Bipolar Plate Technologies and Ex-Situ Tests for Material Selection

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1 ZBT Institute

2 Bipolar Plate Technologies

Injection Molded Composite Plates

Hydroformed Metallic Plates

3 Ex-Situ Tests for Material Selection

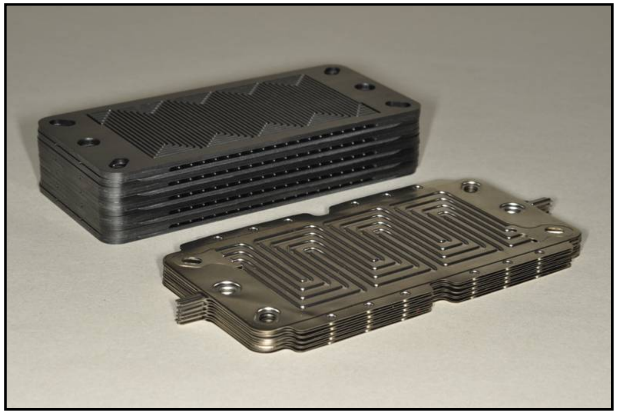
Project BREEZE

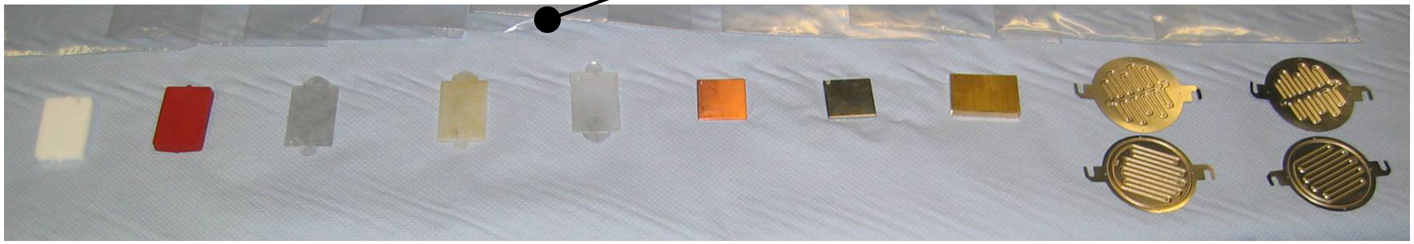
Qualification Methods

Approaches and Specific Results – Project BREEZE

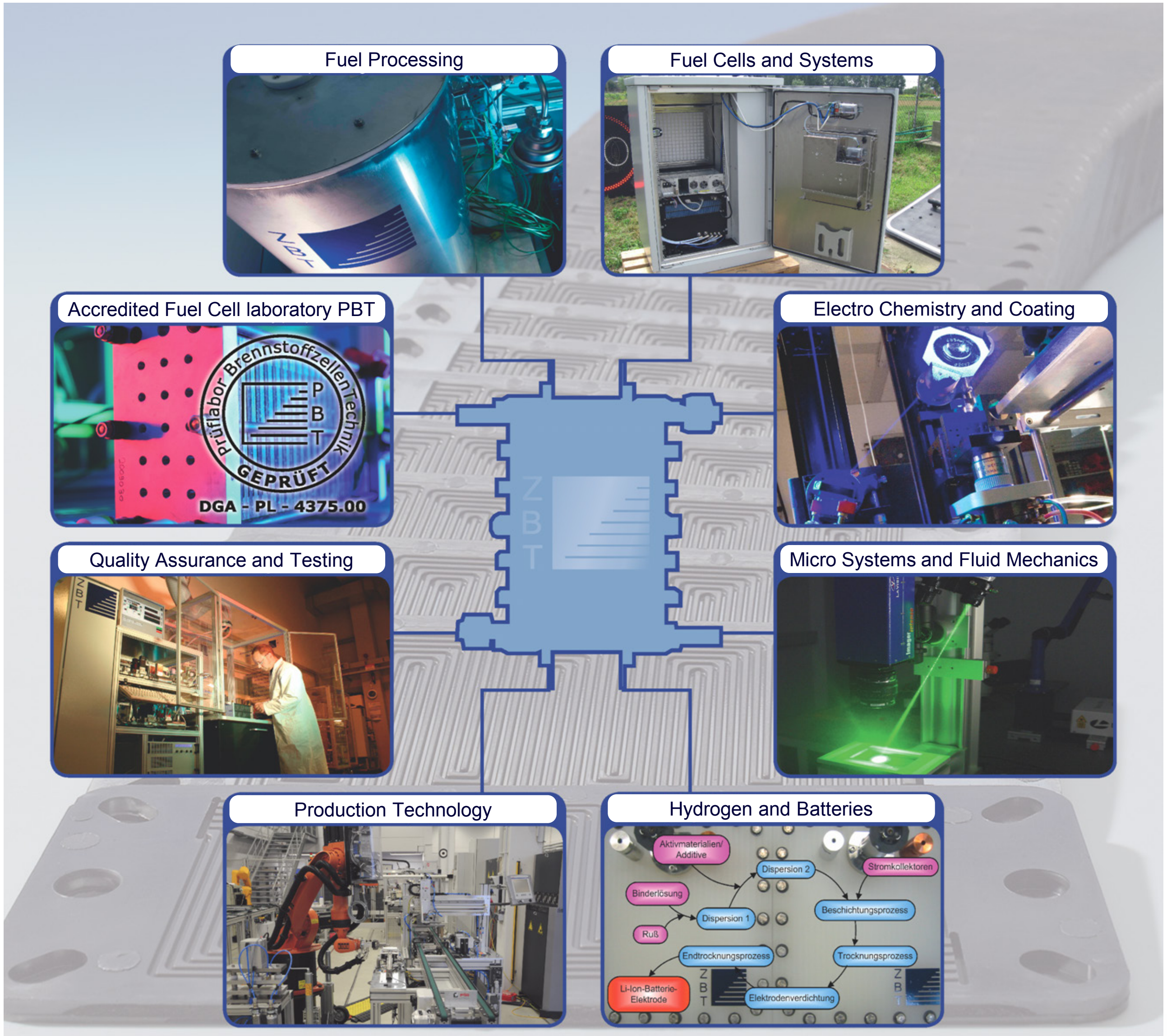
Metallic Bipolar Plates

PEMFC coolant / coolant cycle materials



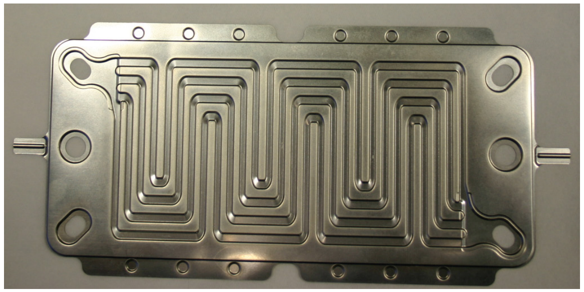


1 ZBT Institute

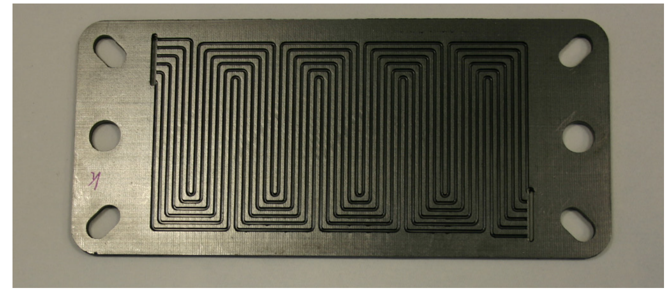


2 BPP Technologies at ZBT

Metallic Bipolar Plates



Composite Bipolar Plates



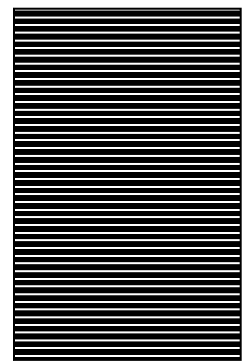
Example:
Stack of 80 cells
Active area 50 cm^2

Cell height ~ 1,6 - 2,0 mm (*)

16,0 cm

1,33 kg

Cell height ~ 5,8 mm (*)



46,4 cm

5,12 kg

automotive …transportable… **stationary**

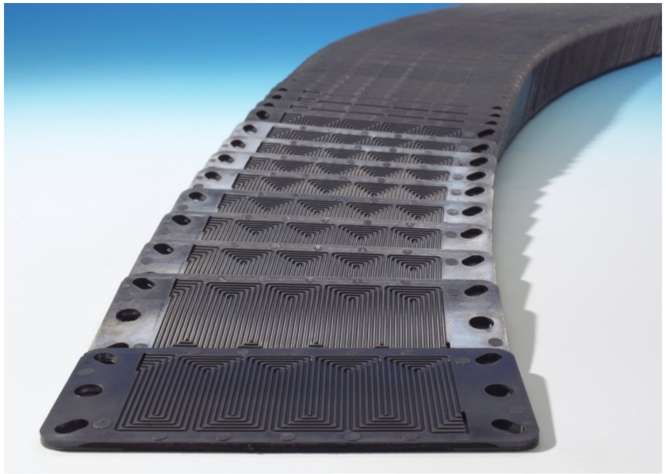
(*) ZBT values

Challenges with Injection Molding:

- High melt viscosity ➔ requires high pressures
- High thermal conductivity of the material
  ➔ fast solidification
- Size of bipolar plates is limited by material & machine parameters

Benefits:

- Mass producability ➔ production cycle < 20 s
  (clamping force 5000 kN, maximum working space 300 cm^2)
- High reproducibility
- High accuracy
- Thermoplastics are recycable



- **Material and Process Technology is valid for Low Temperature <u>and</u> High Temperature PEMFC!**

Feedstock

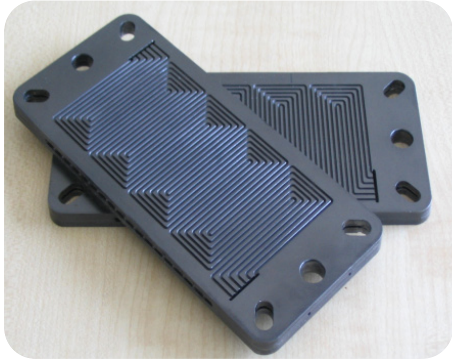
Extrusion

1

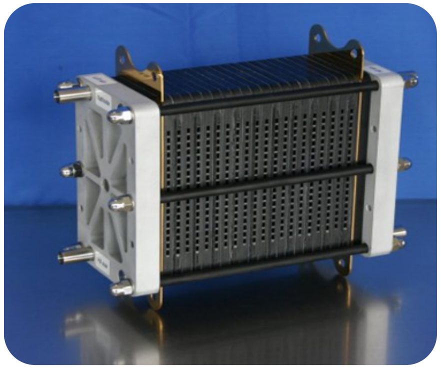
Compound

2

Injection molding



IM- bipolar plates



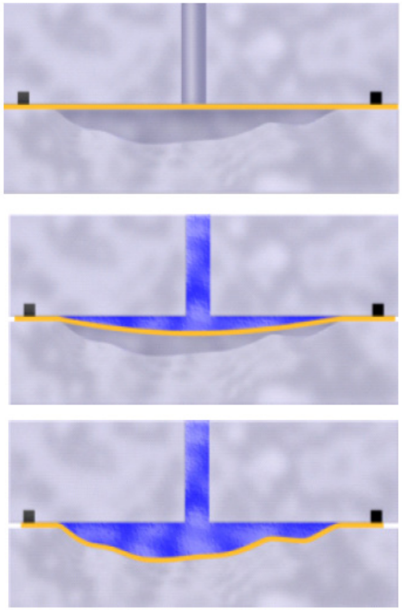
FC-stack

ZBTs partner:

GRAEBENER NEUE TECHNOLOGIEN

- maximum clamping force: 65.000 kN
- maximum working space: 400 cm^2

Hydroforming: PowerBoxx ®



1. **Sheet insertion, close press**
2. **Insertion of the active fluid medium with up to 4000 bar ➔ Expansion of the sheet into the die**
3. **Nearly stress-free device**

Substrate materials for hydroformed bipolar plates:

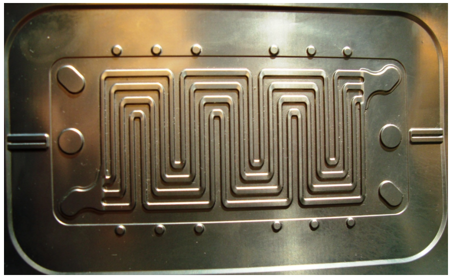
- **1.4301, 1.4303, 1.4306, 1.4372**
- **1.4401, 1.4404**
- **1.4539**
- **1.4562 (Nicrofer, 3127 hMo)**
- **2.4856 (Nicrofer, 6020 hMo)**
- **1.4760 (Crofer 22 APU)**
- **1.4750 (Crofer 22H)**
- **Titan Grade 1 (Ticrutan)**
- **Aluminum**
- **Multilayered metals**

➔ Electrolyzers!

2 Hydroformed Metallic Plates

Hydroforming

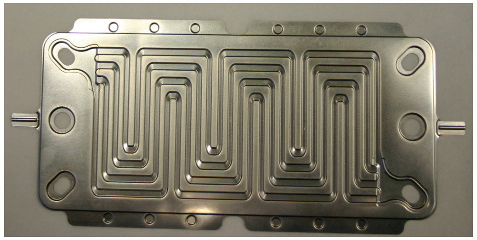
Semi-shell plate, uncutted



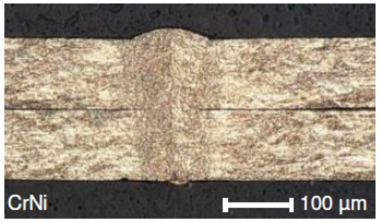
Laser cutting

Production process

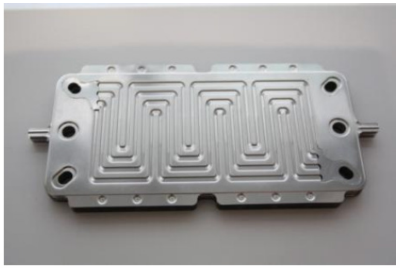
Cutted semi-shell



Laser welding

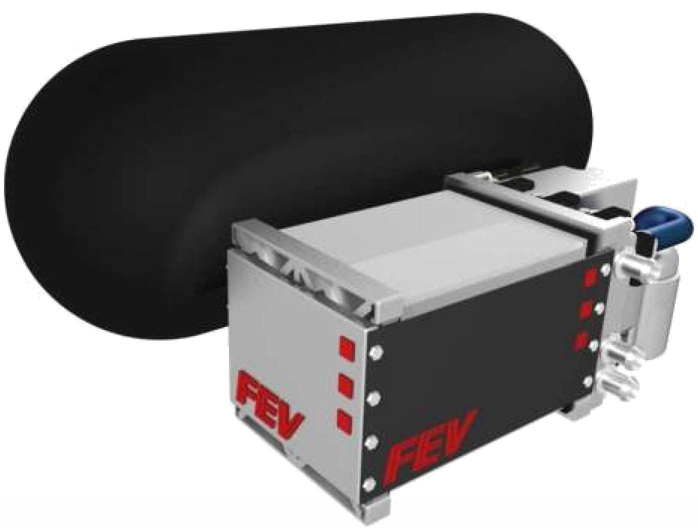


Metallic Bipolar Plates



BREEZE: Fuel Cell Range Extender Module (REM) for Battery Electric Vehicles

- Zero emissions during REM operation
- Significant NVH advantages compared to ICE REMs
- High efficiency
- Heat available for cabin heating



Project Partners:

FEV
GRAEBENER Maschinentechnik
VKA
RWTH Aachen University
ZBT

With financial support from:

Ziel2.NRW
Regionale Wettbewerbsfähigkeit und Beschäftigung

EUROPÄISCHE UNION
Investition in unsere Zukunft
Europäischer Fonds
für regionale Entwicklung

Ministerium für Wirtschaft, Energie, Bauen, Wohnen und Verkehr des Landes Nordrhein-Westfalen

Bipolar Plate Performance Guidance of US Department of Energy (2009)

Table 1 Performance requirements for PEM fuel cell bipolar plates.

Property	Unit	Value	Available tests at ZBT:
Tensile strength – ASTM D638	MPa	>41	**being established**
Flexural strength – ASTM D790	MPa	>59	**established**
Electrical conductivity	$S\ cm^{-1}$	>100	**established**
Corrosion rate	$\mu A\ cm^{-2}$	<1	**established**
Contact resistance	$m\Omega\ cm^2$	<20	**established**
Hydrogen permeability	$cm^3\ (cm^2\ s)^{-1}$	$<2.10^{-6}$	**established**
Mass	kg/kW	<1	**established**
Density – ASTM D792	$g\ cm^{-3}$	<5	**established**
Thermal conductivity	$W\ (m\ K)^{-1}$	>10	**being established**
Impact resistance (unnotched) ASTM D-256	$J\ m^{-1}$	>40,5	**not established**

[1] Antunes, R.A., Oliveira, M. C. L., Ett, G. et al. 2010. International Journal of Hydrogen Energy 35 (2010) 3632-3647

3 Metallic Bipolar Plates

- Main Criteria for Material Selection
  - **- Chemical stability**
  - **- Interfacial contact resistance**
  - - Formability
  - - Material costs

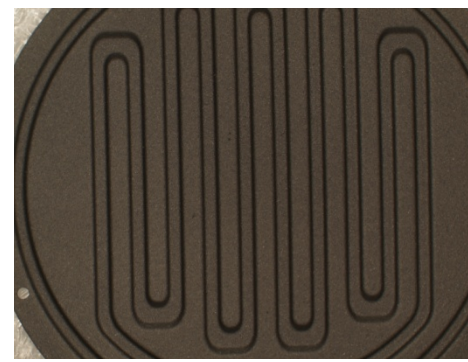
- Ivestigation of: 4 subrates + 1 coating
- Performing all tests on the basis of a small, hydroformed bipolar plate

1.4301 (AISI 304)

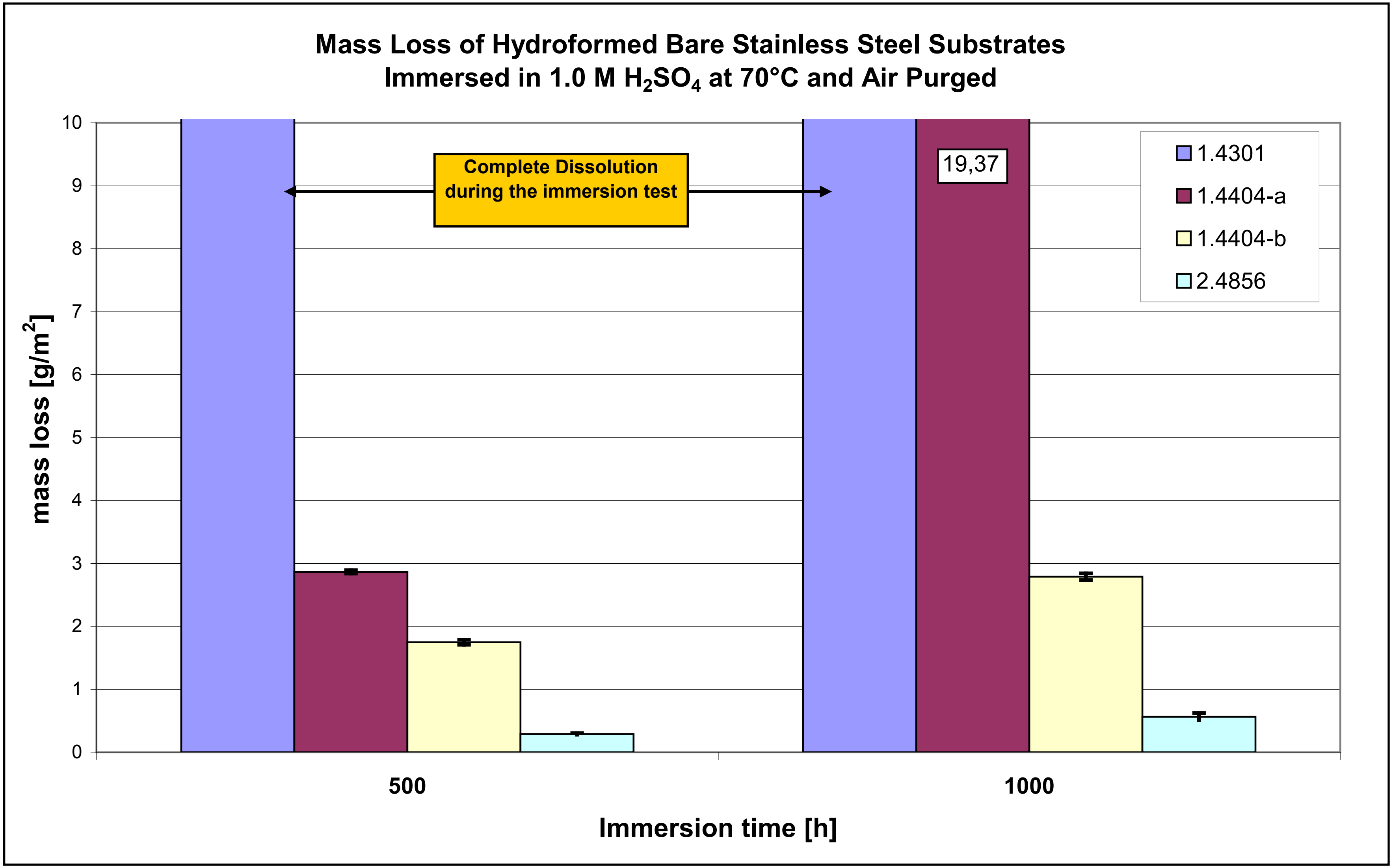
1.4404 (a) (AISI 316L)

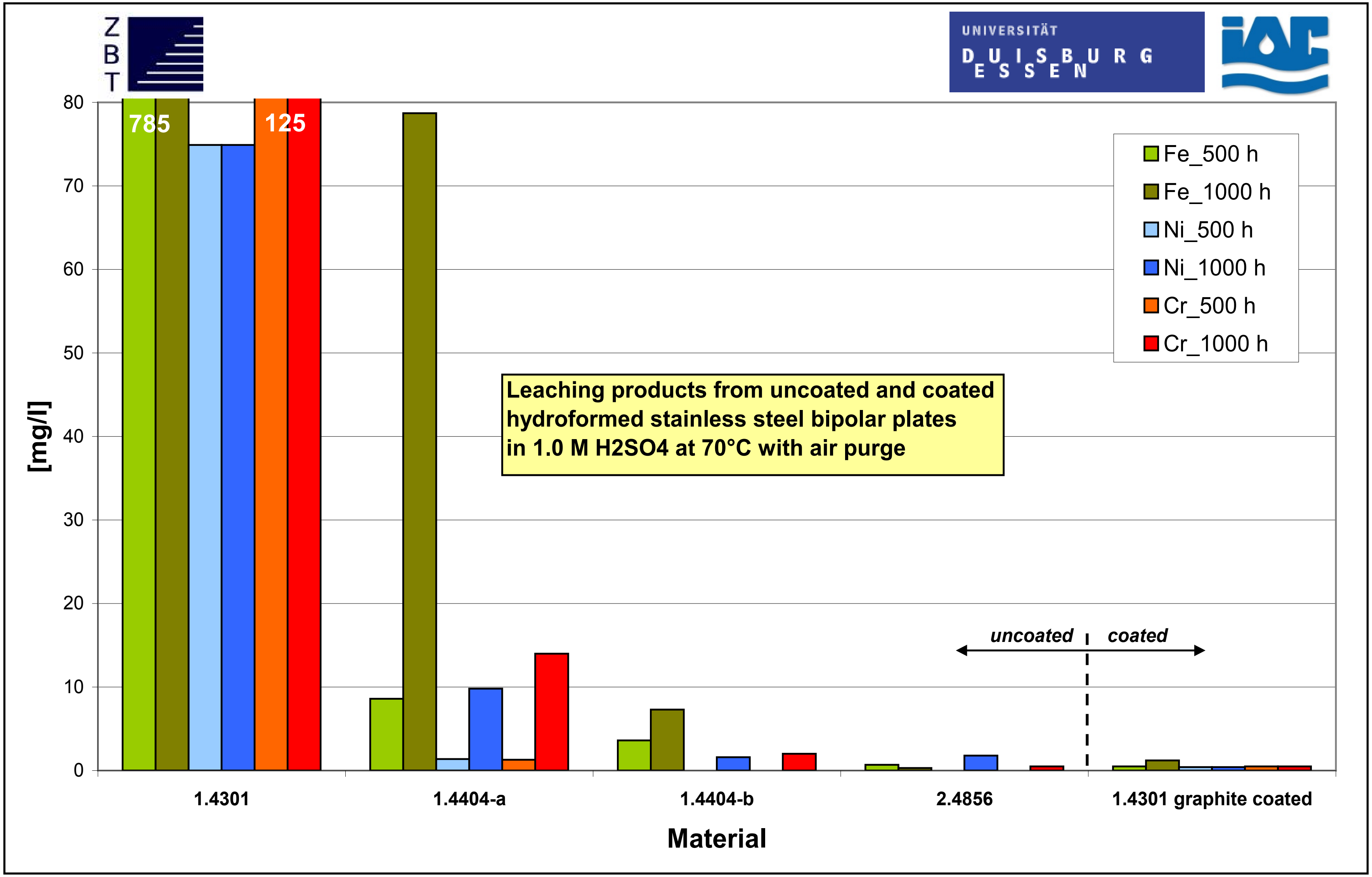
1.4404 (b) (AISI 316L)

2.4856 (Nicrofer ® 6020 hMo)

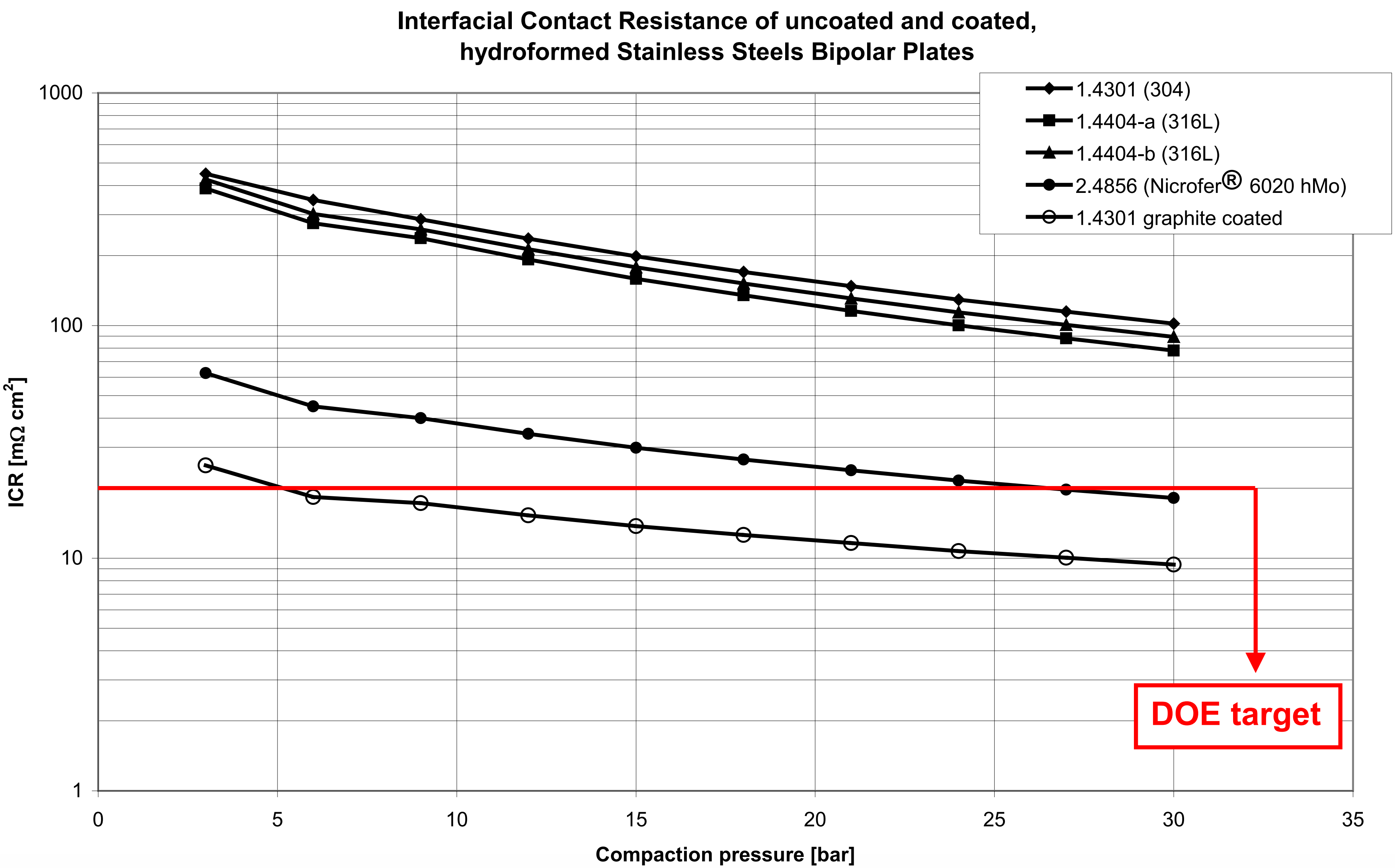


1.4301 + graphite coating


Mass Loss of Hydroformed Bare Stainless Steel Substrates
Immersed in 1.0 M H_2SO_4 at 70°C and Air Purged
Complete Dissolution
during the immersion test
19,37
1.4301
1.4404-a
1.4404-b
2.4856
mass loss [g/m^2]
10
9
8
7
6
5
4
3
2
1
0
500
1000
Immersion time [h]



80
70
60
50
40
30
20
10
0
[mg/l]
785
125
Fe_500 h
Fe_1000 h
Ni_500 h
Ni_1000 h
Cr_500 h
Cr_1000 h
Leaching products from uncoated and coated hydroformed stainless steel bipolar plates in 1.0 M H2SO4 at 70°C with air purge
uncoated
coated
1.4301
1.4404-a
1.4404-b
2.4856
1.4301 graphite coated
Material


Interfacial Contact Resistance of uncoated and coated,
hydroformed Stainless Steels Bipolar Plates
1.4301 (304)
1.4404-a (316L)
1.4404-b (316L)
2.4856 (Nicrofer® 6020 hMo)
1.4301 graphite coated
ICR [mΩ cm2]
1000
100
10
1
0
5
10
15
20
25
30
35
Compaction pressure [bar]
DOE target

Ziel2.NRW Regionale Wettbewerbsfähigkeit und Beschäftigung

GRAEBENER NEUE TECHNOLOGIEN

	Formability (standardized on 1.4301)		Material costs* (standardized on 1.4301)
	Hydroforming	Stamping	* precision steel
1.4301 (AISI 304)	**100 %**	**90 %**	**1**
1.4404 (a) (AISI 316L)	**75 %**	**65 %**	**1,6 – 2,2**
1.4404 (b) (AISI 316L)	**75 %**	**65%**	**3**
2.4856 (Nicrofer ® 6020 hMo)	**< 50 %**	**< 40 %**	**16**

→ Reasonable selection: 1.4404 (b) + graphite coating

3 PEMFC Coolant / Coolant cycle

Reguirements for coolant media acquisition:

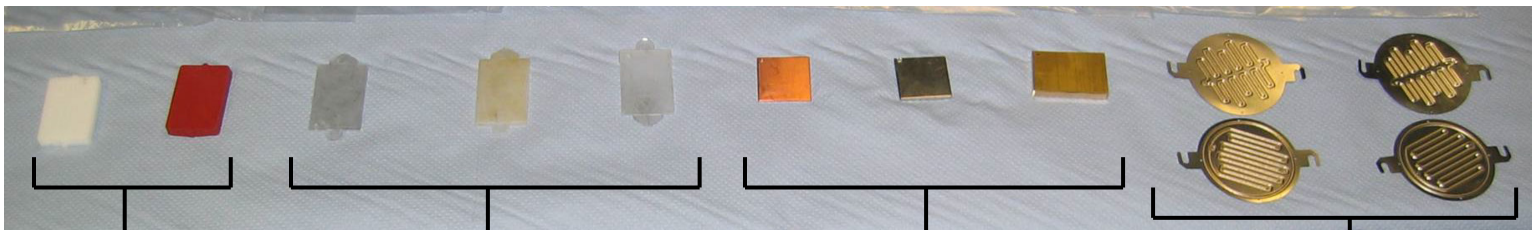
- non corrosiove

- non conductive

(- heat capacity)

Tested cooling media

Coolants	A1	A2	B	C	D	E
Description	Automotive Coolant	Designated Fuel Cell Coolant	Perfluorinated Polyether	CPU Coolant	CPU Coolant (bio-degradable)	DI-water



<u>Gaskets:</u>
Silicones

<u>Tubing:</u>
PP, PA, PE

<u>Heat Exchanger:</u>
Cu, Al, brass

<u>Bipolar plates:</u>
SS 304, Nicrofer ® 6020 hMo

Immersion of all materials at the same time for 500 h / 70 °C in each coolant

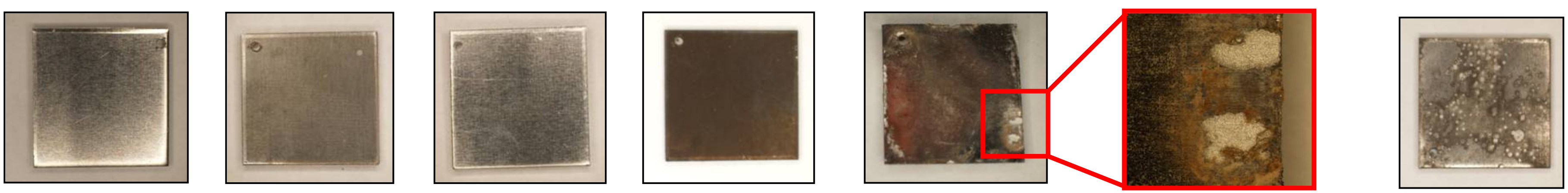
- Reduce testing time
- Provoke a measurable increase of conductivity within 500 h
- Cross effects do exist in <u>real</u> cooling cycles

3 PEMFC Coolant / Coolant cycle

Coolant Selection:

Coolants	A1	A2	B	C	D	E
Description	Automotive Coolant	Designated Fuel Cell Coolant	Perfluorinated Polyether	CPU Coolant	CPU Coolant (bio-degradable)	DI-water
Conductivity before immersion [µS]	5360	3,05	0,01 (instrument sensitivity)	1484	430	1,42
Conductivity after 500 h immersion [µS]	5360	3,91	0,01 (instrument sensitivity)	1551	475	8,46
suitability	**no**	**yes**	**no**	**no**	**no**	**possibly**
attribute	conductivity too high	non corrosive, low conductivity	harmful to environment, low thermal capacity	conductivity too high, corrosive	conductivity too high, corrosive	Conductivity increases with time. An ion exchanger has to be used.

Example Aluminum:



A1 **A2** **B** **C** **D** **E**

➔ DI-water as coolant only suitable with ion exchanger. Some materials need to be avoided.

corrosive to Al, Cu and PA6 / Intense increase of Electrical conductivity

➔ Coolant A2 is suitable as fuel cell coolant.

non corrosive to projected cooling cycle materials / Increase of electrical conductivity very low

Summary

- Stationary applications are addressed by injection molded composite bipolar plates for low temperature and high temperature PEMFC at ZBT
- Automotive applications are addressed by hydroformed metallic bipolar plates in cooperation with industrial partners
- Many ex-situ (and also in-situ) methods are available for materials, components and stacks

- Pre-Assessment of metallic substrates for bipolar plates is conducted by ICR-measurement, immersion test and analysis of leached ions
- A graphite coating was found to be a promising candidate for corrosion protection
- A cooling medium was selected from 6 candidates as suitable for PEMFC application without ion exchanger by ex-situ immersion test

Acknowledgements:

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Thank you for your attention!