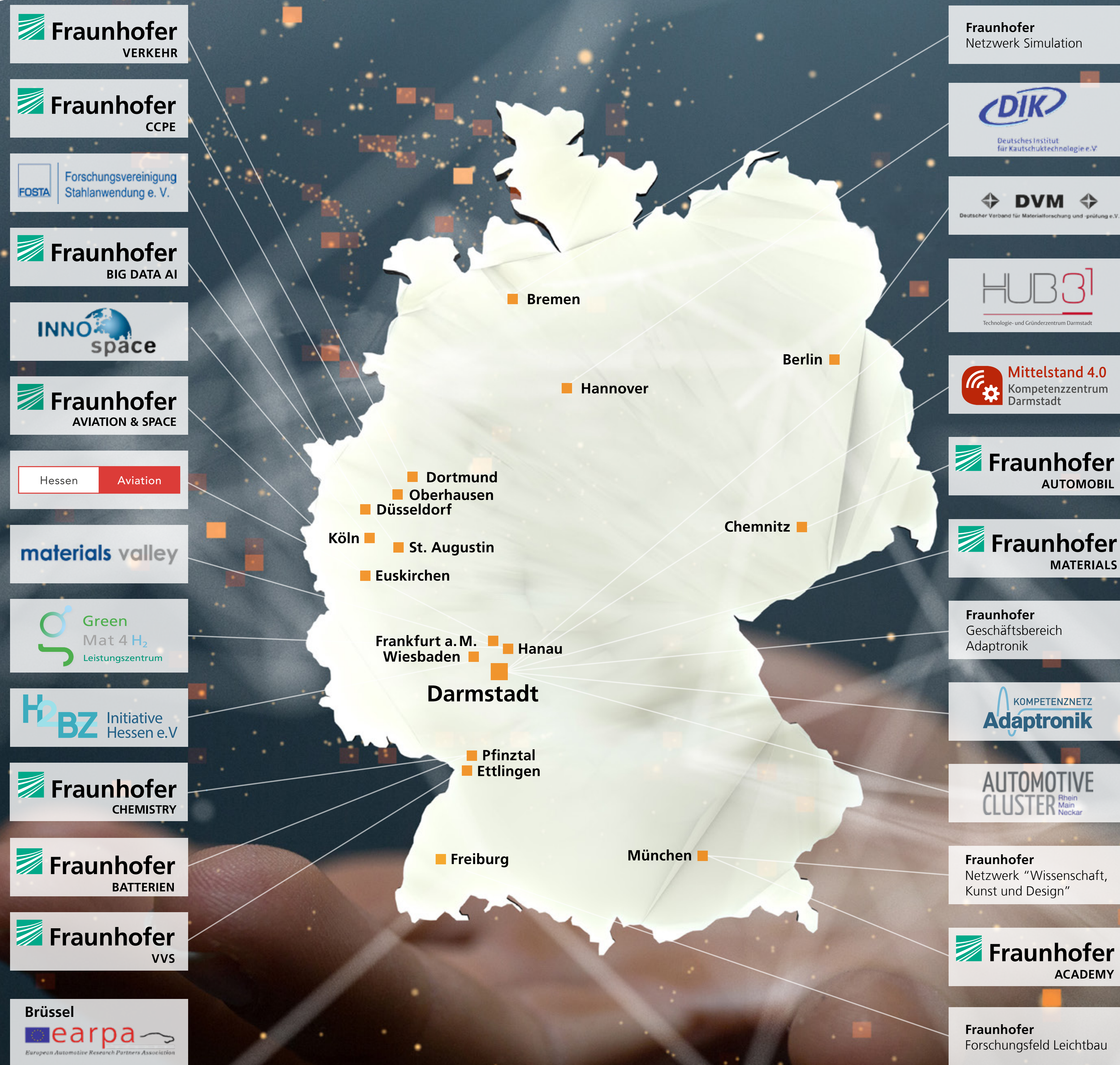

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