Fraunhofer

High Performance Center GreenMat4H_2

Green Materials for Hydrogen, Hesse

A sustainable and reliable hydrogen economy

For Hesse and beyond

Hydrogen - a versatile energy carrier and a real alternative to fossil fuels in terms of energy transition and climate protection. Studies predict an increase in demand for hydrogen in Germany of up to 800 TWh in 2050. Climate-friendly produced hydrogen enables a significant reduction of CO2 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 synthesis products thus take on a central role on the path to greenhouse gas neutrality for all energy-consuming sectors.

Reducing the demand for critical materials

The fields of competence of the two institutes involved in the High Performance Center - Green Materials for Hydrogen complement each other optimally and ensure a holistic view of the hydrogen life cycle: from production, storage and transport to use, each phase places diverse demands on systems and components. This requires materials, some of which contain critical raw materials and thus have a negative impact on the positive climate balance of green hydrogen.

Lifetime and safety

How is hydrogen used for mobile applications in transportation? Can the existing infrastructure be used? What are the challenges in terms of reliability and service life for hydrogen-loaded materials and systems?
With the help of individually developed analysis and validation methods, the High Performance Center - Green Materials for Hydrogen determines the influence of hydrogen on the fatigue of materials, parts and components under realistic stresses and derives optimized methods for service life estimates.

The opportunity: an holistic approach

The aim of the research is a sustainable circular economy for all material components around green hydrogen. In addition to the material criticality of the components used in terms of performance, service life and recyclability, a critical view of the carbon footprint of various technologies is crucial. The High Performance Center Hydrogen creates a basis for decision-making for individual applications with comprehensive life cycle assessments (LCA).

Green materials and technologies

For a 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 High Performance Center 's research aims to develop "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 value-added stages.

A decisive factor for the work at the High Performance Center is the direct transfer of research results to industrial applications. This research transfer is accelerated by the partner network, with representatives from industry and science as well as the public sector.

As a central contact point for the hydrogen economy in the Rhine-Main region and beyond, the High Performance Center Hydrogen is the link to sustainably close material cycles of the H_2 economy.

Goals

- Development, design and investigation of sustainable 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 Hesse as a high-tech state

Current research projects

Fraunhofer Research Institution for Materials Recycling and Resource Strategies IWKS

At Fraunhofer IWKS, about 100 employees, scientists and interdisciplinary specialists conduct research on the development of sustainable and innovative solutions for a circular economy. The overarching goal of Fraunhofer IWKS is the responsible use of resources. Through the use of sustainable materials and the development of efficient procedures and recycling processes, the amount of critical raw materials should be minimized and these materials should be kept in the cycle for as long as possible.

Research focus

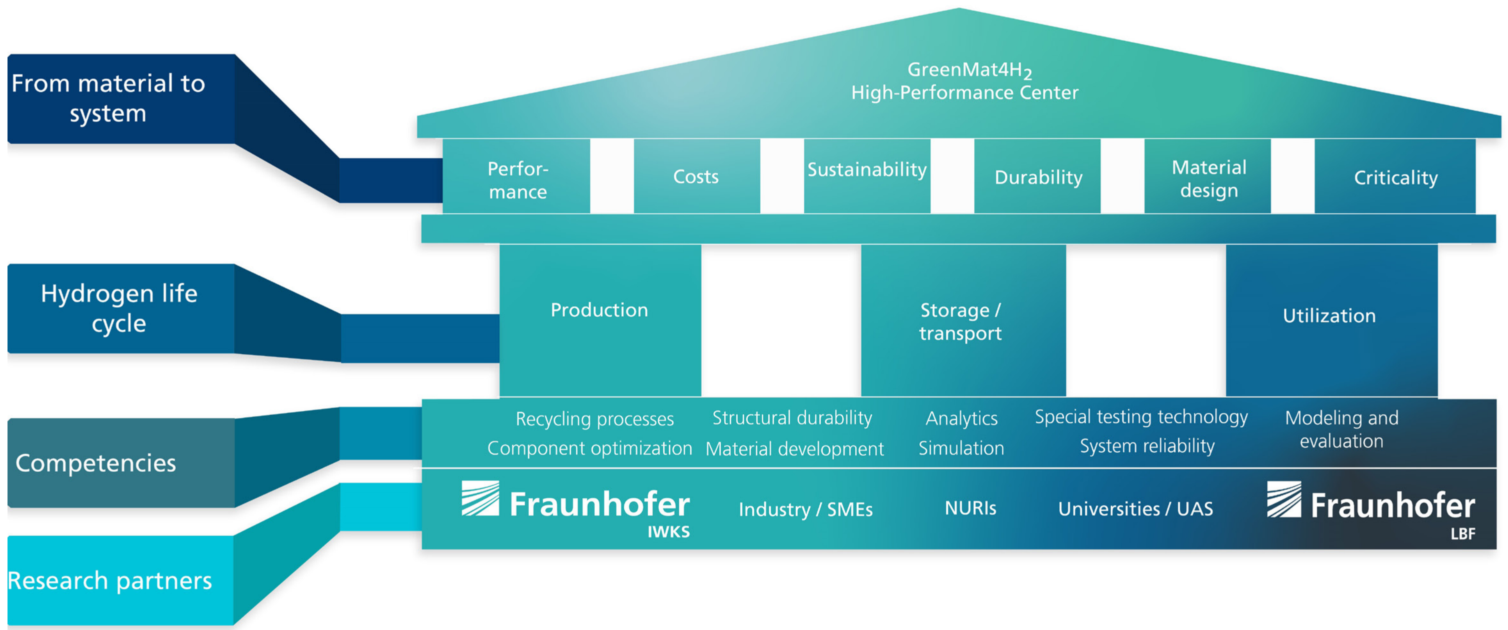
At two sites in Hanau, Hesse and Alzenau, Bavaria specialist teams from materials science, chemistry and physics are working on issues along the entire hydrogen life cycle.
The interdisciplinary approach enables the development of sustainable, viable and innovative processes and to consider and evaluate them with regards to ecological and economic criteria.

Fraunhofer Institute for Structural Durability and System Reliability LBF

The focus of the research work of the approximately 400 employees, experts from various disciplines is the development of reliable methods and processes and thus the realization of lightweight, 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 in terms of safety and reliability.

Research focus

Based on its expertise, the main focus of the Fraunhofer LBF is the evaluatation of the safety and reliability of H_2 systems and the optimization and evaluation of the service life of materials and components in contact with hydrogen. In addition, a focus is on the integration of suitable sensor technology for condition monitoring of H_2 pressure vessels.



Research fields

Analytics

Exposure to hydrogen chemically and physically affects many materials. Their strength and ductility decrease, and changes in the microstructure can occur, causing in the worst case cracks or fractures. In short, hydrogen severely shortens lifetime of components for many materials. In other applications, however, the absorption of hydrogen into the substance to be treated proves extremely beneficial. For example, hydrogen can be stored in solids, so-called metal hydrides. Here, the ability to adsorb hydrogen in certain alloy compositions plays a decisive role. Another possibility for the use of hydrogen in the production of high-quality sintered magnets containing rare earths is to convert the starting material in form of cast ingots into a magnetic powder with improved grindability in a targeted manner using hydrogen.
The High Performance Center Hydrogen has several autoclaves that allow the examination of very small components with a pressure range of a few mbar up to samples weighing 25 kg and a maximum pressure of 10 bar excess pressure hydrogen and temperatures up to 500 °C.

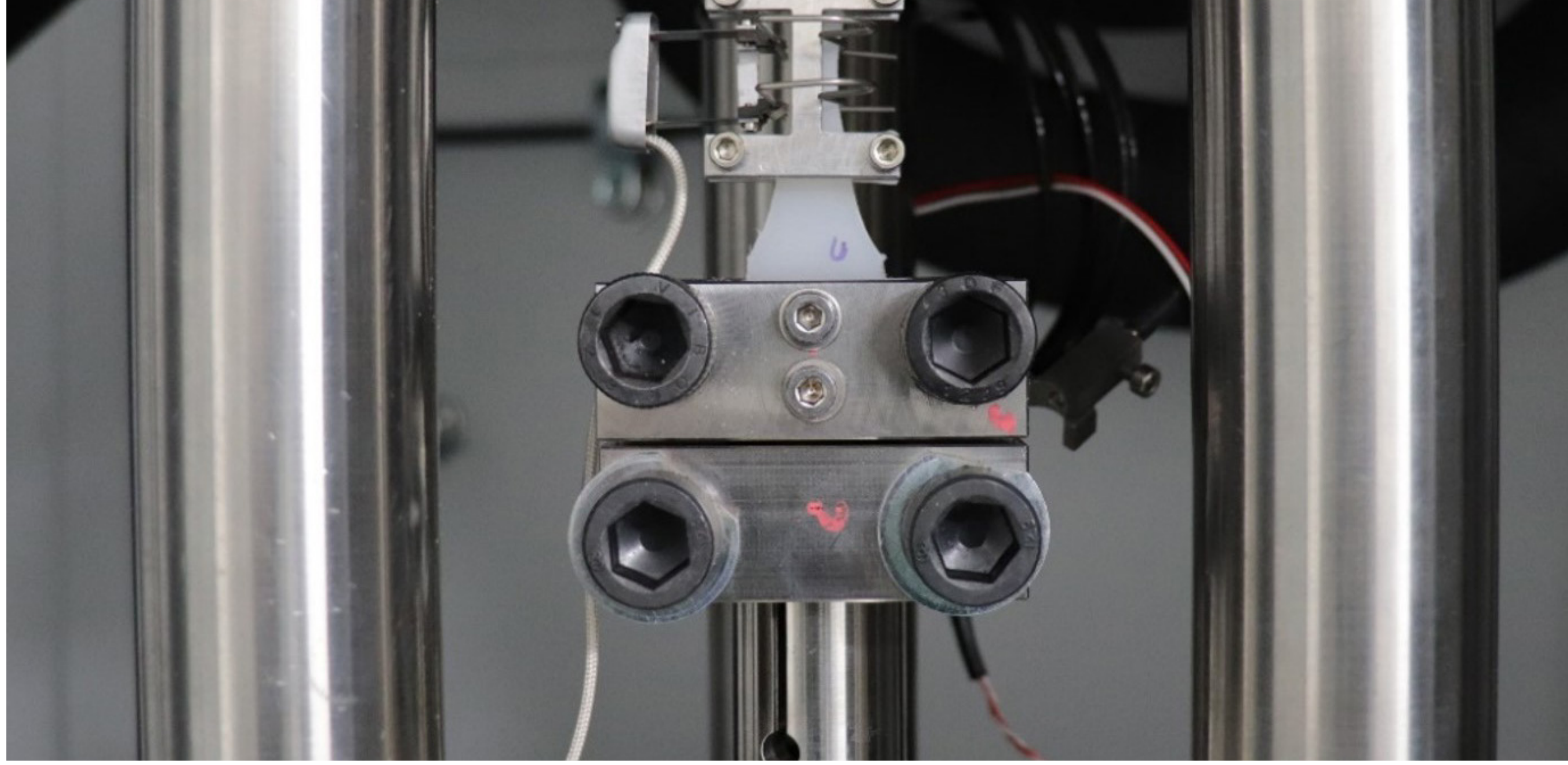
The accompanying comprehensive analytical procedures enable a deeper understanding and thus a meaningful evaluation of the material change processes.

The portfolio of the High Performance Center Hydrogen is continuously being expanded. It currently includes:

- Determination of the hydrogen content in solids and gases
- Determination of macro- and microstructural changes caused by hydrogen impact
- Analysis of temperature-dependent effects due to hydrogen impact
- Electrochemical investigations of half and full cells (including extensive impedance measurements)
- Visualization of aging effects in fuel cells and electrolyzers (segment-wise)
- Electrode stability: electrolyte investigations
- Analysis for SOFC/EC: tests of the reaction of catalytically active materials with impurities from gases used and other electrolyser and fuel cell components from cell to small stack level
- Time-dependent measurement of electrical processes within a SOFC/EC cell and separation of ionic and electronic charge transports

Specialized functional materials are required for hydrogen applications such as fuel cells and solid-state storage systems. In daily use, damage can occur due to mechanical, thermal and electrochemical loads, which can be visualized using high-resolution electron microscopy or metallographic methods. Understanding the damage processes under stress enables targeted optimization of materials, components and systems.

In applications of plastics with direct contact with hydrogen, the focus is primarily on mechanical behavior, chemical and physical aging, sorption or diffusion properties, and swelling behavior when media are absorbed. Depending on the application, special requirements with regard to behavior under liquid media, temperatures or complex stress scenarios may also be relevant. One example is fuel cells in which cooling liquids act on plastic components.



Clamped plastic specimen in the hydrogen test rig for cyclic mechanical testing under pressurized hydrogen. © Fraunhofer LBF

Modeling and evaluation

The requirements for new hydrogen technologies are manifold and will become more stringent in the future:

- Safety
- Economic efficiency / costs
- Environmental protection and resource efficiency
- Technical practicability and performance

For the development of new materials as well as the operation of hydrogen generation plants and applications, it is therefore necessary that all relevant criteria are considered from the product launch. This enables the establishment of technologies and their transfer into practice on a large scale. Aspects of sustainability are just as relevant as those of technical performance.

Life Cycle Assessment (LCA) is used to evaluate the environmental impact of products, processes and services. These are evaluated in a holistic system approach along the entire life cycle. The LCA refers to the potential effects of raw material extraction, production, application, waste treatment, recycling up to final disposal or reuse. The focus is on the influence on the media water, air and soil. The process- and product-oriented life cycle assessment is carried out in accordance with the current DIN EN ISO14040/ 44 standards.

With experience in the ecological evaluation of new technologies and the optimization of existing processes, Fraunhofer scientists can analyze customers' decision-making alternatives at an early stage of development, identify hotspots and thus highlight environmentally related potentials and risks. This provides customers with decision-making aids to sustainably improve processes even before market entry. The research focus is on providing an up-to-date and uniform database. A specially developed database for certain key technologies creates strategic market advantages through an information edge. Topics include solar cells and the recycling of batteries and magnetic materials.

For preparation of the life cycle assessments the High Performance Center Hydrogen mainly works with the software openLCA as well as with various databases such as ecoinvent, ELCD, ProBas, USDA or NEEEDS. The special expertise of the research team focuses on LCA of recycling systems and new (material) technologies.

Operational stability

An essential prerequisite for the sustainable use of hydrogen is the safety of the hydrogen-loaded system. This applies to the production of hydrogen in electrolysers, its transport in tanks, as well as its use in mobility, especially in fuel cell systems for operating vehicles on land, on water or in the air. The operationally stable design of parts and components in contact with hydrogen is of high importance when taking into account costs and lightweight construction.

As part of the High Performance Center Hydrogen, load and stress analyses are carried out on hydrogen-loaded components for drive components, pipelines or storage units for operational stability and service life evaluation as well as for the analysis of material behavior under cyclic load. The research activities include the investigation and evaluation of the influence of hydrogen on different metallic and polymer-based materials, taking into account influences of operation, for example pressure, purity and residual moisture content of the hydrogen, as well as vibrations and oscillations caused by the gas flow and effects of temperature, e.g. during the refueling process.

The aim is to evaluate the chain of load-stress-design-material-system reliability. On the one hand, to derive statements about degradation or service life of the overall system and individual components and, on the other hand, to determine optimization potential with regard to reliability and efficiency of individual components, such as electrolysis cells.

System reliability

The loads and stresses on fuel cells and their peripherals and the resulting service life of the components in mobile applications have not been adequately investigated to date. Therefore, one focus of the work at the High Performance Center Hydrogen is the determination of corresponding data and their interpretation for lifetime estimations for fuel cell systems.

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

The research work includes corrosion studies, environmental simulations, the development of material-specific rapid aging processes and 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. For this purpose, probabilistic and quantitative representation of cause-effect relationships (FMEA) is used to determine failure probabilities and safety figures.

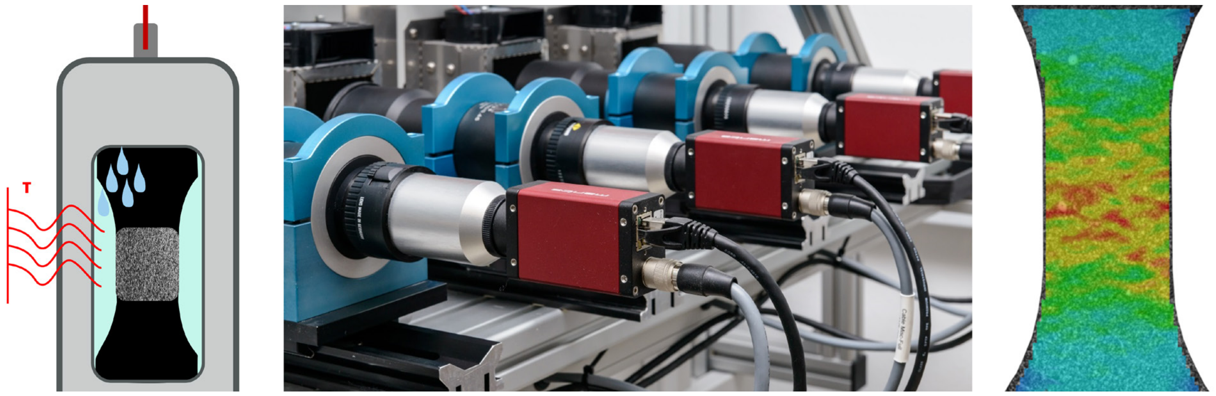
Component optimization

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

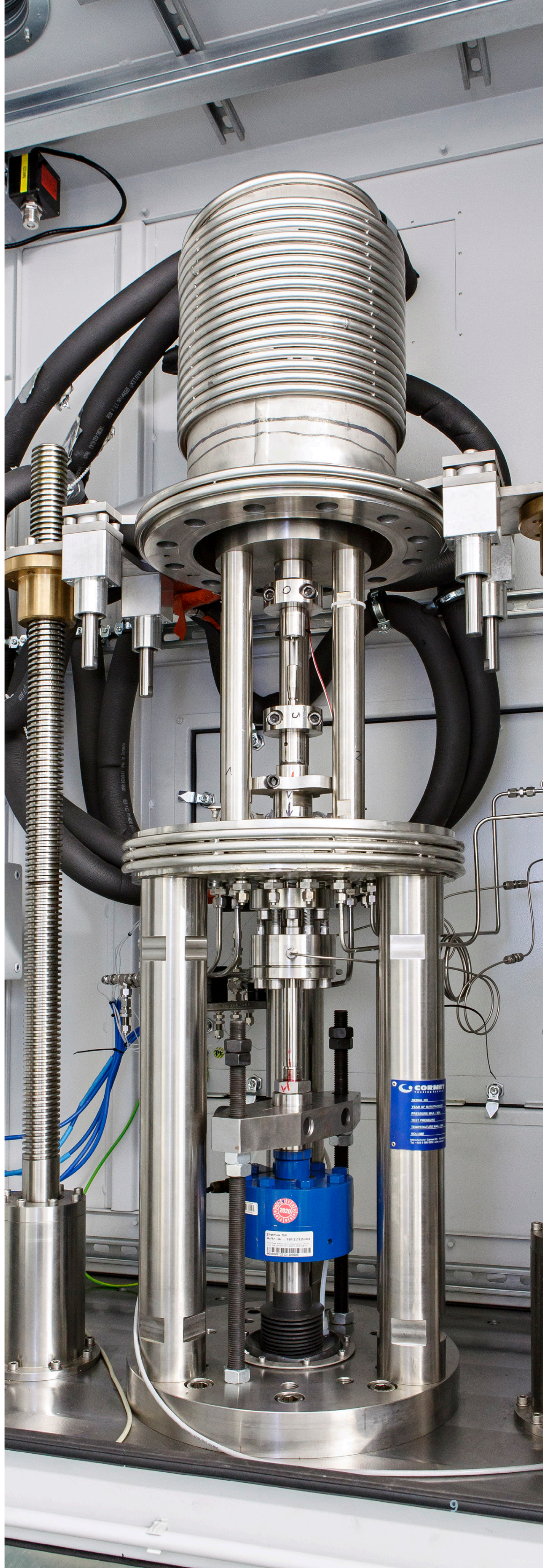
Based on decades of experience in the field of component and system optimization, the scientists offer numerous methods and approaches for optimizing application- and use-specific components with regard to service life, safety and stressability.

Based on experimental and numerical investigations of material and component vibration strength as well as fatigue analyses of transport and storage components, service life evaluations are carried out for critical components and optimization potentials are derived for the component design of infrastructure elements, drive components or systems of fuel cells, for example with regard to geometry or material thickness.

With the help of this knowledge, the service life of the components and systems can be increased. Through optimized component design, the use of new (optimized) materials will also have a positive influence on the efficiency of fuel cells.



Creep testing under the influence of media: sketch of the media cell (left), creep test rig with cameras for optical strain measurement (center), two-dimensional strain signal evaluated via Digital Image Corrrelation (right). © Fraunhofer LBF



Test equipment for carrying out fatigue tests under tests in a pressurized atmosphere. © Fraunhofer LBF

Plasma chemical process (plasma analysis) for the production of hydrogen (gaseous) and carbon (solid) through the utilization of carbon-hydrogen-containing waste streams. © Fraunhofer IWKS

Impact mill/impact crusher for comminution. © Fraunhofer IWKS

Material development

Efficiency and performance are basic requirements for materials used in hydrogen technologies. But what about their sustainability and longevity? Is substitution by "greener" materials possible without loss of performance? And if not, can the proportion of non-green materials at least be reduced by changing the process or design?

The researchers are addressing these questions along the entire hydrogen life cycle. For example, catalysts are being developed that use little or no critical raw materials. In the field of hydrogen storage, the scientific teams are researching solid-state storage materials that combine high storage capacities with excellent cost efficiency. For processing, the High Performance Center uses facilities that are unique in Germany. This enables to provide a wide variety of production and shaping technologies that allow to process innovative catalyst materials and electrode structures from materials that have been synthesized by the High Performance Center's scientists (e.g. via induction or electric arc furnaces) using shaping processes ranging from spark plasma sintering and melt spinning to additive manufacturing via selective laser melting (SLM).

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

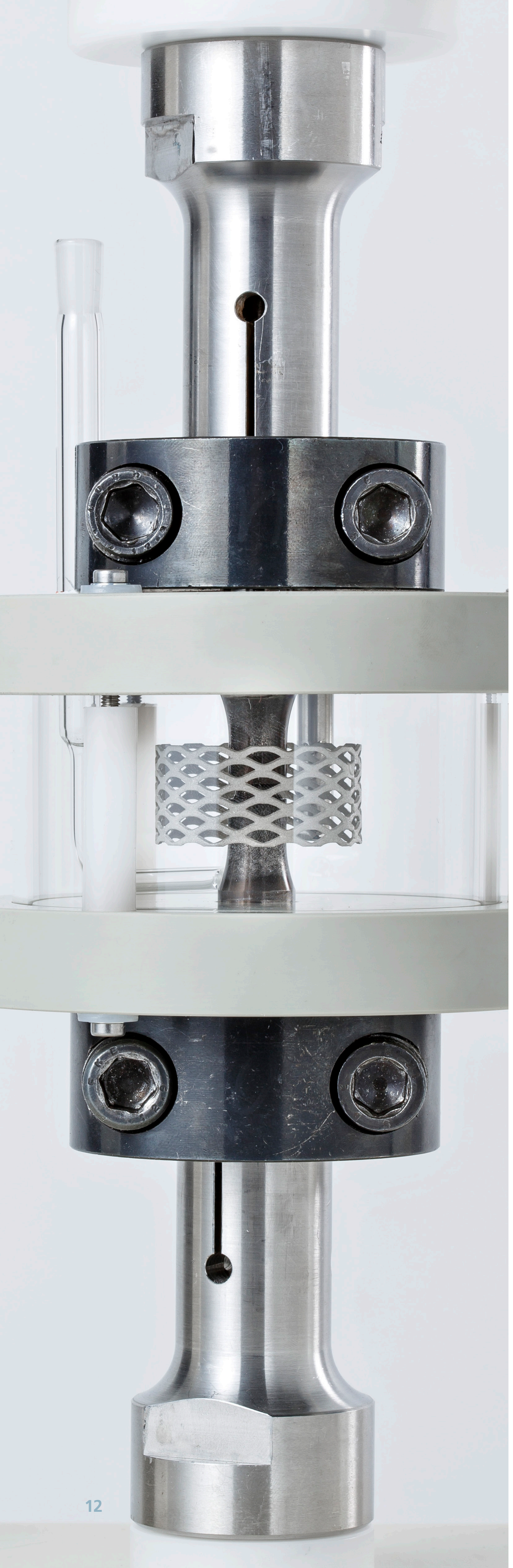
Recycling processes

The expansion of the hydrogen economy is currently bringing about a comprehensive ramp-up in the production of components and systems. Findings from recycling processes are increasingly being incorporated into the definition of requirements for the product development of circular fuel cell and electrolysis systems. These synergies are decisively contributing to gradually improving recyclability.

Components such as fuel cells, electrolysers and battery storage systems use valuable materials that require efficient recycling. For the practical execution of separation and sorting experiments, the High Performance Center Hydrogen has the necessary plant technology with interfaces for detailed digital modeling with AI support. For evaluation, various analytical methods are used for material characterization up to accompanying life cycle analysis. 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 remanufacturing processes is geared to optimizing the recyclability of high-grade material fractions, precious metals such as platinum and ruthenium, and other valuable rare metals - according to the principle of a holistic view along the product life cycle.

In the development of business models for a circular economy, the High Performance Center is thinking beyond pure material recycling: The scientists are evaluating options for the reuse of functional assemblies for media supply, electronics and key components in electrolysers and fuel cells, such as bipolar plates or the membrane electrode assembly (MEA).



Special test engineering

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

For this purpose, the scientists are developing new analysis technologies or use established special test technology:

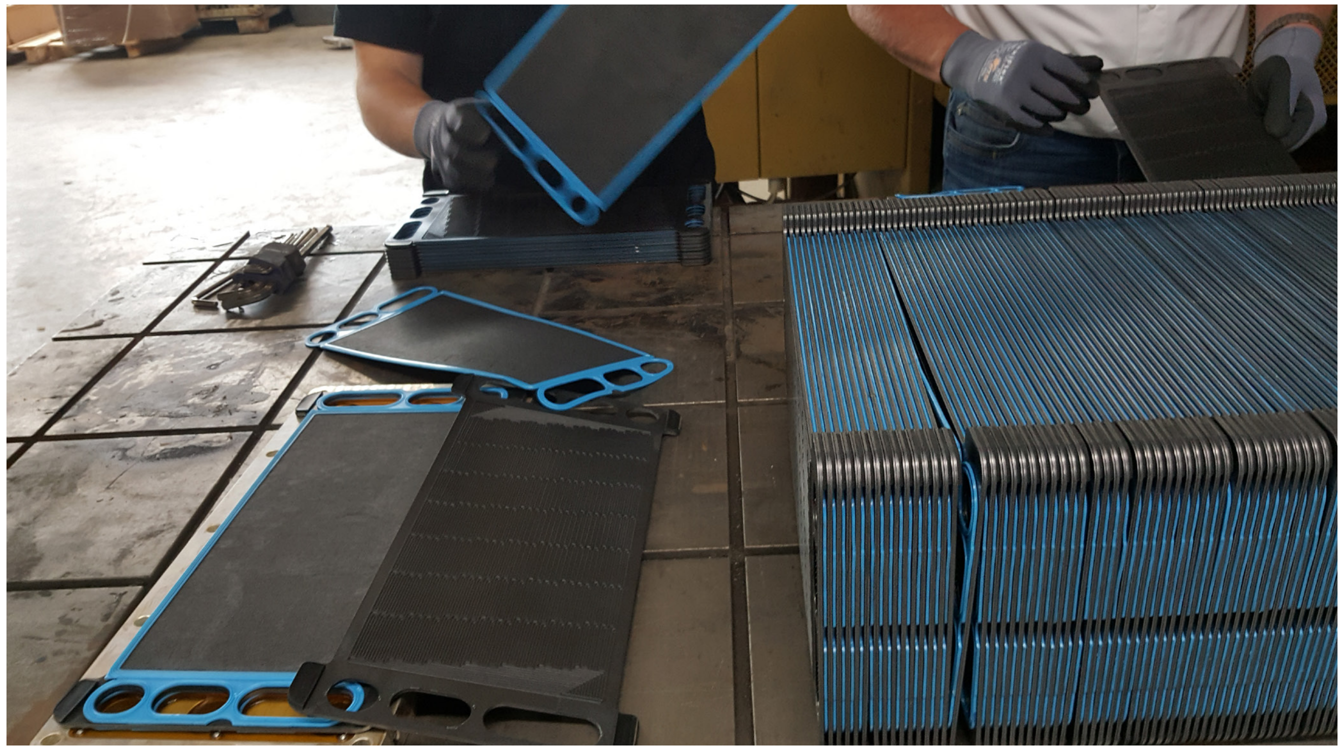
- A servo-hydraulic testing machine which, equipped with a pressure autoclave up to 50 bar and 100 bar and a temperature control unit, allows quasi-static as well as stress- and strain-controlled, cyclic tests under the medium hydrogen 5.0 or 6.0 and, depending on the type of test, also at temperatures from -40 °C to +120 °C.
- A multi-axial oscillating table (MAST) which allows the service life of batteries or fuel cells, for example, to be verified under combined mechanical, electrical and thermal stresses under virtually real operating conditions.
- Special insitu measurement setups that allow the mechanical behavior (quasi-static, cyclic, creep) to be investigated directly in relevant environments (e.g. cooling liquids) and thermal interaction to be considered simultaneously.
- A high-pressure gas sorption balance can be used to analyze the absorption of hydrogen into elastomers and plastics at temperatures up to 150 °C and pressures up to 350 bar. Methods for determining diffusion coefficients of hydrogen as a function of pressure and temperature are being developed.

Further information on
the research fields

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 prediction 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 replaced by simulations.

The scientists at the High Performance Center develop 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 on units that have in part been specifically developed for this purpose. Systems and subsystems, such as fuel cells, batteries or elements of an electric engine, 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 variations can be analyzed, evaluated and selected with a high degree of accuracy before the creation of physical prototypes, e.g. of vehicles.



The composite of a fuel cell stack is separated into the individual fuel cells. © Fraunhofer IWKS

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Hydrogen Roundtable Rhine-Main

Green Mat 4 H_2 Leistungszentrum

Meeting point for the hydrogen economy

The event series Hydrogen Roundtable Rhine-Main has been established as ***the*** meeting place for the hydrogen economy in the region and beyond. Participants from industry, politics and research as well as interested citizens regularly exchange information on trends and developments concerning the safe and reliable production, storage and use of hydrogen.
At alternating venues, experts give keynote speeches and guided tours through laboratories, plants and companies and provide insights into current projects and activities. Furthermore, the High Performance Center Hydrogen offers with this format a proven option to network and initiate joint projects. Participation is free of charge.

All details, dates and registration to this and other events:

High Performance Center

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