Testing Facilities for Fuel Cells and Electrolysis in Baden-Württemberg

e-mobil BW

State Agency for New Mobility Solutions
and Automotive Baden-Württemberg

Introduction

Baden-Wuerttemberg is home state of leading industry segments such as automotive, machinery equipment manufacturing or electrical equipment, to name a few. Hydrogen and fuel cell technologies offer a wide range of new technological and industrial opportunities for each of the former named industries. In addition, numerous model and demonstration projects are located in Baden-Wuerttemberg and illustrate the generation and application of hydrogen technologies along the whole value chain.

Among hydrogen technologies, fuel cells and electrolysis play a crucial role as they are the most common application fields. However, to put these technologies into practice it is often necessary to receive support related to development, testing or simulation.

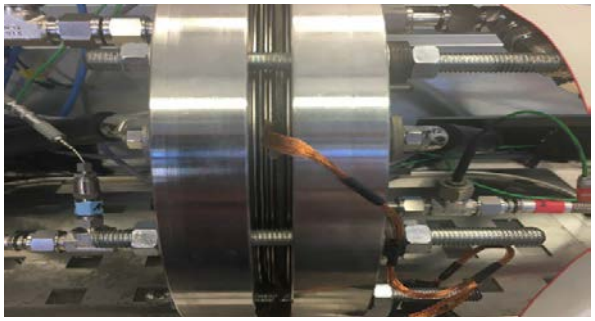
Excellency in research and development institutes as well as centers focused on hydrogen technologies are well established in Baden-Wuerttemberg for many years. These institutes offer a wide range of technical support to third parties. This summary paper of e-mobil BW – the State Agency for New Mobility Solutions and Automotive Baden-Wuerttemberg – provides an overview of their testing and simulation capabilities for fuel cell stacks, fuel cell systems, electrolysis stacks and electrolysis systems along with contact information for all sites.

Table of Content – Testing facilities

Full insititute names:

TT-ECE – Institute of Engineering Thermodynamics, Department Electrochemical Energy Technology
FK-FEK – Institute of Vehicle Concepts, Vehicle energy concepts
FK-WVG – Institute of Vehicle Concepts, Material and process applications - complete vehicle
IAM-ET – Institute for Applied Materials – Electrochemical Technologies

Source: DLR



Source: DLR

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Hydrogen related testing at DLR Stuttgart (TT-ECE)

Low temperature testing facilities (PEMFC, PEMEL, AEMEL)

- **PEMFC:** 24/7 testing of MEAs (e.g. performance characterization, load cycling, AST, …) at different size using high precision MFCs for reactant flow control and direct reactant pressure control
- **Material and component characterisation:** quality and defect analysis of materials of all fuel cell and electrolyser components (MEAs, BPPs, …). Typical anaylticalmethods are FIB-SEM, AFM, XRD, XPS, FTIR, Raman as well as simple preparation e.g. via microtome or ion cutting

High temperature testing facilities (SOFC, SOEC)

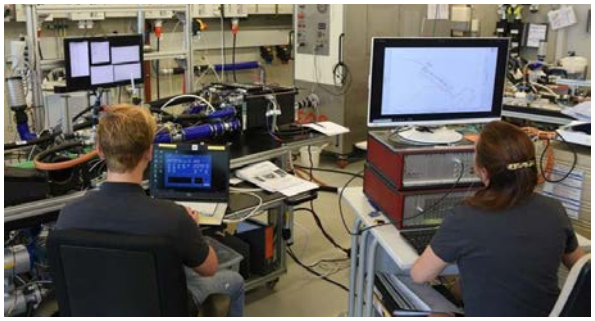
- 4 stack test stations for: fuel cell (SOFC), electrolysis (SOEL), reversible SOFC/SOEL, intermitted renewable energy profile operation
- Stack power up to 5 kW, up to 400 cm2 footprint, up to 10.000 h test duration,
- temperature range 650–900°C
- **PEMEL and AEMEL:** 24/7 testing of MEAs (e.g. performance characterization, AST, long-term stability), water flow in the anode and/or the cathode, H2generation up to 30 bar
- **Segmented cell:** Local characterisation and degradation phenomena in PEMEL and AEMEL cell and stacks

Investigations & Characterization methods:

- stack homogeneity anaysis and stack analysis by electrochemical impedance spectroscopy (EIS)
- Electrochemical process analysis by distribution of relaxation times (DRT) and electrical resistance evaluation by equivalent circuit model (ECM)

Contact person:
Prof. Dr. Andreas Friedrich
Andreas.Friedrich@dlr.de

Source: DLR



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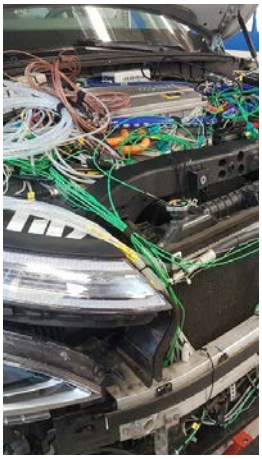

Source: DLR

Hydrogen related testing at DLR Stuttgart (FK-FEK, FK-WVG)

PEMFC electrical testing facilities

- **Thermal and electric tests on cell level:** Fiber sensing for spatially resolved temperature measurement, accelerated electrochemical impedance spectroscopy
- **Stacks:** esting of operating parameters, specially conditioned air supply, up to 250kW under environm. conditions
- **BoP, metal hydride comp. test:** Common modular FC-system and BoP-test rig (equipped with 15 kW FC)

PEMFC mechanical and environmental testing facilities

- **Mechanical tests on component or stack level:** static force and dynamic test, corrosion test, H2 embrittlement testing

Roller test bench with climate chamber for vehicle and system testing

- **FCEV testing UNECE R 101** with continuous hydrogen supply in climate chamber –40°C…+60°C, different loads and driving resistance, ISO 23828 consumption measurements, fuel cell exhaust measurements (EI-Sense), airflow simulation
- **Fuel Cell system testing solutions** 24/7, up to 250kW in climate chamber –40°C…+60°C, connected to DC-source/sink, external cooling

Contact person:
Dr. Michael Schier
Michael.Schier@dlr.de

Source: Fraunhofer ICT

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Source: Fraunhofer ICT

Source: Fraunhofer ICT

Hydrogen related testing at Fraunhofer ICT

Fuel Cell Testing

- Characterization of single cell and fuel cell stacks: LT-PEM up to 10 kW and HT-PEM fuel cell stack up to 6 kW. Also Pressure cycling tests.
- Characterization of MEA by polarization, electro-chemical impedance spectroscopy (EIS), cyclo voltammetry, linear sweep voltammetry, limiting current density, CO stripping and of catalyst by rotating disk electrode (RDE)
- Characterization of system components as compressor, humidfier, and valves

Electrolysis Testing

- AEMEL single cell testing and PEMEL single cell and stack testing with focus on reversible degradation effects
- Characterization of catalyst materials by rotating disk electrode (RDE)

Hydrogen Combustion Engine

- Characterization of a hydrogen combustion engine
- Single cylinder engine with optimized combustion and injection

Contact person:
Fuel Cell: Max Cleven,
max.cleven@ict.fraunhofer.de
Electrolysis: Stefan Bürger,
stefan.buerger@ict.fraunhofer.de

Source: Fraunhofer ISE

Source: Fraunhofer ISE

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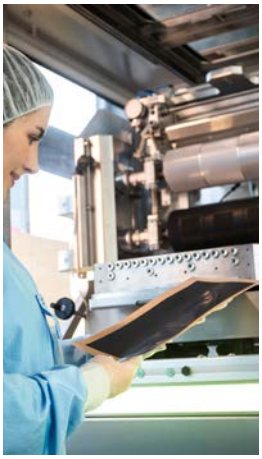


Source: Fraunhofer ISE

Hydrogen related testing at Fraunhofer ISE

Fuel Cell Testing

- In-situ characterization of membrane fuel cell stacks up to 200 kW (up to 1,800 A, up to 130 °C, freeze start testing)
- In-situ characterization of fuel cell membrane electrode assemblies (MEAs) by polarization, electro-chemical impedance spectroscopy, cyclo voltammetry, linear sweep voltammetry, limiting current density, CO stripping, CO displacement
- In-situ characterization of local effects in segmented fuel cells (with customer flow-field design)

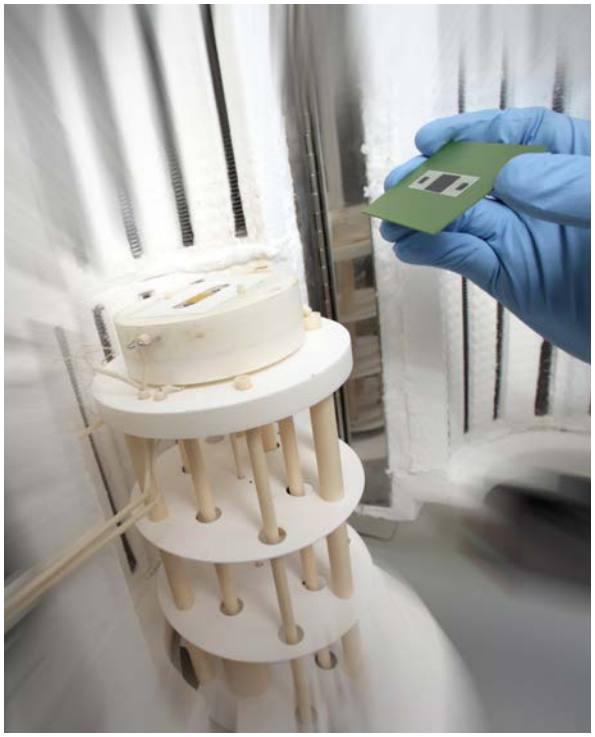
Electrolysis Testing

- Single cell testing in AEMEL (up to 200 A) and PEMEL (up to 600 A, 120 °C and 50 barg) incl. EIS with focus on MEAs, MPL/PTL, and corrosion protecting coatings
- Stack testing PEMEL (up to 1500 A, 80 °C and 50 barg) with focus on highly dynamic operation
- Segmented and along the channel test hardware for PEMEL single cells with RE, incl. EIS

General

- Ex-situ analytics of electrolysis & fuel cell components (FIB-SEM, XRF, NAP-XPS, porosimetry, laser scanning microscopy, ICP-MS)
- MEA development for electrolysis and fuel cell
  - Investigation of production processes from ink formulation to full size MEAs (lab scale & sheet to sheet as well as industrial scale & roll to roll)
  - Quality control for each production step
  - Protoype production

Contact person:
Fuel Cell: Ulf Groos, ulf.groos@ise.fraunhofer.de, +49 761 4588-5202
Electrolysis: Dr. Tom Smolinka, tom.smolinka@ise.fraunhofer.de, +49 761 4588-5212



Source: KIT

Source: KIT

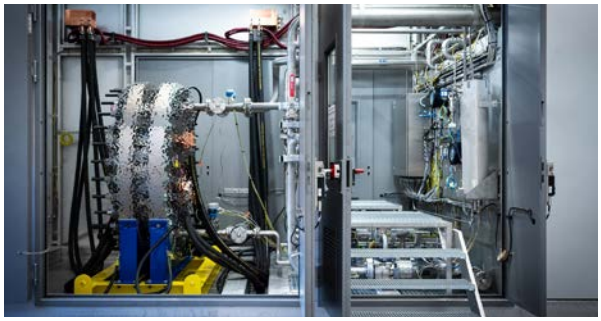
Hydrogen related testing at KIT, IAM-ET

Testing facilities and Simulation methods

- analysis of SOC and PEM –fuel cells and electrolyzers
- performance testing and detailed electrochemical characterization of single cells and repeat units
- durability and poisoning testing
- impedance spectroscopy and DRT analysis to deconvolute and quantify loss and degradation mechanisms
- focus on incremental (~ 1 cm²) cells, possibility to test larger and segmented cells
- chemical, structural and microstructural analysis including tomography (FIB-SEM, µCT)
- characterization of electrocatalysts
  - low T (PEM, CO2-reduction): RDE, CLs in CCMs, various operando approaches
  - high T (SOC): sym. cells

Contact person:
André Weber
andre.weber@kit.edu
+49 721 608 47572

Source: ZSW



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ElyLab – electrolysis testing at ZSW Stuttgart

Testing facilities and Simulation methods

- **ElyLab test** centre offers support for industry with independent facilities for **alkaline electrolysis and AEM** tests ranging from electrode analysis right through to stack tests on a megawatt scale.
- Support with system, stack and component development
- **Electrode characterization** with data acquisition at single cell level (U/I, EIS, LSV, CV, ...)
- **Material analyses** (SEM, EDX, artificial ageing...)
- Development of **accelerated stress tests**
- Configurable test stacks as a flexible basis for the validation of cell components
- Test rigs for short and full-size stack tests up to MW scale
  - Up to 30 bar
  - Up to 20.000 A
- Online access to measured data in real time
- Development of data analysis applying AI
- Automated running of load profiles, 24/7 operation

Contact person:
Dr. Marc-Simon Loeffler
marc-simon.loeffler@zsw-bw.de
+49 711 7870 233

Source: ZSW

Electrolysis technology at ZSW Stuttgart

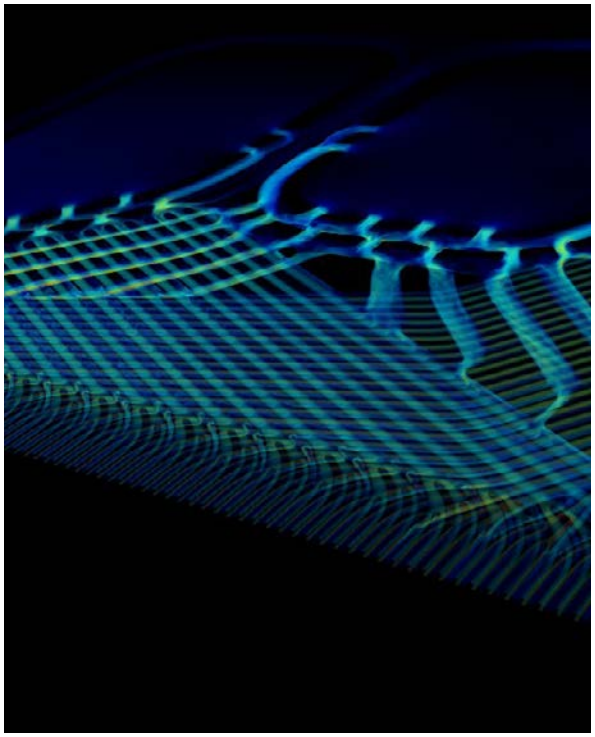
Alkaline high-pressure electrolysis system technology

- Almost 15 years of R&D with several real world applications, TRL5-6
- Certification and operating approval, full system documentation, CE
- Intelligent heat management for rapid start-up from standby
- Separate electrolyte circuits for high level of gas purity, up to 30 bar
- Modular and flexible system configuration
- Compact design for container or rack installation (outdoor or indoor)
- Own software incl. remote control, performance & status monitoring
- Option of licensing system design & software to industrial customers

Alkaline high-pressure electrolysis stack technology

- Proven and patented stack designs (active cell areas from 100 cm² to 15.000 cm², pressure range atm. up to 30 bar)
- Individual stack development (incl. validation or prototype in relevant operational environment, full documentation of all components)
- Components ready for series production (cell frames (EPDM or injection molded plastic), electrode packages in flexible and rigiddesigns, various coating technologies)
- Option of licensing components & stacks to industrial customers

Contact person:
Dr. Marc-Simon Loeffler
marc-simon.loeffler@zsw-bw.de
+49 711 7870 233



Source: ZSW

Source: ZSW/Elvira Eberhardt

Hydrogen related testing and simulation methods for hydrogen components and systems at ZSW Ulm

- Characterization for PEM stacks components (like bipolar plates, diffusion media, catalysts, membranes, and combinations like CCM, MEA, etc.), stack and system testing up to 250 kWel
- Full flexible in-house developed real-time data management systems based on MQTT broker, MariaDB, Grafana, Python, with interfaces to commercial software like Excel, MatLab, etc., including real-time data analysis (e.g. cell voltage decay over time), supported by AI methods (digital twins for all objects under investigation).
- Low and medium temperature PEM fuel cell stacks and PEM/AEM electrolyzer
- Hydrogen quality lab HyLaB: analyze hydrogen (and water) quality according to international standards
- Simulation of fuel cell flowfieldsand components, including electrochemistry, water balance and multi-phase simulations (CFD, MC)
- Fuel cell stack simulations (media distribution over the cells, temperature distribution, ...)
- Use of Ansys FluentTM, including VoFand Fuel Cell module, AVL Fire, open source software (open foam)
- Performance-, Degradation-and Contaminant gas performance model (Matlabbased)
- Simulation of thermal processes in battery packs or parts thereof (heat transfer, for cooling design)

Contact person:
Dr. Alexander Kabza
alexander.kabza@zsw-bw.de
+49-731-9530-832

Testmöglichkeiten in BW

		Fuel cell stack						Fuel Cell system				Fuel Cell Stack Components											Main BoP components Fuel Cell System					
		stack tests	power range	tempera-ture				system	Power range	sub zero testing	environ-mental conditio-ning	characteristics testing				bipolar plate	CCM/MEA	GDL	membrane	catalyst	sealing	other	humidifier	anode recircu-lation blower	filter	water separator	air compres-sor	other
			(kW)	(sub zero <0°C)	(low <90°C)	(mid <120°C)	(high >120°C)		(kW)	(sub zero < 0°C)		techno-logy	mechani-cal	electrical	chemical													
fuel cell	DLR Stuttgart, Inst. für Fahrzeugkonzepte	PEMFC	0.1 - 15	yes	yes	yes		yes	< 250	yes	yes	PEMFC	yes	yes														common modular fc test rig up to 15 kW
	DLR Stuttgart, Inst für tech. Thermodynamik	SOFC	0.1 - 2.5				650 - 900°C																					
		PEMFC	0.1 - 5	yes, for MEA	yes							PEMFC				yes	yes	yes	yes	yes	yes	yes						
	Fraunhofer ICT	PEMFC	< 6	yes	yes	yes	yes	yes	< 75			PEMFC	yes	yes	yes	yes	yes	yes	yes	yes			yes	yes	yes	yes	yes	hoses, valves
	Fraunhofer ISE	PEMFC	4, 10, 20, 200	yes	yes	yes	< 130 °C					PEMFC	yes (dimen-sion)	yes	yes	yes	yes	yes	yes	yes								
	KIT							yes	tbd.	during winter	in container	PEMFC, SOFC		yes	yes		yes	yes	yes SOFC	yes								
	ZSW Ulm	PEMFC	up to 250	yes	yes	yes	yes	yes	< 100	no	partly	PEMFC	yes	yes	yes	yes	yes	yes	yes	yes	yes		yes	yes	yes	yes	yes	sensors

		Electrolyser stack						Electrolylser system				Electrolyser Stack Components											Main BoP components Electrolyser System			
		AEL	PEMEL	AEMEL	SOEC	power range	max pressure, max current	system	Power range	sub zero testing	environ-mental conditio-ning	characteristics testing				bipolar plate	CCM/MEA	PTL	membrane	catalyst	sealing	other	water treatment	gas separators	gas dryer/ processing	other
						(kW)			(kW)	(sub zero < 0°C)		techno-logy	mechani-cal	electrical	chemical		Electrode	Current collector/ flow field	separators							
electrolysis	DLR Stuttgart, Inst für tech. Thermodynamik				yes	0.1 - 5						SOEC														
			yes			0,2	<50 barg, < 1500 A	yes	50		lab testing	PEMEL	yes	yes	yes	yes	yes	yes		yes	yes					
	Fraunhofer ICT		yes			< 20	< 30 bar					AEMEM, PEMEL	yes	yes	yes		yes	yes	yes	yes						pipes, valves
	Fraunhofer ISE		yes			< 20	< 50bar, < 1.500 A	yes	50		lab testing	PEMEL	yes	yes	yes	yes	yes	yes		yes	yes					
	KIT							yes			system in container	PEMEL, SOEC		yes	yes		yes	yes	SOEC	yes						
	ZSW Stuttgart	yes		yes		0.1 - 500	< 30 bar, < 20.000A	yes	< 500			AEL, AEMEL	yes	yes	yes	yes	yes	yes	yes	yes	yes		yes	yes	yes	
	ZSW Ulm		yes	yes		< 1.000		yes	< 1.000		partly	AEMEL, PEMEL	yes	yes	yes	yes	yes	yes	yes	yes	yes					

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