ZBT Zentrum für BrennstoffzellenTechnik

OPERATING PEM FUEL CELLS ON HIGHER TEMPERATURES - OPPORTUNITIES AND CHALLENGES

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-fuel cells and systems -

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ZBT Zentrum für BrennstoffzellenTechnik is

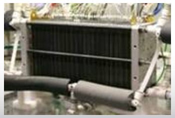
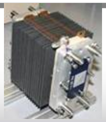
- Independent R&D service provider
- Dedicated to hydrogen and fuel cell technology
- ~ 100 full time employes
- Focussing on applied technologies

Core technologies and services

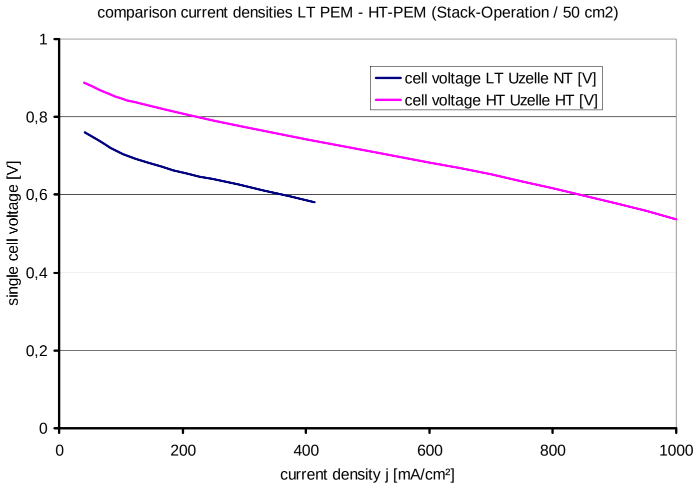
- Bipolar plates
- Fuel cell stacks < 3 kW
- Fuel reforming
- Fuel cell system technologies (H_2, reformate)
- Production technologies
- Testing for certificates
  (accredited testing lab)

„PEM“-Technologies - system & controls point of view

	LT-PEMFC	**HT-PEMFC**	**MT-PEMFC**
Protone conductivity	High with sufficient humidity of Membrane	High at temperatures at >150°C	**Strongly depending on humidity and temperatures**
Typical operation	20 - 80°C	130 - 200°C	100 – 130 °C
Material temperature stability	**Up to 110 °C**	**Up to 220 °C**	**Up to 150 °C**
Cold start	Good also at moderate negative temperatures	Poor performance at low temperatures, condensing water reduces quality (degradation)	Probably comparable to LT MEA
Cooling media / temperature	**water, max. approx. 70°C; air**	**Thermo oils, special cooling media, condensation, air**	**Pressurized liquid water, condensation, air**
Reformate operation CO-Tolerance	<100 ppm	approx. 1 Vol.-% (10.000 ppm)	approx. 0,1 Vol.-% (1.000 ppm)
Typical applications	Fast starting systems (UPS, automobiles), preferabily hydrogen, reformate possible	Reformate systems	Upcoming: automobiles
Commercial MEA suppliers	Gore, 3M, Solvicore, JM, …	BASF, Advent, Elcomax, Danish power systems	-

HT PEM opportunities and challenges



Operational parameters

- working at 130 °C – 200 °C

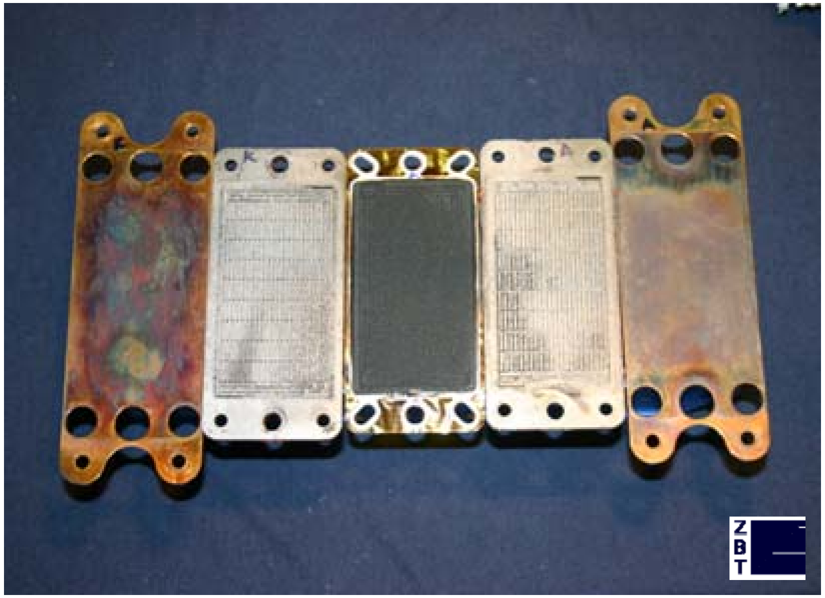
opportunities

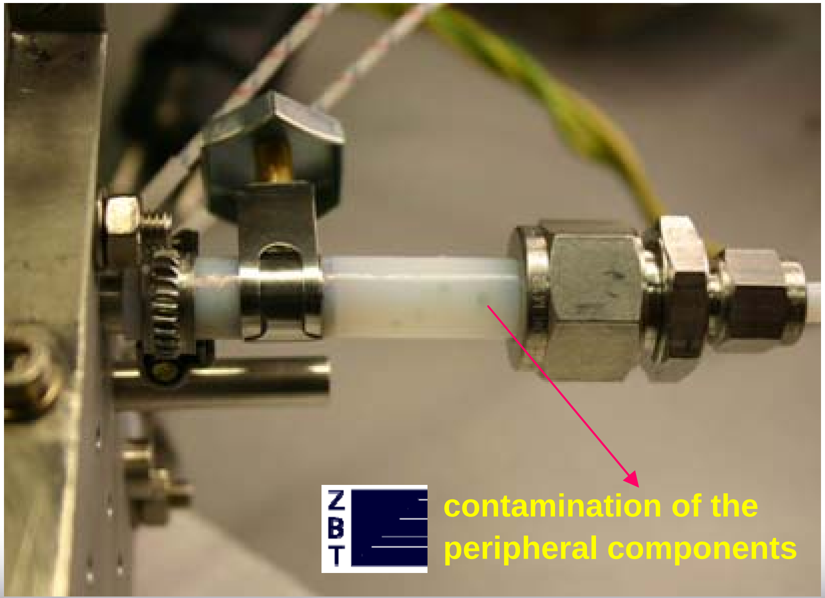
- Temperature level optimal for heat recovery
- highly stable against harmful gases
- No humidification, no gas purification
- Optimal for reformer coupling (CO, temperature, humidity etc.)
- System control is robust

challenges

- Identification of stack and system materials is critical
- High material and machining costs for the fuel cell stack
- MEA sensitive against (liquid) water
- Poor efficiency and power density of the MEA compared to LT PEM

Lessons learned: Cell components after various long term testing





HT PEM FC / PBI based @ ~ 170°C

BPP:

- Surface deterioration was negligible, no cracks
- Electrical conductivity / gas tightness constant
- Some Plate materials show weak stability depending on (local) operation temperature

MEA / GDL:

- No visible changes
- Other degradations (catalyst, membrane conductivity etc.) seen in iv-curve

Gaskets

- FKM materials proof to be stable
- Other materials show incompatibility against phosphoric acid

Current Collector (gold-plated copper):

- Conductivity deterioration was observed
- Gold plating diffused

Furthermore external circuits and components might get harmed by phosphoric acid

Lessons learned: requirements for materials

(Cell-)Components

- MEA / GDL
- Bipolar plates
- Gaskets (active)
- Gaskets (cooling)
- Current collectors
- Isolating plates
- End plates
- Fittings, pipes
- **Also: peripheral components**

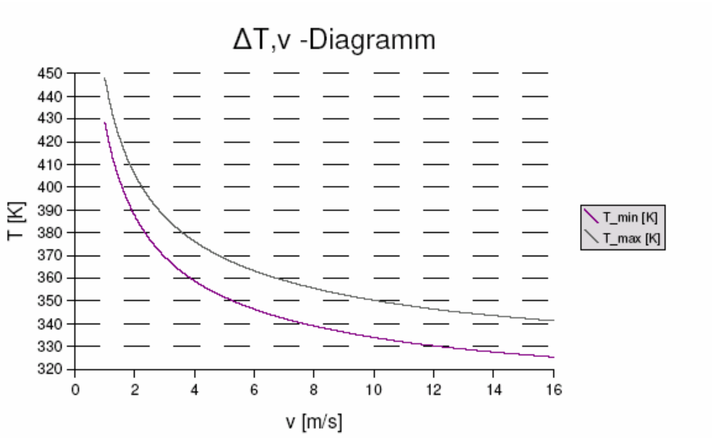
General requirements

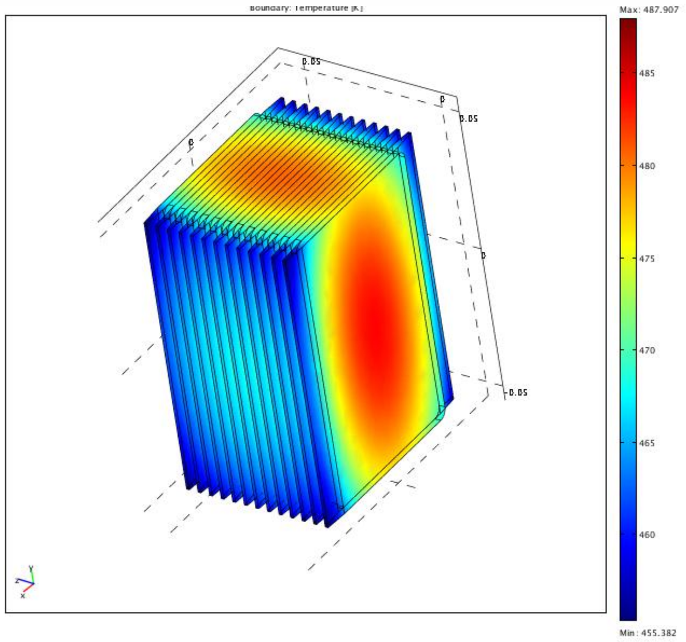
- Temperature up to **200 °C**:
  - Dimensional stability
  - Ageing
- Chemical stability in the presence of:
  - Fuel (hydrogen / reformate)
  - Oxidant (Air)
  - Product water
  - Mineral acids (**Phosphoric acid**)
  - Cooling liquid (if appropriate)
- Stable against mechanical pressure
- Stable under steady electrical potential

(As the cross links are complex concrete specifications are not available)

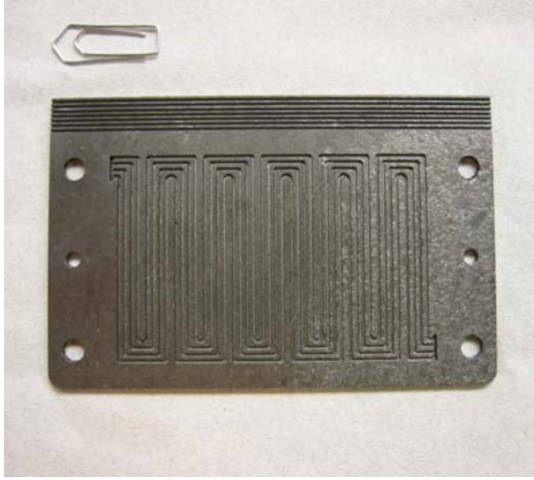
Optimization: Reduce stack volume by external air cooling

- High operating temperature of HT PEM allows an efficient air cooling at most outside conditions
- Internal cooling structures demand halfplate designs
- Real bipolar plate approach with outside cooling
- Modelling and Simulation for optimized geometric setups performed using COMSOL multiphysics
- Result: External structured fins for a most efficient active cooling at low cooling stream





stack design – ZBT air cooled HT PEM



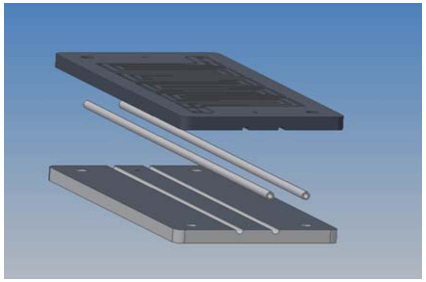
- Graphite based bipolar plates with external cooling fins
- Alternating cell assembly
- FKM gaskets (fluororubber / injection moulded)
- Operating temperature **160** – 180°C
- Start-up heating by hot air stream or reformate off gas ~ 15 mins
- Cooling by air stream / fan
- 24 cell / 27.6 cm^2 active area / 140 W_{el} (@ H_2) / 120 W_{el} (@ reformate)
- 24 cell / 48 cm^2 active area / 300 W_{el} (@ H_2) / 260 W_{el} (@ reformate)

Lessons learned: Thermal management

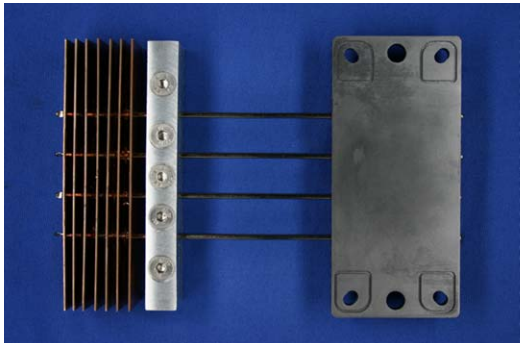
- Air cooling is most beneficial for HT PEM fuel cell stacks
  - No additional media necessary
  - High operating temperature allows optimal cooling independent from outside temperatures
  - Startup heating is possible with reformate off gases / hot air
- But: most applications demand heat extraction
  - Standard cooling media for this temperature range: thermo oils
  - Sealing of cooling structures is insufficient for oils
  - Oils do harm the MEA and other components
  - Constructions with standard halfplate cooling concepts are not possible

Liquid cooling – possible concepts

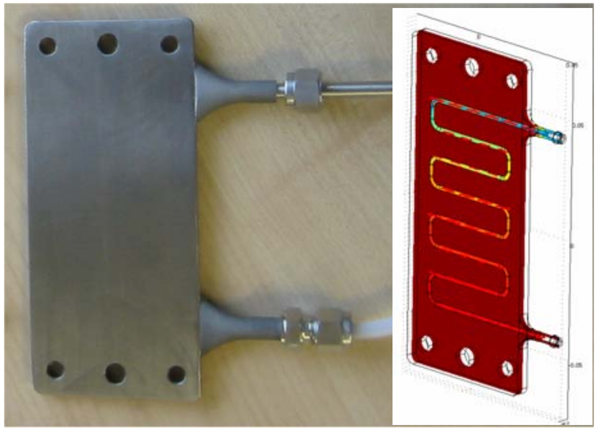
Heat exchanger pipes between two bipolar halfplates



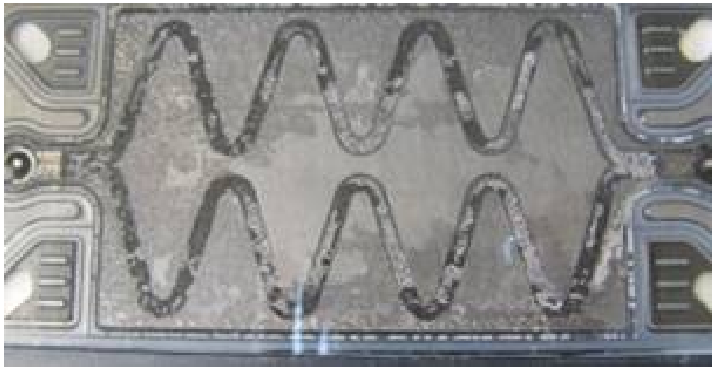
Heat pipes



cooling plates

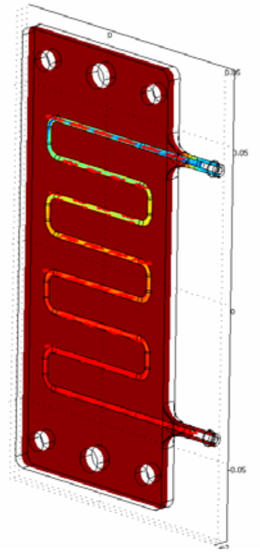


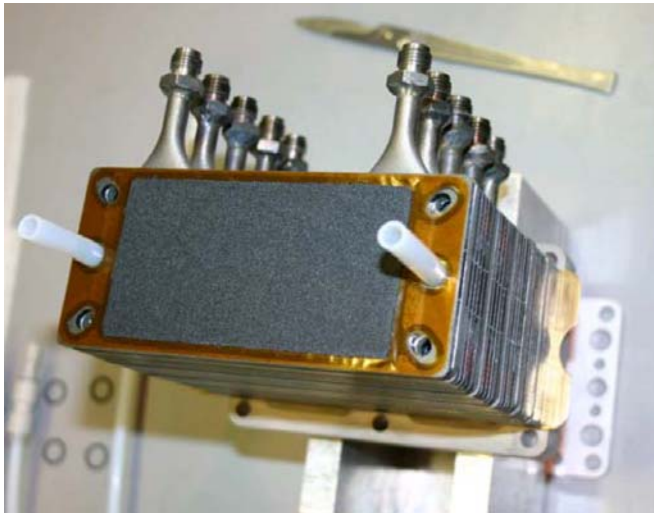
Water evaporation



Alternative cooling media

realized: physical integration of cooling architecture



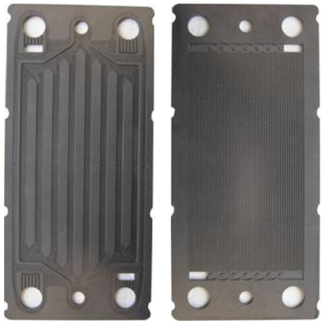


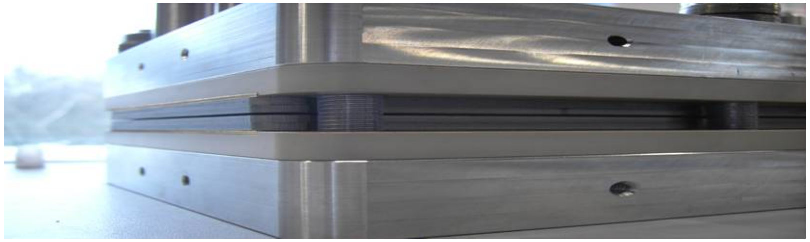
Realized: Alternative cooling media

Towards a 3.5 kW stack technology:

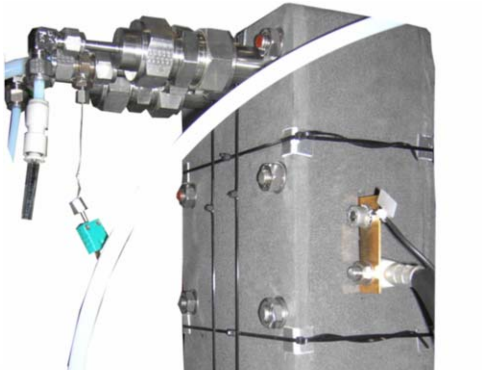
- 65 cells / 200 cm²
- dimensions: 280 mm x 160 mm x 570 mm
- 3 kW @ 80 Amps
- Cooling via halfplate technology
- inert cooling medium: Fluorinated heat transfer fluid
- application: absorption chiller based cooling system

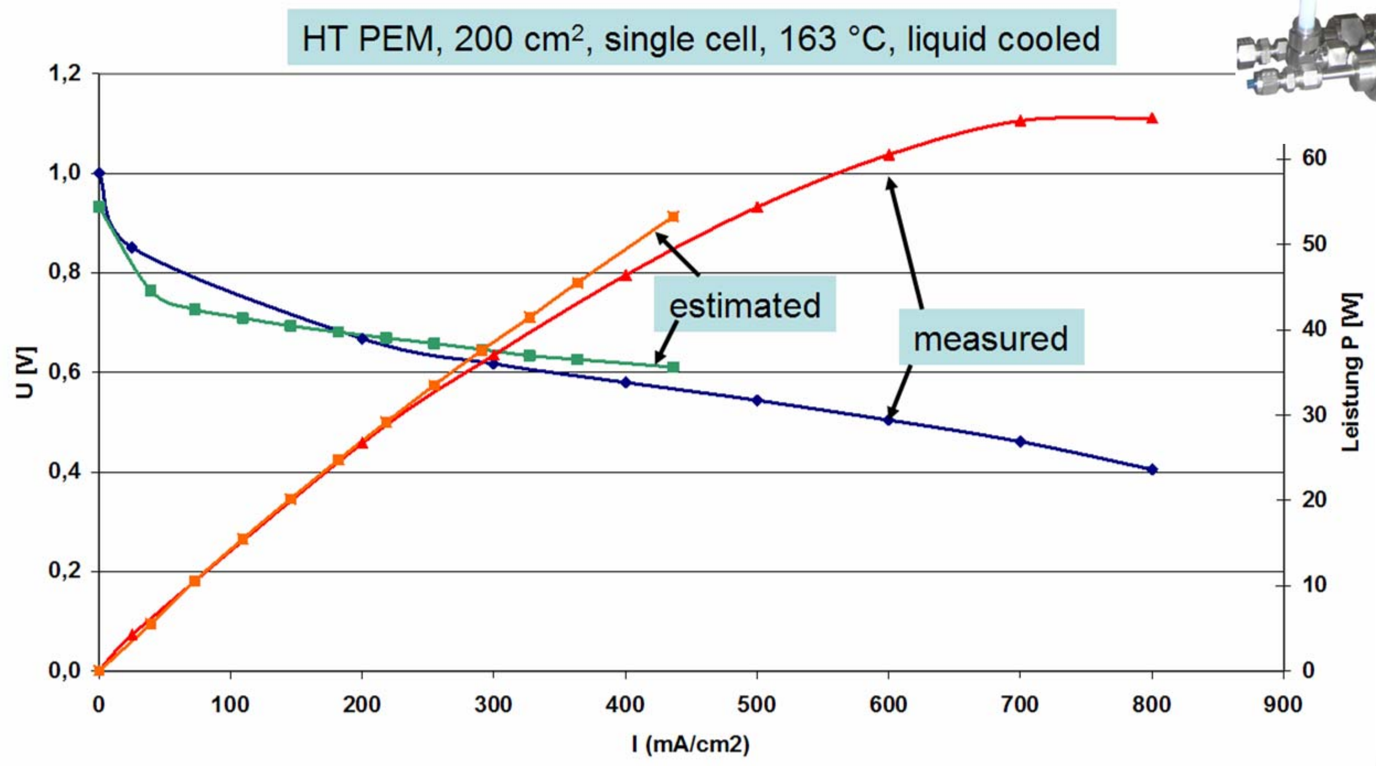
Single cell performance tests





280 mm x 160 mm





Power: 46 W at 80 A

MT PEM opportunities and challenges

Operational parameters

- working at 0 °C – 130 °C

opportunities

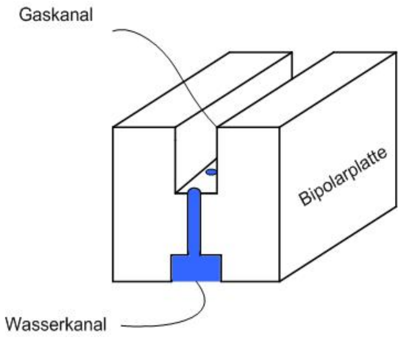
- Temperature level optimal for heat removal
- Good stability against harmful gases and operational influences
- System control probably robust

challenges

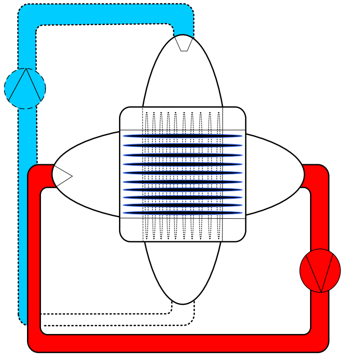
- material costs for the fuel cell stack probably higher than for LT PEM
- efficiency and power density depending on media supply
- Humidification and pressure operation demand high BOP power
- No commercial MEA technology available

Goal: internal humidification & cooling by water evaporation

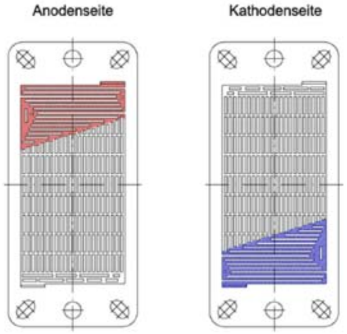
- Option 1: feed liquid (cooling) water to gas channels by capillary channels



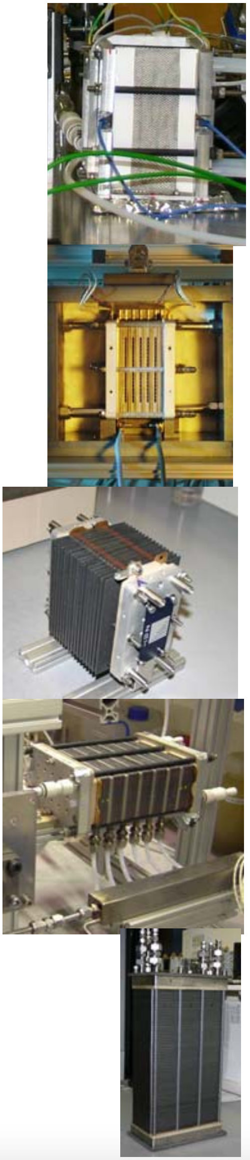
- Option 2: spray water fog (generated e.g. by Ultrasonic Water Fogger) into open anode and / or cathode channels



- Option 3: use evaporation zones / additional media channels in the gas media supply flow fields



Summary



- Selection of suitable materials for **HT PEM stack** components is crucial (and partly still an open topic)
- Optimum for the stack: cooling with air
  - cooling plates (Halfplate technology)
  - External fin cooling
- Optimium for many systems and applications: liquid cooling
  - Oils will harm the MEA
  - Secure separation of oil and fuel cell
  - Or: alternative cooling media (inert)

- **MT PEM** Technology under discussion
- Lack of MEA technologies
- Cooling and humidification to be combined

Thanks for supporting:

- State of Northrhine Westfalia and European Union for supporting ZBT and the initial R&D regarding HT PEM stacks
- Bundesministerium für Bildung und Forschung – Project MicroPower 2006-2009 03X3511 G and the (main) partners BASF FC, Schunk, IMM, Flexiva
- Bundesministerium für Wirtschaft und Technologie (BMWi) for sponsoring the Projects “HT-PEM + Metallhydride (IGF 247ZN)”, “HT PEM plus adsorbtion chiller (IGF 311ZN) ” and “MT-PEM stack IGF 16594” within the Industrial common research funds (IGF).
- State of Northrhine Westfalia and European Union for supporting the HiperLoCo project (Pro 010)
- Our R&D partners
- The team at ZBT (George Bandlamudi, Frank Filusch, Christian Heßke, Wilhelm Krutsch, Sina Souzani, Jens Burfeind and others)