Fraunhofer
LBF

Fraunhofer Institute for Structural
Durability and System Reliability LBF

Safe. Sustainable. Efficient.

Materials, Components and Systems for a Reliable Hydrogen Industry

www.lbf.fraunhofer.de/hydrogen

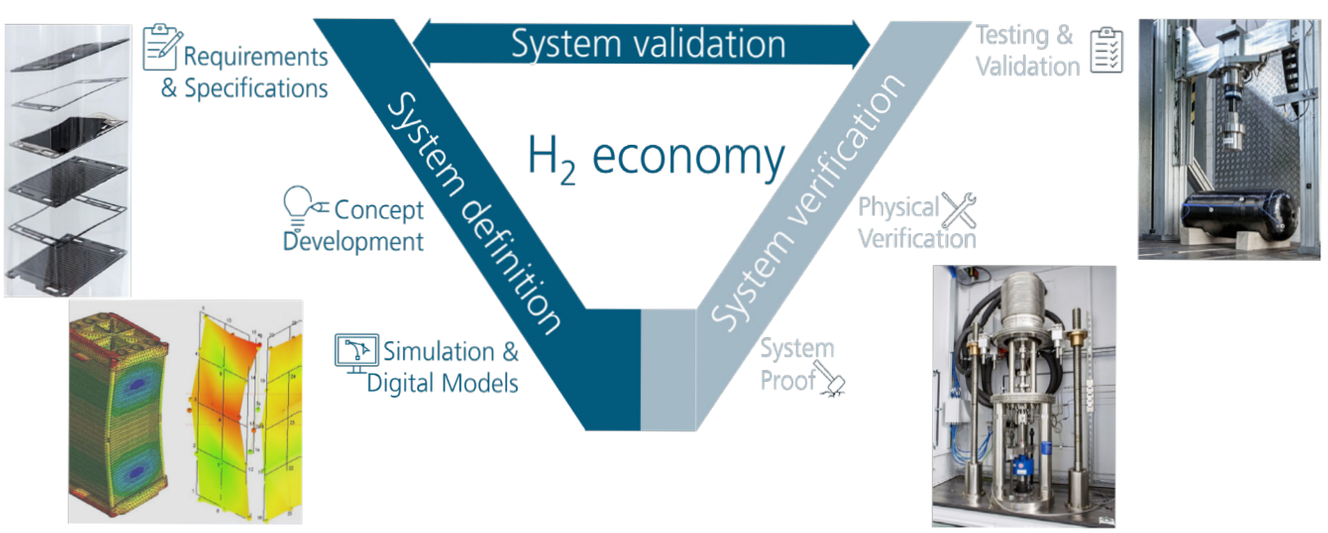
Services for the Hydrogen Industry

Hydrogen is an energy carrier that has a positive impact on the energy transition and counteracts climate change. With over 85 years of experience in reliability and durability topics, Fraunhofer LBF's interdisciplinary teams of experts are developing new procedures and methods for evaluating and optimizing the reliability of materials, components and systems in the hydrogen industry.

As development partner, we offer a comprehensive range of services. This covers the entire value chain, from materials and components to complete systems for the hydrogen economy. We are delighted to support our partners every step of the way – from concept development through construction and testing to the operational phase and beyond, right up to the end of the product's life cycle.

From Concept to Validation

Services and Research along the V-model.
We support the entire development process – from concept to proof!



Materials

Test Bench Development for Realistic Testing of Hydrogen Industry Materials

- Servo-hydraulic test system with nominal load of 63 kN
- Autoclave with internal volume of 25 l
- Pressure range: 7 to 50 bar (for end of 2026: up to 100 bar)
- Pressure nitrogen: 10 bar
- Temperature range: - 40 °C to + 110 °C
- Static and cyclic testig of samples preferably in the shape of tensile specimens
- Characterization of the barrier effect of protective coatings against hydrogen embrittlement
- H_2 / N_2 concentration up to 99.9999 %
- O_2 concentration < 4 ppm
- No gas mixtures and humidity possible
- In-situ gas sensor technology during the test
- Compliance with gas purity requirements according to ANSI/CSA CHMC 1-2014
- Fulfillment of the required accuracy in the execution of tests according to ISO 1099 and the Code of Practice (ISBN-92826-9681; EUR 161382_EN)

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Test rig for measurements under H_2 athmosphere up to 100 bar pressure.

Material Development Based on Relevant Data for the Hydrogen Industry

Our Services

- Application-oriented evaluation of mechanical behavior under complex stresses in liquid and gaseous media
  - Metals, polymers and composites
  - Test bench development for static and cyclic ageing experiments under hydrogen atmosphere
  - Static, cyclic and creep
  - Pressurized hydrogen and nitrogen
  - Cooling liquids, acids & alkalis
  - Various load, pressure and temperature ranges
- Physical and chemical characterization of polymers for hydrogen applications
  - DMTA, FTIR, µFTIR, Raman microscopy and SEM-EDX
  - Analysis methods for ionomer dispersions (DLS, 19F-NMR, viscometry, GPC)

Your Benefits:

- Evaluation of the strength, deformation and fatigue behavior of materials exposed to hydrogen
- Optimization of material selection and development for cost-efficient hydrogen systems
- Enhancing the performance of polymers and metals for hydrogen systems
- Improved reliability of (lightweight) structures

Rapid Test for Metallic Samples in Relation to Hydrogen

Our Services:

- Material analyses under electrolytically generated hydrogen
- Pre-loading of material samples with different hydrogen contents.
- Adjustment of material conditions with very high hydrogen contents (saturated)
- Quick test' under hydrogen environment for screening different material alloys
- Examination of very small components

Your Benefits:

- Based on the test results obtained, conclusions can be made regarding the impact of hydrogen on the strength and deformation behavior as well as the influence on the lifetime and fatigue behavior
- Supporting data for the improvement of materials and components of the H_2 industry

Fatigue Corrosion

Our Services:

- Examination of the corrosion fatigue strength in liquid media, to evaluate the influence of a corrosive environment on the lifetime behavior
- Use of different media (e. g., methanol, ethanol, biofuels ...)
- Evaluation of the corrosive impact of synthetic fuels (liquid energy sources) on the fatigue strength behavior

Your Benefits:

- Service in the specific material properties in corrosive environments
- Support in the selection, evaluation and optimization (e. g., coating) of materials for the design of media-carrying components
- Support in ensuring operational stability and system reliability
- The early detection of materials with potential weak points in terms of media resistance

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Hydrogen Sorption

Our Services:

- Analysis of the hydrogen absorption by polymers at a pressure of up to 350 bar and a temperature of up to 150 °C
- Illustration of the sorption isotherm for different temperatures
- Examinations of thermoplastics (tank housings), elastomers (sealing materials), hydrates (hydrogen storage tanks)
- Ageing of polymers in a hydrogen atmosphere at pressures up to 300 bar and temperatures up to 300 °C under static or dynamic conditions

Your Benefits:

- Optimized material selection for components used in hydrogen atmospheres at different pressures and temperatures
- Sorption behavior and material properties for assessing material performance

Material Optimization and Processing, Along With PFAS Substitution, in Specific Hydrogen Applications

Our Services:

- Evaluation and selection of substitution options for PFAS in specific hydrogen applications
- Development and optimization of polymer materials through optimized formulations and additives (e. g., heat conduction and flame retardancy) for polymers in the hydrogen industry
- Selective modification of sealing materials
- Consultation on material-specific processing and optimization of preparation process for polymers in hydrogen systems

Your Benefits:

- Selective choice of materials
- Optimised product performance and manufacturing processes
- Sustainable, fit-for-the-future products for hydrogen technology
- Conformity with EU regulations

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Test environment for hydrogen absorbtion of materials (weight up to 25 g).

Components

Experimental Examination of Components

Our Services:
- Experimental investigation of, e. g. Membrane Electrode Assembly (MEA) in single fuell cell tests under vibration loads
- Characterization and endurance testing of e. g., MEA in Proton Exchange Membrane (PEM)
- Dynamic Mechanical Analysis (DMA) for characterization of temperature- and humidity-dependent mechanical behavior, including viscoelastic properties (storage/loss modulus), relaxation behavior, and time-temperature superposition (TTS).
- Sorption Analysis (SA) for characterization of water uptake and diffusion behavior, including sorption isotherms, diffusion coefficients, humidity-dependent membrane response, and transport model fitting.

Your Benefits:
- Ensuring the long-term performance and stability of components through comprehensive characterization and durability testing
- Improving the efficiency and lifetime of components through precise experimental analyses

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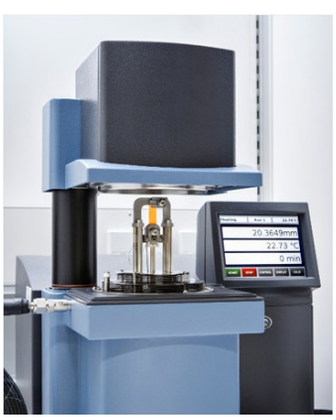

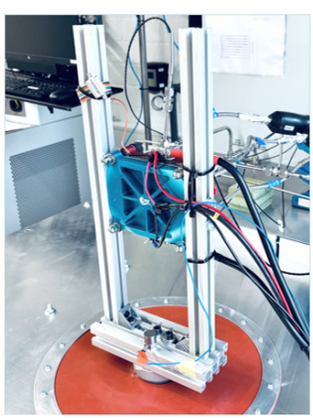

Experimental methods for fuel cell testing, including dynamic mechanical analysis (DMA), sorption analysis (SA) and single cell testing under vibration to assess mechanical behavior and transport properties.

Efficient Modeling Approach and Experimental-Numerical Analysis of Fuel Cell Stack Vibrations

Our Services:
- Development of digital twins for fuel cells as well as for metallic and polymer components
- Determination of preload force of stacks in operation
- Experimental vibration analysis of e. g., fuel cell stacks and cells
- Efficient modeling approach for vibration behavior (development of parametric simulation models, comparison of models with experimental measurement data, investigation of model and parameter uncertainties)

Your Benefits:
- Support in the optimization of the design and structure of fuel cell stacks and cells
- Insights and technical consultant:
  - Improving the efficiency and reliability of fuel cell stacks and cells
  - Simulation and modelling of the behavior of components under different conditions

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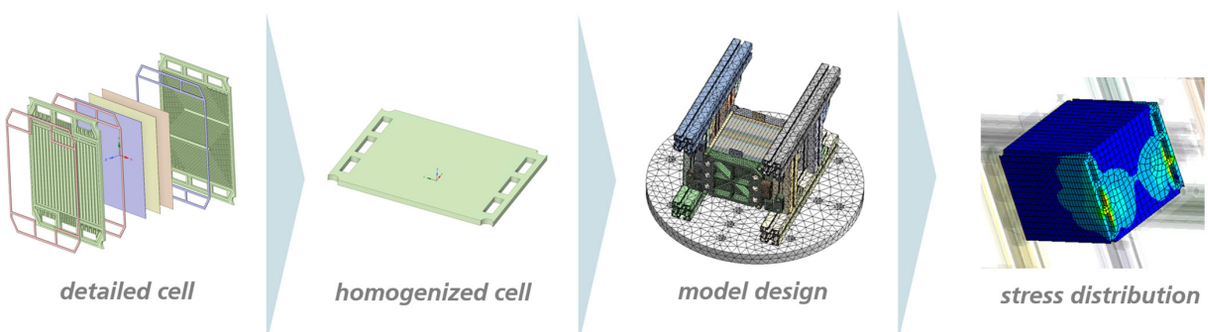

Efficient modeling approach for fuel cell stack vibrations - from model development to identification of damage zones.

Testing To Ensure the Performance of Electrolytic Components Under Extreme Environmental Conditions

Our Services:
- Analysis of polymer components, e. g. seals or membranes for fuel cells and electrolysers:
  - Static and dynamic
  - Huminity and temperature dependency
  - Coolants, acids and alkalis
  - Various loads, pressure and temperature ranges

Your Benefits:
- Ensuring the long-term performance and lifetime of components
- Increasing the efficiency, safety and lifetime of components through precise experimental investigations
- Reliable design of components for hydrogen systems

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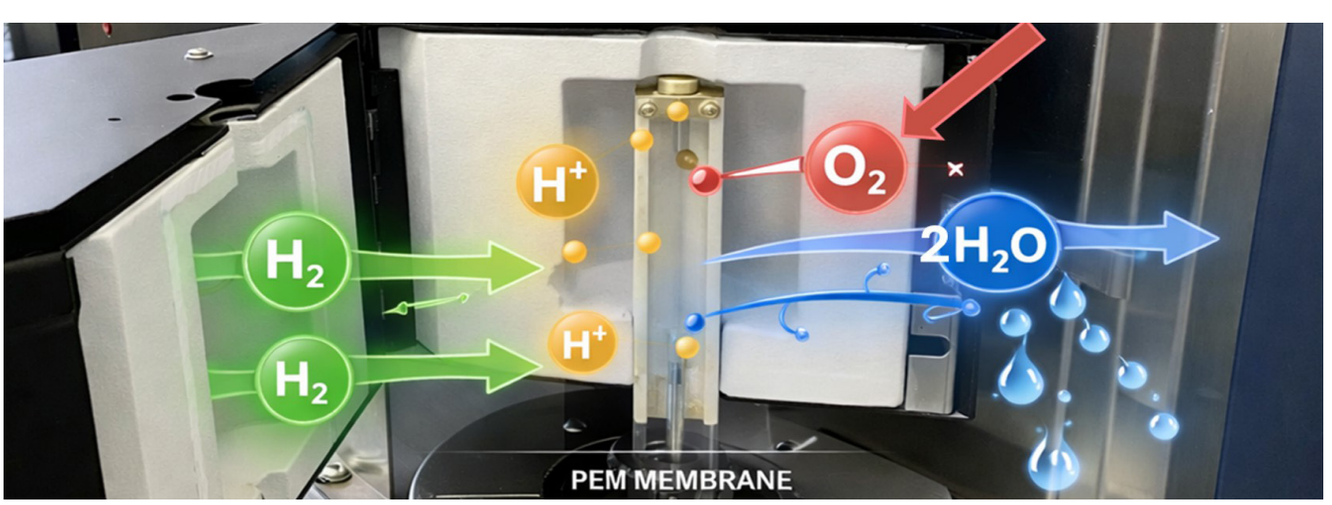

Dynamic-mechanical characterization of PEM membranes for fuel cells and electrolysers.

Systems

Sensorized Hydrogen Tanks With Focus on Acoustic Emission

Our Services:

- Application of monitoring systems based on acoustic emission (AE) sensors for material samples up to entire hydrogen tanks
- Early detection of material cracks, delaminations and pressure cycling stresses through the release of transient ultrasonic signals
- Continuous monitoring enables the reliable detection of leaks, structural failures and safe operation alerts
- Combination of different sensor systems for a holistic analysis of the influence of combined physical parameters, e.g. temperature, elongation, pressure, vibration
- Support in evaluating tank safety after a road accident
- Mobile or stationary monitoring system for tank systems

Your Benefits:

- Support in the development of more robust and durable materials and components through detailed investigations and analyses
- Selective product design through knowledge of the physical-technical relationships (damage mechanisms, material stress)
- Reduction of product costs by identifying and eliminating weak points and recognising potential for optimization
- Identification of damage mechanisms and the location of damage initiation
- On-time damage detection can prevent costly failures and repairs
- Reliable tank installation in the vehicle

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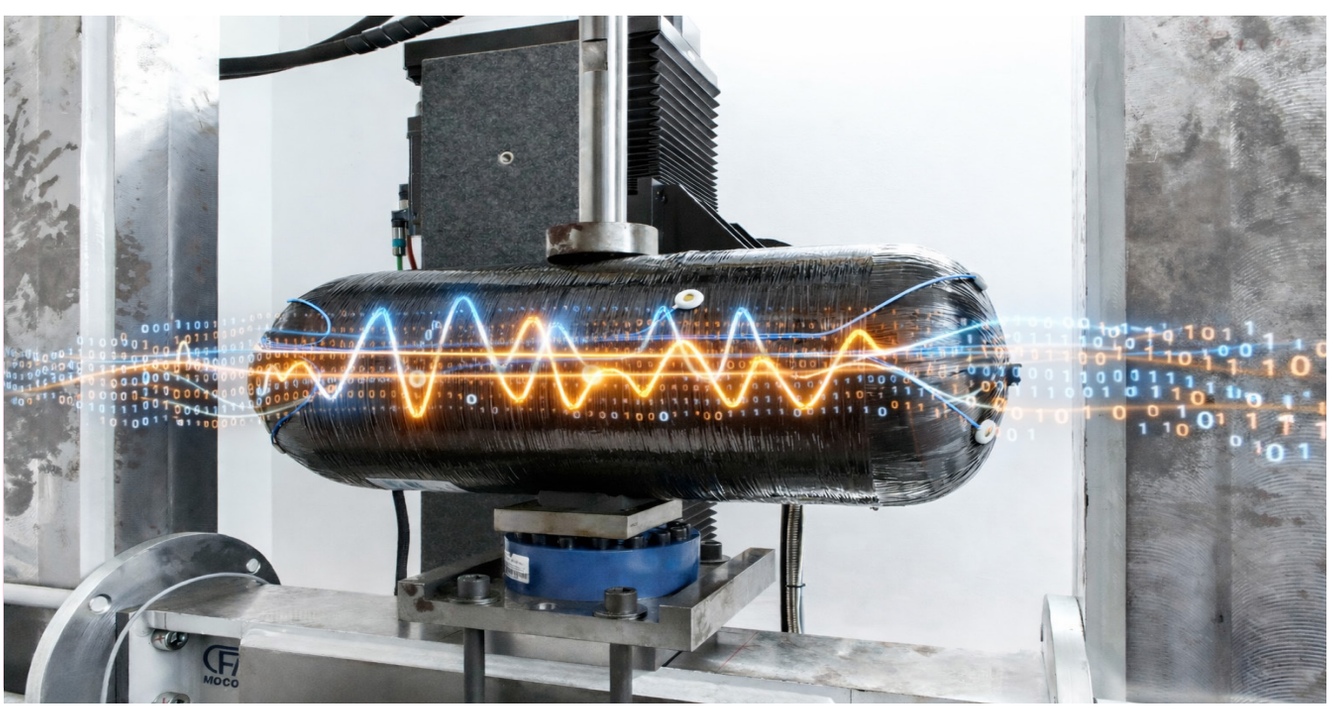

Test rig for the characterisation and validation of the AE sensors applied on H_2 tank.

Holistic Fuel Cell Testing Across All Levels – From Material to System

Reproduction of superimposed multiphysical loads during operation

- Enables "frontloading" in development process

Holistic testing approach for flexible and realistic characterization, performance/long-term tests in all system development stages including BoP (Balance of Plant)

Singel cell

- Dynamic, monoaxial vibration loads
- Dynamic electrical load
- Electrical power $P_{el} \leq 0.1$ kW

System

- Multi-axial vibration loads (≤ 200 Hz, ≤ 1000 kg)
- Climatic ambient conditions (- 40 °C to + 80 °C)
- Fuel cell system conditioning

Stack, System

- Dynamic, monoaxial vibration loads (55 kN, ≤ 2.5 kHz)
- Climatic ambient conditions (- 60 °C to + 120 °C)
- Dynamic electrical load
- Electrical power $P_{el} \leq 10$ kW
- Electrical power $P_{el} \leq 100$ kW (planned)

Fuel Cell Systems in Mobility Applications

Our Services:

- Predesign: evaluating how different integration approaches influence system behavior and stress beyond standard assumptions
- Advanced load data acquisition and customized measurement networks tailored to real operating conditions
- Sensor instrumentation, data acquisition, and implementation of sophisticated measurement campaigns (including in-depth data analysis)
- System identification and high-fidelity numerical simulation
- In-depth evaluation of vibration effects on fuel cells considering:
  - Position within the vehicle
  - Structure and stiffening of the cell stack
  - Integration and interaction of BoP (Balance of Plant) components
- Engineering support and technical consulting in:
  - Experimental system identification under real-world and edge conditions
  - Model calibration and parameter identification for predictive accuracy
  - Structural dynamic modeling beyond standard load cases
  - Holistic analysis of components and complete systems
- Advanced vibration investigations using shaker systems (with or without H_2), extending beyond standardized test profiles
- Development and execution of tailored load scenarios to assess:
  - Mechanical integrity under realistic and extreme conditions
  - Operational vibration behavior in application-relevant environments
  - Leak tightness under coupled loads and dynamic influences

Your Benefits:
- Deeper system understanding through data-driven insights beyond standard testing approaches
- Ability to make informed engineering decisions based on realistic, application-oriented data
- Early identification of critical influences and interactions in the development process
- Reduced development risks through predictive models and advanced analysis methods
- Support from an engineering partner focused on understanding and optimizing your system, not just testing it
- More reliable assessment of aging behavior based on realistic, laboratory-based and application-driven measurement campaigns

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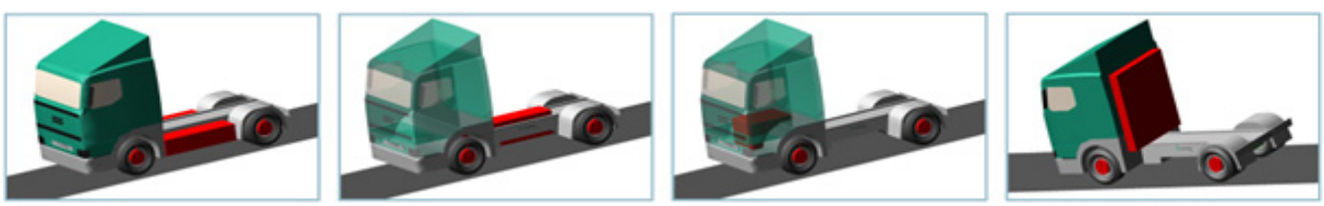

Different integration approaches lead to different mounting positions, e.g. low mounted lateral, central or above the front axle in the frame vs. high mounted behind the driver's cabin.

Probabilistic FMEA (Failure Mode and Effects Analysis)

Our Services:
- Performing reliability and safety analyses
- Qualitative methodical failure analyses (e. g. FMEA)
- Probabilistic system evaluation (probabilistic FMEA)

Your Benefits:
- Insights and technical consultant on system reliability and safety
- Determination of failure probabilities at system and subsystem level
- Utilisation of the findings for further considerations, e. g., functional safety

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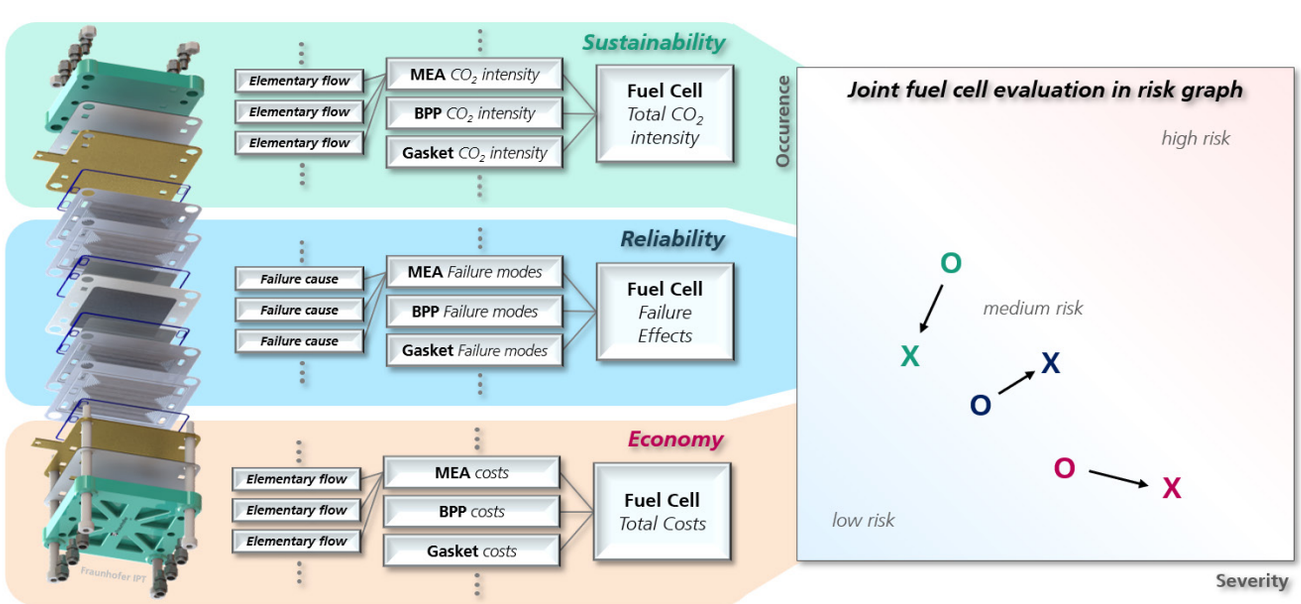

Probabilistic FMEA (left) delivers quantitative failure probabilities as an input for the assessment of functional safety (right).

Training Programs

As Part of Our Hydrogen Service, We Offer Know-How Transfer, Market Studies and Specialized Training Courses

Our Services:

- Training courses offered for reliability and safety assessment and the sustainability of hydrogen industry systems
- Shaping customized training programes for your specific needs, examples:
  - Reliability and safety assessment and sustainability of systems for hydrogen industry
  - Mechanical behaviour of polymers & composites and elastomers as well as methods for their design and simulation
  - Polymer Service for metal engineers: understanding mechanics and fatigue, implementing material substitution
- Trouble-Shooting: Consultant services in the case of damage: Investigation of cases of damage and derivation of measures
- Offering webinars, online consultation, exchange sessions and training sessions covering topics from materials to systems for a range of target groups

Your Benefits:

- Knowledge gain of own employees
- Improved decision-making for the optimal design of hydrogen systems

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Fraunhofer LBF and High-Performance Center GreenMat4H$_2$

The Fraunhofer LBF, together with the Fraunhofer Research Institution for Materials Recycling and Resource Strategies IWKS, forms the Fraunhofer High-Performance Center GreenMat4H$_2$, which is directed by Prof. Dr. Tobias Melz, head of the Fraunhofer LBF.

The focus of this High-Performance Center is to provide the best possible support for the hydrogen industry in the Rhine-Main region and beyond. To accomplish this goal, projects are carried out with industry and other research institutions as well as universities and institutions of higher education.

Public events are organised, such as the Hydrogen Round Table and the Civil Dialogue on Hydrogen, in order to create a broad acceptance of hydrogen across and to network companies, associations, research institutes, universities and institutions of higher education. Fraunhofer LBF together with Fraunhofer IWKS organize workshops on hydrogen-related topics, and exhibit their services at official events such as exhibitions and congresses to the hydrogen industry.

You can find more information at: ***www.leistungszentrum-wasserstoff-hessen.de***

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