Fraunhofer

High-Performance Center Hydrogen

GreenMat4H_2

High-Performance Center Hydrogen

Green materials and technologies for the safe production, storage / transport and use of hydrogen.

Efficient and high-performance materials as well as systems form the basis for a sustainable hydrogen economy. The research work in the performance center pursues the goal of developing »green« resource-saving materials and technologies.

The entire cycle of the hydrogen economy is considered, from safe production, storage and transport to use. The research work also focuses on the development of materials and technologies for the conversion of existing structures to hydrogen applications in the aforementioned stages of the value chain.

Crucial to the work at the center is the immediate transfer of research results to industrial applications. This research transfer is accelerated by the partner network, with representatives from industry and science and the public sector.

As a central contact point for the hydrogen economy in the Rhine-Main region and beyond, the high-performance center is the link to sustainably close material cycles in the H_2 economy.

Aims

- Development, design and investigation of sustainable materials, materials and systems for hydrogen technologies
- Development of scalable process technologies
- Transfer of materials and systems into applications for sustainable mobility
- Training of a highly qualified workforce
- Strengthening Hessia as a high-tech state

Fraunhofer Research Institution for Materials Recycling and Resource Strategies IWKS

At Fraunhofer IWKS, more than 100 employees, scientists and interdisciplinary specialists conduct research on the development of sustainable and innovative solutions for the circular economy.

The overriding goal of Fraunhofer IWKS is the responsible use of resources. By using sustainable materials and developing efficient procedures and recycling processes, the use of critical raw materials is to be minimized and these materials otherwise kept in the cycle for as long as possible.

Research focus

At both locations, in Hanau and Alzenau, materials scientists, chemists, physicists and engineers work on issues along the hydrogen life cycle. The interdisciplinary approach makes it possible to develop sustainable, viable and innovative processes and also to consider and evaluate them under ecological and economic criteria.

Fraunhofer Institute for Structural Durability and System Reliability LBF

The focus of the research work of the about 400 employees, experts from various disciplines is the development of reliable methods and processes and thus the realization of reliable lightweight structures and systems for mobility, mechanical engineering or the energy sector.

The Fraunhofer LBF team develops innovative solutions along the entire value chain, from the material and its processing, through the realization of the finished component and the complex system, to qualification with regard to safety and reliability.

Research focus

Based on its expertise, Fraunhofer LBF focuses on evaluating the safety and reliability of H_2 systems as well as the optimization and lifetime assessment of materials and components in contact with hydrogen.

Motivation

A sustainable and reliable hydrogen economy for Hessia

Hydrogen - a versatile energy source and a real alternative to fossil fuels in terms of energy transition and climate protection. Studies predict that the demand for hydrogen in Germany will increase to up to 800 TWh in 2050. Hydrogen produced in a climate-friendly way makes it possible to significantly reduce CO_2 emissions, especially in industry and transport, where energy efficiency and the direct use of energy from renewable sources are not sufficient or not possible. Hydrogen and its other synthesis products thus play a central role in achieving greenhouse gas neutrality in all energy-consuming sectors, such as transport, industry and buildings.

Reducing the demand for critical materials

The research work of the participating institutes of the »High-Performance Center Hydrogen Hessia« always follows the principle of a holistic approach along the life cycle. From the generation to the storage and transport to the use of hydrogen, the systems and components used must meet a wide range of requirements. This involves the use of materials that contain critical raw materials and significantly reduce the positive climate footprint of green hydrogen.

Lifetime and safety

How can hydrogen be used for mobile applications in transport? Can existing infrastructures be used for this purpose? What challenges does this pose for hydrogen-loaded materials and systems in terms of reliability and service life? Using individually developed analysis and validation methods and the infrastructures required for this, the influences of hydrogen under realistic stresses on the fatigue of materials, parts and components are determined and optimized methods for lifetime estimation are derived from this.

Opportunity: Holistic view

The aim of the research work is the development of a circular economy for all material components for more sustainability in the field of green hydrogen. The evaluation of material criticality, for example of fuel cells and their components, and alternatives to the fuel cell or the evaluation of the influence of increased hydrogen concentrations in the gas pipeline network play a major role. Alternatives to the fuel cell are also part of the research.

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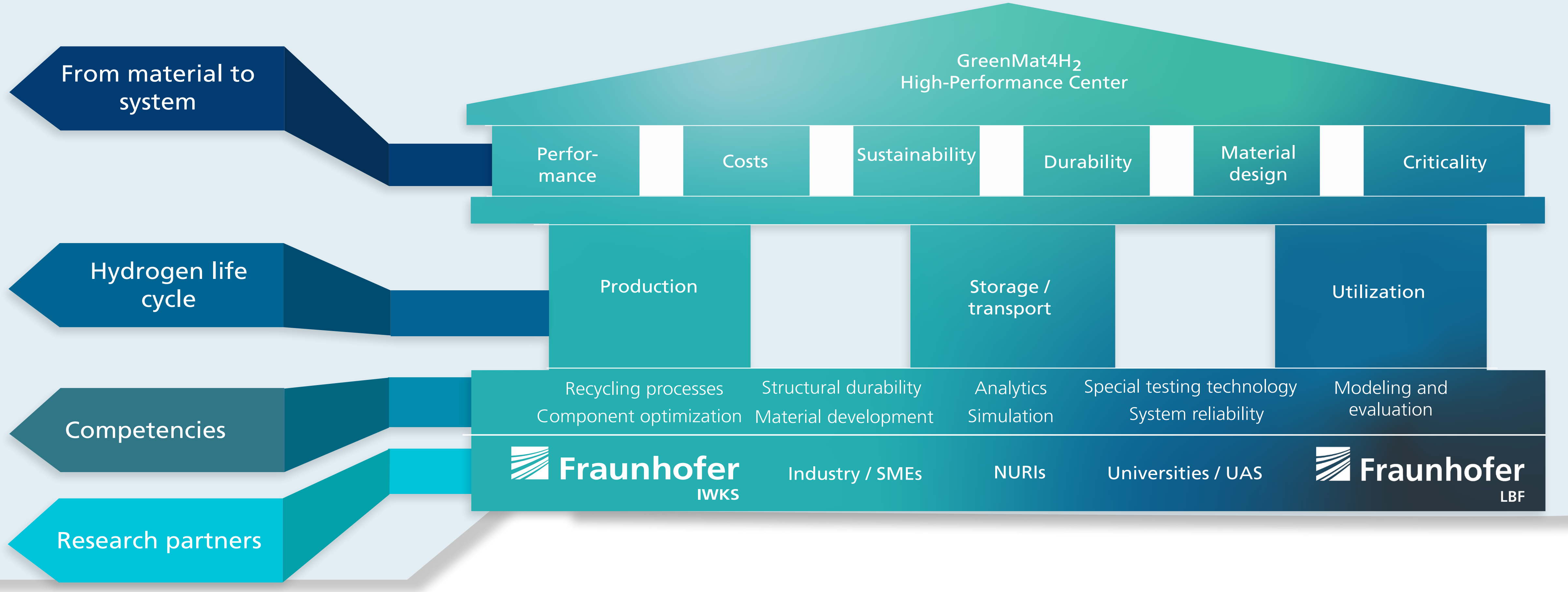
»We are committed to strong networking between research, industry, politics and society in order to jointly develop solutions for a sustainable hydrogen economy and thus actively counter climate change.«

Dr. Saskia Biehl,
Head of Division Reliability

The research work of the high-performance center range from the development of materials to the individual components to the analysis of to the analysis of entire systems on the generation of hydrogen, its storage and storage and transport through to use.



Fields of Research

Analytics, Simulation, Modeling and Evaluation

Analytics

Several materials are chemically and physically affected by exposure to hydrogen. Strength and ductility decrease, changes in the microstructure can occur, which in the worst cases can lead to cracks or even fractures. In short, for many materials, hydrogen can severely shorten the lifetime of components. In other areas, however, the absorption of hydrogen into the substance to be treated proves extremely beneficial. For example, in the production of high-quality sintered magnets containing rare earths, the starting material in the form of cast ingots is specifically converted into a magnetic powder with improved grindability by means of hydrogen.

The high-performance center has several autoclaves at its disposal to investigate the effect of hydrogen not only on individual materials but also on complete composite bodies. For components of smaller dimensions, a hydrogen reactor with a pressure range from a few mbar up to 100 bar is available for this purpose. Further autoclaves allow the investigation of samples weighing up to 25 kg, up to a maximum pressure of 10 bar.

Overpressure hydrogen and temperatures up to 500 °C. Comprehensive analytical procedures accompany the investigations and enable a meaningful assessment of the extent as well as a deeper understanding of these change processes. The service portfolio is continuously being expanded and currently includes:

- Determination of hydrogen content in solids and gases
- Macro- and microstructural changes due to hydrogen impact
- Temperature-dependent effects due to hydrogen impact
- Microstructural changes

Hydrogen applications such as fuel cells and solid-state storage systems rely on functional materials. In daily use, damage can occur due to mechanical, thermal and electrochemical stresses, which can be visualized using high-resolution electron microscopy or metallogrpaphic methods. The understanding of damage processes under the aforementioned stresses enables targeted optimization of the materials, components and systems used materials, components and systems.

Simulation

In order to meet high and diverse requirements with regard to quality, safety and reliability of materials, components and hydrogen systems, safe experimental development tools and realistic digital models are required. The aim is to increase the predictive quality of the actual component and system behavior by means of suitable modeling in such a way that, among other things, the number of prototype systems can be reduced and physical validations can be replaced by simulations.
Within the framework of the performance center, scientists are developing modern experimental, numerical and cyber-physical simulation and validation methods. For example, environmental simulations under electrical, thermal and mechanical loads are carried out for components and systems, in some cases on systems specifically developed for this purpose. Systems and subsystems, such as fuel cells, batteries or elements of an electric motor, are also emulated and digitized as virtual models. Load data, based on driving operation measurements, are introduced into digital simulation environments and cyber-physical test benches as combined mechanical and electrical loads, thus stressing the individual components and systems as realistically as possible. In this way, design-relevant parameter variants can be analyzed, evaluated and selected with a high degree of accuracy before physical prototypes, e.g. of vehicles, are created.

Modeling and Evaluation

The requirements for new hydrogen technologies are diverse and will become more stringent in the future.

These are:
- Safety
- Economy / Costs
- Environmental protection and resource efficiency
- Technical practicability & performance

For the development of new materials and materials as well as the operation of hydrogen generation plants and applications, it is therefore necessary that all relevant criteria are taken into account right from the start. Only then can technologies exist and be transferred into practice on a large scale. Aspects of sustainability are just as relevant as those of technical performance. For example, a catalog of criteria for the development of new catalysts for electrochemical hydrogen electrolysis (OER: Oxygen Evoluation Reaction) was developed at Fraunhofer IWKS in collaboration with the Max Planck Society.

The complexity of properties and processes makes the use of digital models necessary. These not only make it possible to holistically improve individual processes, components and an entire system with regard to material behavior, lightweight construction or the product life cycle, but also to uncover previously unknown physical relationships and thus better understand cause-effect relationships.

Fields of Research

Structural Durability, System Reliability, Component Optimization

Structural Durability

An essential prerequisite for the future use of hydrogen is the safety of the hydrogen-loaded system. This applies both to the production of hydrogen in electrolyzers, its transport in tanks, as well as for use in mobility applications, especially in fuel cell systems for the vehicles on land, on water or in the air. The operational design of parts and components in contact with hydrogen, taking into account costs and lightweight construction, is of paramount importance.

Within the framework of the high-performance center, hydrogen-loaded components such as drive components, pipelines or storage units, load and stress analyses for fatigue strength and lifetime evaluation as well as for the analysis of the cyclic material behavior were carried out. The research activities within the performance center include the investigation and evaluation of the influence of hydrogen on various metallic and polymer-based materials, taking into account operating influences such as pressure, purity and residual moisture content of the hydrogen. Stresses during operation, such as vibrations and oscillations caused by the gas flow, as well as effects of temperature, e.g. during the refueling process, are also taken into account.

The aim is to evaluate the load-stress-design-material-system reliability chain. On the one hand, to degradation and the service life of the overall system and individual components, and also to identify potential for optimization with regard to the reliability and efficiency of individual components (e.g. electrolytic cells).

System Reliability

The loads and stresses on fuel cells and their peripherals as well as the resulting lifetime of the components in mobile applications have not yet been not yet adequately investigated. One focus of the work in the high-performance center is therefore to determine data and to use them to carry out lifetime estimates for fuel systems.

For this purpose, the scientists have access to a comprehensive measurement, analysis and validation infrastructure at their disposal. In the combination of modeling and simulation with experimental methods of reliability assessment, the researchers develop solutions for operational, multi-physical (thermal, electrical and mechanical) validation of the service life of, for example, fuel cell battery systems for mobility applications.

The research work includes, among other things, corrosion studies, environmental simulations, the analysis of aging effects and oxidation phenomena and their effects on the service life and efficiency of the overall system. In addition, scientists are developing solutions for the quantitative reliability assessment of fuel cells. To this end, the probabilistic and quantitative representation of cause-effect relationships (FMEA) is used to determine failure probabilities and safety figures are determined.

Component Optimization

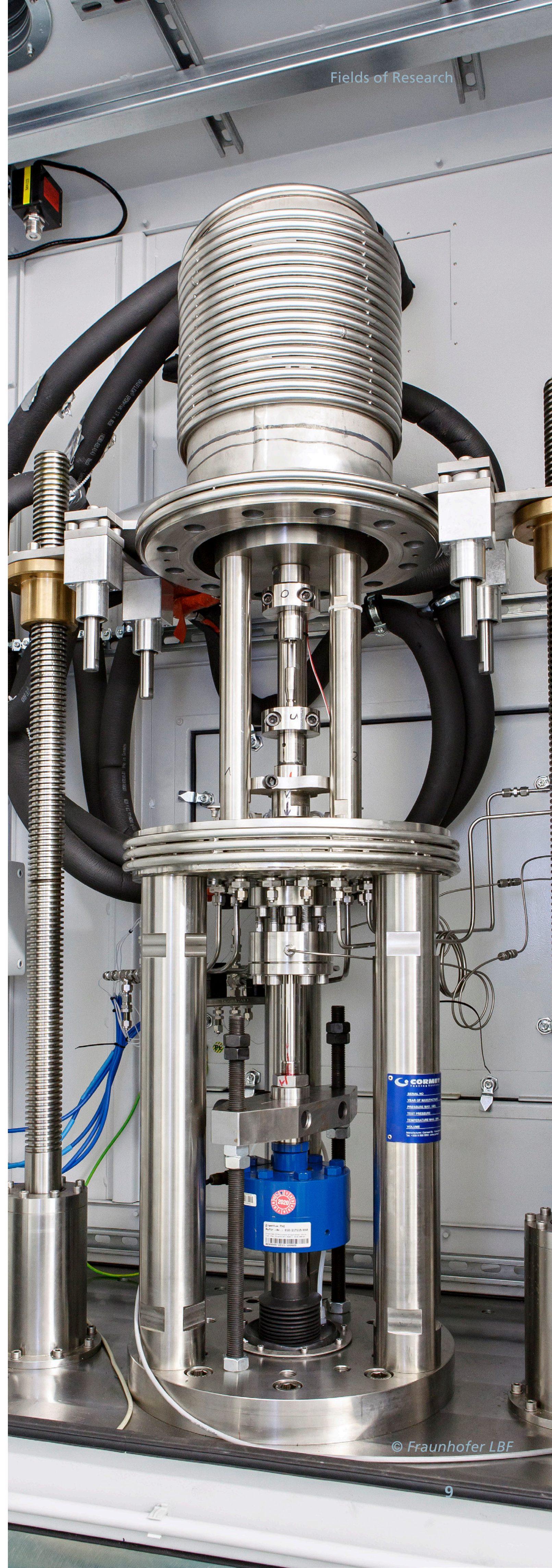
Numerous components and systems are in use or have yet to be put into operation for the production, transport and use of hydrogen and use of hydrogen. In order to make the hydrogen economy as efficient as possible, these hydrogen systems must also be designed efficiently and be provided with a high power density.

The scientists offer for this, based on decades of experience in the field of component and system optimization, they offer numerous methods and to optimize components for specific applications and uses, with regard to service life, safety and durability.

Based on experimental and numerical investigations of material and component fatigue strength as well as fatigue analyses of transport and storage components, service life evaluations are carried out for critical components.

With the help of this knowledge, the service life of the components and systems can be increased. The optimized component design, the use of new (optimized) materials will also increase the efficiency of fuel cells.

Fields of Research

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Fields of Research

Material Development, Recycling Processes, Special Test Technology

Material Development

Efficiency and performance are basic requirements for materials used in hydrogen technologies. But what about their sustainability? Is it possible to substitute them with »greener« materials without a loss of performance? And if not, can their share at least be reduced by changing the process or design?

These are issues that researchers are addressing along the entire hydrogen life cycle. For example, catalysts are being developed that are free of critical raw materials (or whose content is greatly reduced). In the area of storage, scientists are researching solid-state storage materials that combine high storage capacities with excellent cost efficiency. For processing, the center can draw on facilities that are unique in this form in Germany.

Alternative methods are also being pursued, such as the utilization of waste streams containing hydrocarbons to produce technologically valuable carbon material (as a solid) and hydrogen. In this process, the starting material is split into its constituent elements of hydrogen and carbon by means of a fast and thus energy-efficient catalyst-supported plasma chemical process.

»The accelerated ramp-up of the hydrogen economy requires sustainable materials, reliable systems and recyclable components.«

Dr. Sven Grieger,
Head of Innovation Transfer Office

Recycling Processes

In view of the dynamic development in hydrogen technology, resource-conserving material cycles as well as sustainable, efficient and economical technologies along the hydrogen life cycle are crucial aspects of the energy transition.

Components such as fuel cells and electrolysers use valuable materials that require efficient recycling. Industrial pyrometallurgical recycling processes do not represent an alternative in the medium term, either ecologically or economically, due to the formation of highly toxic fluorine compounds and the associated purification processes. Together with companies in the industrial value chain, the high-performance center develops customized recycling solutions for the recovery of these technology materials.

The research and evaluation of sustainable reprocessing processes is oriented towards optimizing the recyclability of high-value material fractions, precious metals such as platinum and ruthenium, and other valuable rare metals - according to the principle of holistic consideration along the product life cycle.

Special Test Technology

Lifetime analysis for hydrogen-impacted materials and systems require complex analysis and evaluation methods, both on the experimental and numerical side. The high diffusivity of the hydrogen molecules poses an enormous challenge to conventional analysis methods and test equipment, especially when increased system pressures in the area of fuel cell, piping systems or hydrogen storage tanks have to form the basis for the lifetime verification.

For this purpose, the scientists are developing new analytical technologies or can make use of existing special test technology.

- A servo-hydraulic test rig which, equipped with a pressure autoclave up to 50 and 100 bar and a temperature control unit, allows quasi-static as well as stress- and strain-controlled fatigue tests under the medium hydrogen 5.0 or 6.0 and at temperatures from -40 °C to +130 °C.
- A multi-axial oscillating table (MAST) that makes it possible to perform structural durability analysis on batteries or fuel cells, for example, under combined mechanical, electrical and thermal stresses and under virtually real operating conditions.

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Contact

Dr. Sven Grieger
Head of Innovation Transfer Office
info@leistungszentrum-wasserstoff-hessen.de
www.leistungszentrum-wasserstoff-hessen.de