Advanced bipolar plates without flow channels, for PEM electrolysers operating at high pressure

Hydrogen Session – Bipolar plates for PEM fuel cells and electrolyzers

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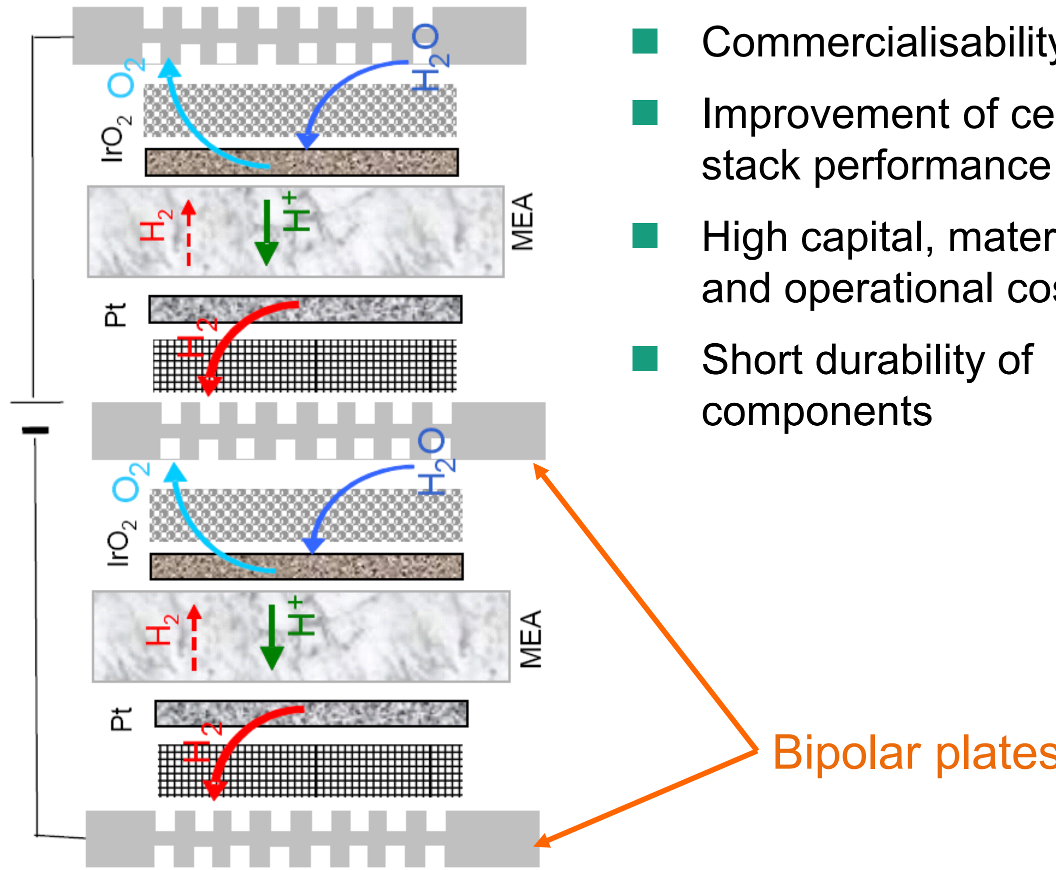
Merits and challenges of high pressure PEM water electrolysis

Merits

- Splitting of water into its constituent elements by use of electricity
- Storage of excess power from renewable energy sources
- Highly efficient with zero carbon footprint
- Reduced system cost for operation at high pressure



Challenges

- Commercialisability
- Improvement of cell and stack performance
- High capital, material and operational costs
- Short durability of components

→ Bipolar plate is the critical component for costs and life span improvements

The multifunctional bipolar plate

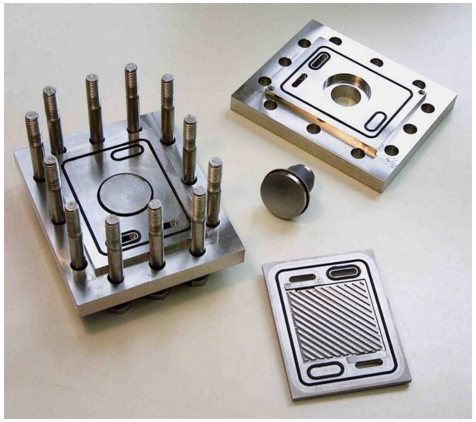
Functions	Required properties
Conduction of electrical current from cell to cell	High electrical conductivity
Facilitation of heat management	Good thermal conductivity

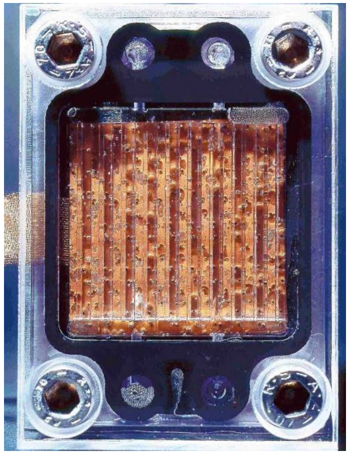
Flow distribution of reactant water and product gases	• Highly impermeable to gases
	  • Corrosion resistant on anode side
	  • Hydrogen embrittlement resistant on cathode side
	• High electrochemical stability

Constitutes most part of the mass and volume of electrolyser	• High mechanical stability • Low material and production costs • Availability

Bipolar plates development at Fraunhofer ISE

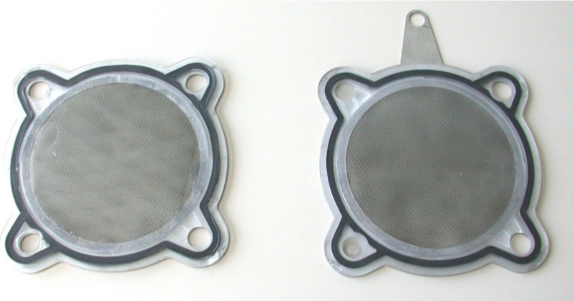
- Conventional design
  - Machined Ti plates, 50 cm² active area
  - Expensive





- Gold coated design
  - Injection molded PPS
  - 9 cm² active area
  - Highly durable but expensive
- Low cost design
  - Injection molded plate with inner Ti pin
  - 78 cm²active area
  - Low thermal management and low power density

- Second generation low cost design
  - Thin unmachined Ti plate
  - Better thermal management
  - Problems with gas tightness



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Major bipolar plate challenges

- Strong corrosive conditions on the anode side due to:
  - Anodic polarisation
  - Operation at elevated temperatures
  - Presence of oxygen
- Hydrogen embrittlement of metals on the cathode side
- High material costs and manufacturing techniques

R&D focus

- Screening of candidate materials based on corrosion and hydrogen embrittlement resistance
- Comprehensive cost analysis model on material and production techniques
- Novel design concepts

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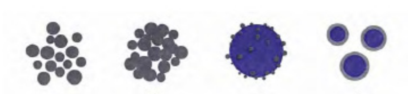
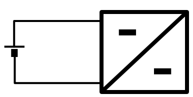
H_2

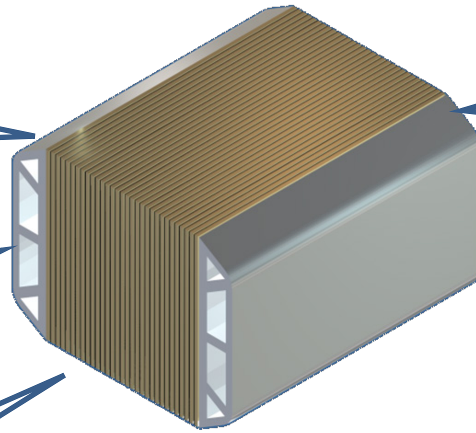
- Develop and demonstrate PEM water electrolyser integrated with RES
- 75% efficiency (LHV)
- Hydrogen production cost ~ €5,000 / Nm3h-1
- Target lifetime of 40.000 h

New catalysts

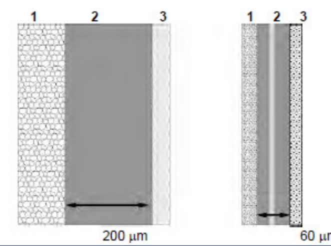


Improved DC-DC converter

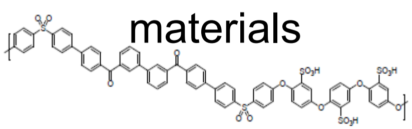




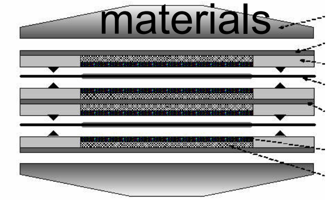
Improved MEAs



New membrane materials



Novel stack design and new construction materials



Jan 2010 - Dec 2012
Co-ordination: SINTEF
Funding: Fuel Cells and Hydrogen JU
Total Budget: € 3,353,549
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SINTEF · University of Reading · Statoil · cea · HELION HYDROGEN POWER · fumatech Funktionelle Membranen und Anlagentechnologie · Fraunhofer ISE

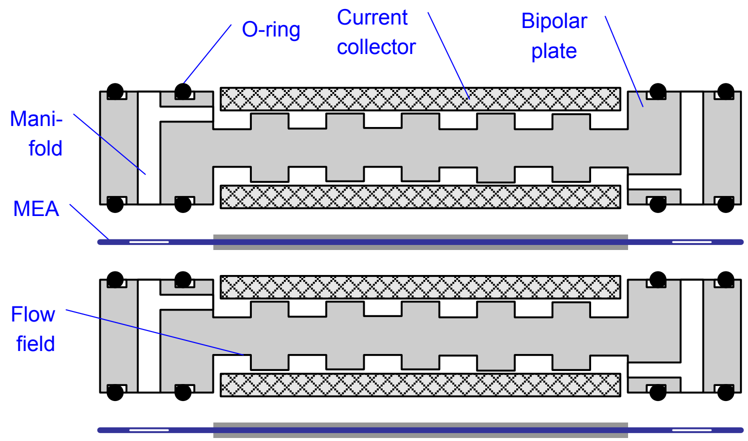
Benchmark materials and Cost break down model

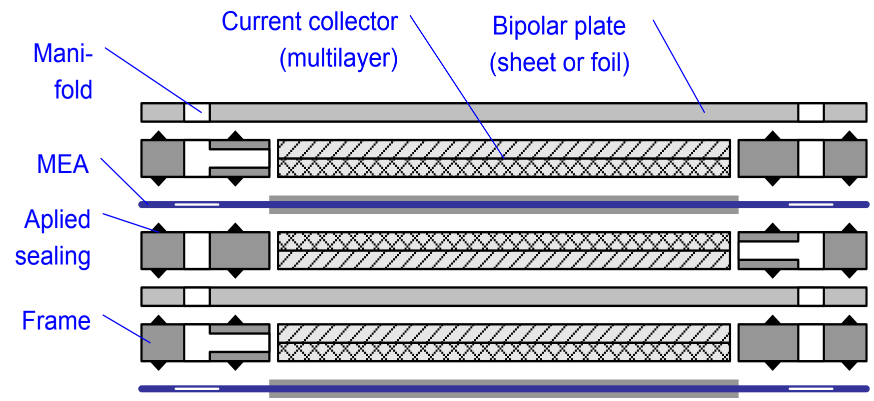
Cost model and assumptions

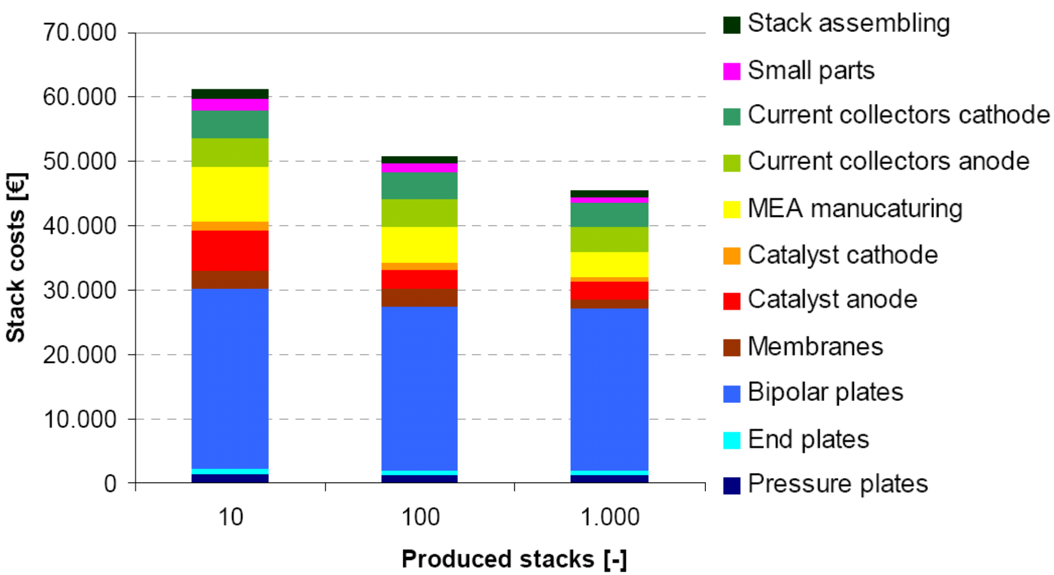
- Material costs based on offers from suppliers that guarantee real market prices
- Manufacturing costs from in-house experience and information from sub-contractors
- Cost model accounts for all steps in the production process
- Waste materials such as shavings are recycled and sold for a third of the original price
- Two stack design concepts (conventional and advanced) are considered

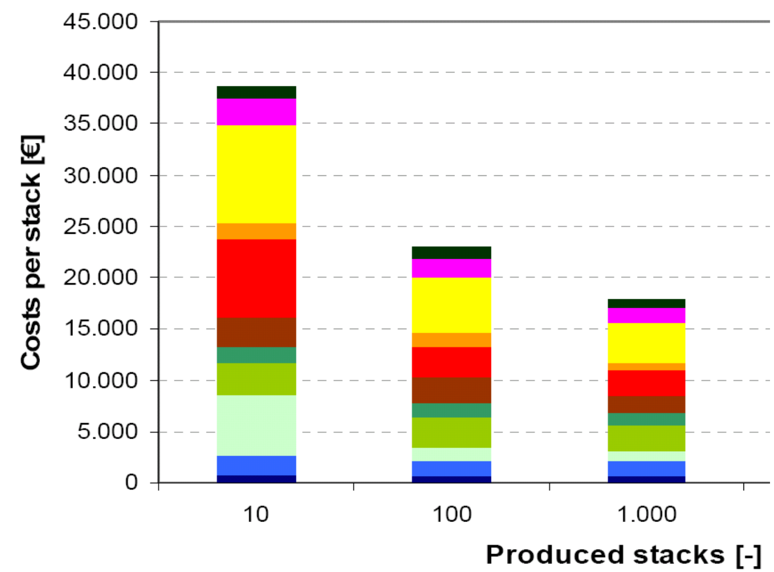
Components	Specifications
Bipolar plates	Titanium
Cell frame	PPS GF40
Anode catalyst	IrO_2
Anode loading	2 mg/cm²
Cathode catalyst	40 wt. % Pt on carbon
Cathode loading	1 mg/cm²
Membrane	Nafion 117
Anode current collector	Sintered Ti, expanded Ti mesh, Ti felt
Cathode current collector	Carbon paper, sintered Ti, expanded Ti mesh, Ti felt

Conventional Vs. Advanced design



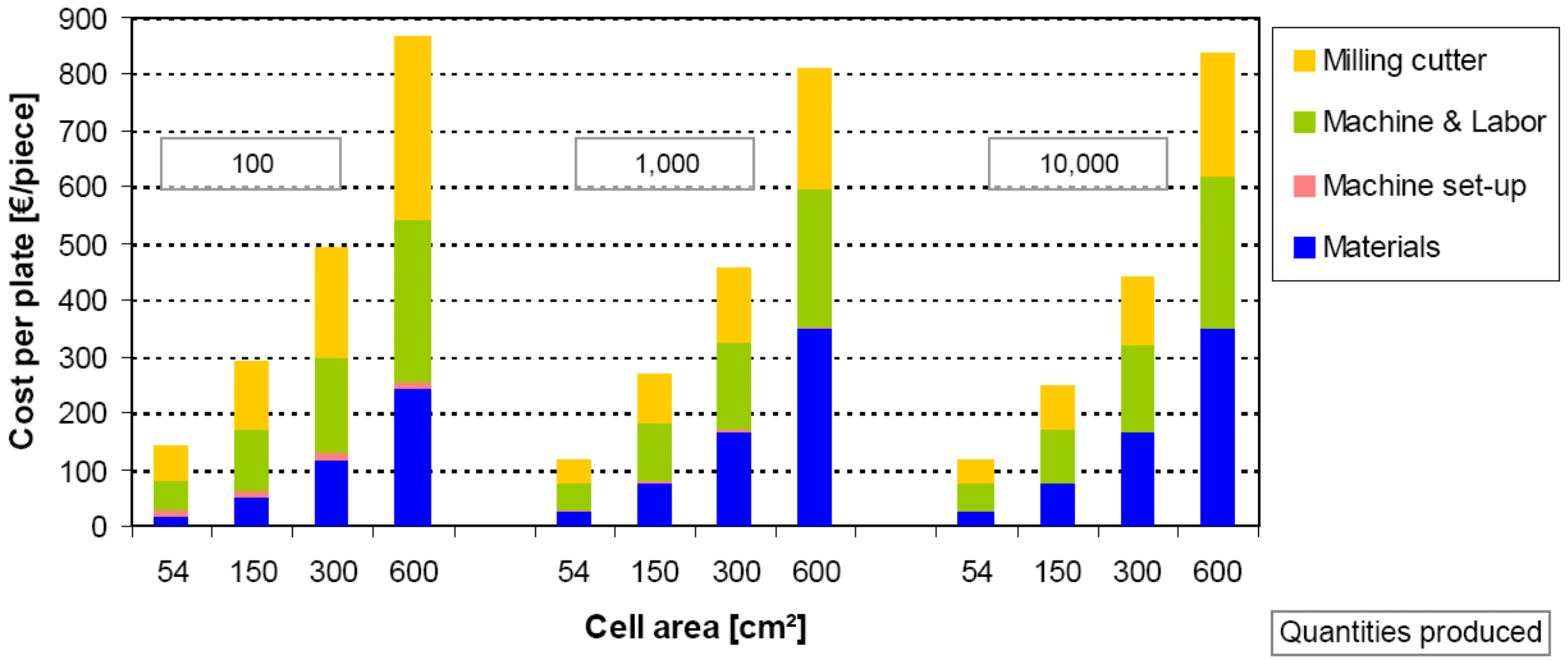




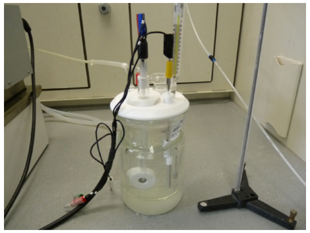


BiP Manufacturing costs break down

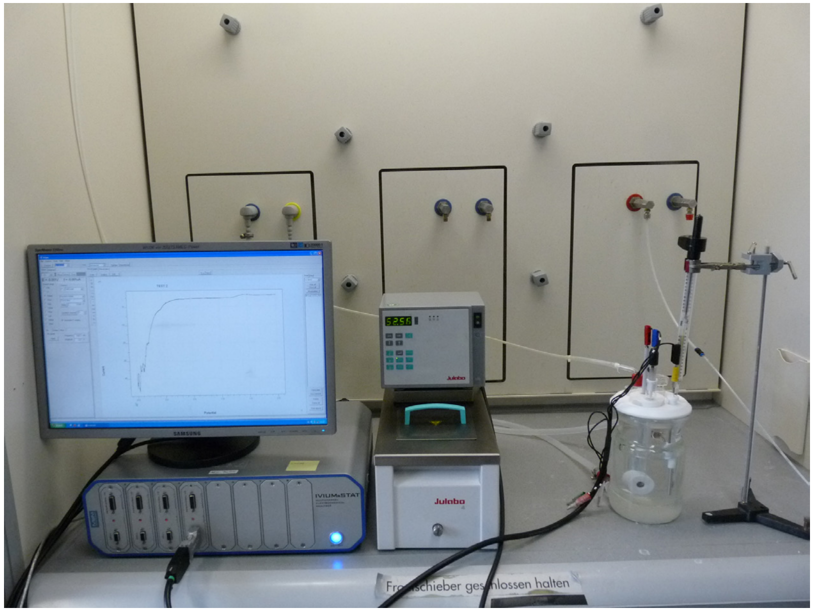
- Machining of Titanium bipolar plates is quite expensive
- Only slight cost reduction with increasing production rate
- Cost target of 2500 € / Nm³h-1 cannot be met using machined bipolar plates



Corrosion screening of candidate bipolar plate materials

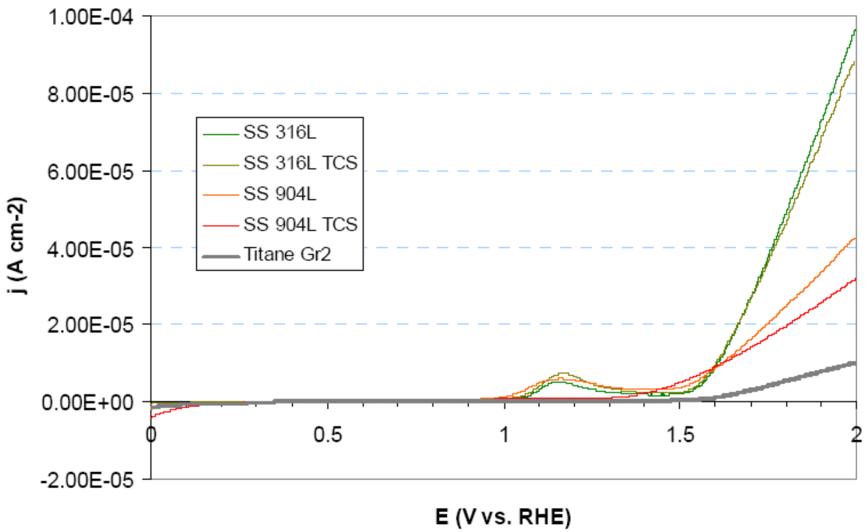


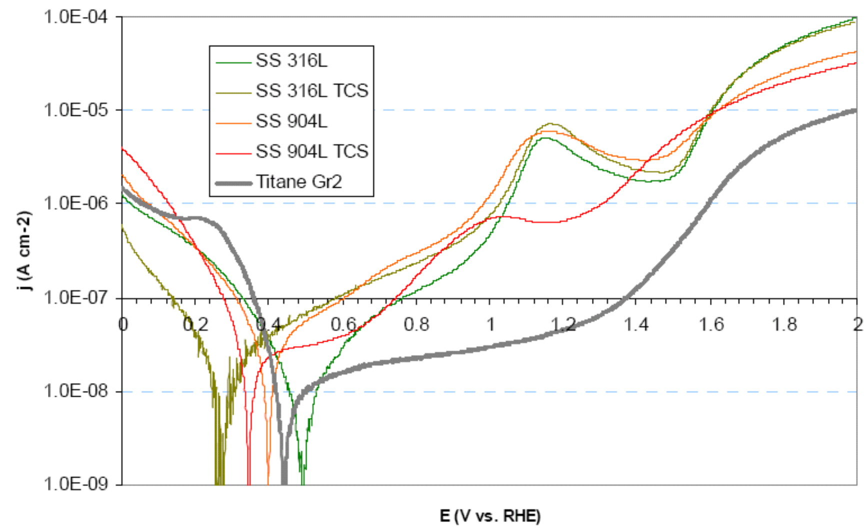
- Corrosion tests performed in a three electrodes electrochemical cell
- Hg/Hg_2SO_4 / K_2SO_4 (0,690 V vs. R.H.E) reference electrode
- 0,5M H_2SO_4 electrolyte
- pH 3,3
- Candidate materials tested
  - Grades of stainless steel
  - Tantalum coated stainless steel
  - Hastealloys
  - Various grades of Titanium



Stainless steel grades

	Fe (Wt%)	Ni (Wt%)	Cr (Wt%)	Mo (Wt%)	Mn (Wt%)
SS 316L	0,68	0,11	0,17	0,02	0,02
SS 904L	0,49	0,26	0,21	0,02	0,01
TCS	Low cost surface modification on 316L and 904L				





	316 L	316LTS C	904 L	904LTS C	Ti Gr2	DOE Objective
Corrosion current at 2V vs. RHE (µA/cm²)	96,1	88,2	42,4	31,8	10	< 16

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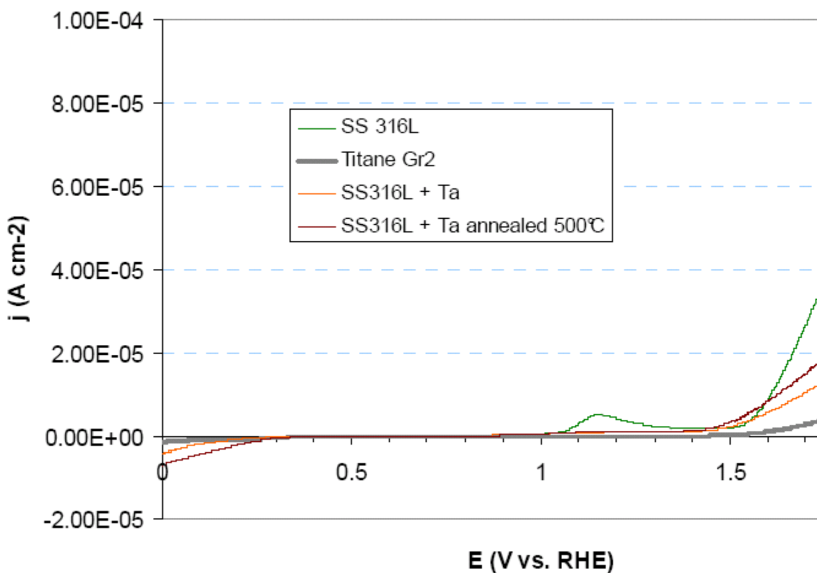
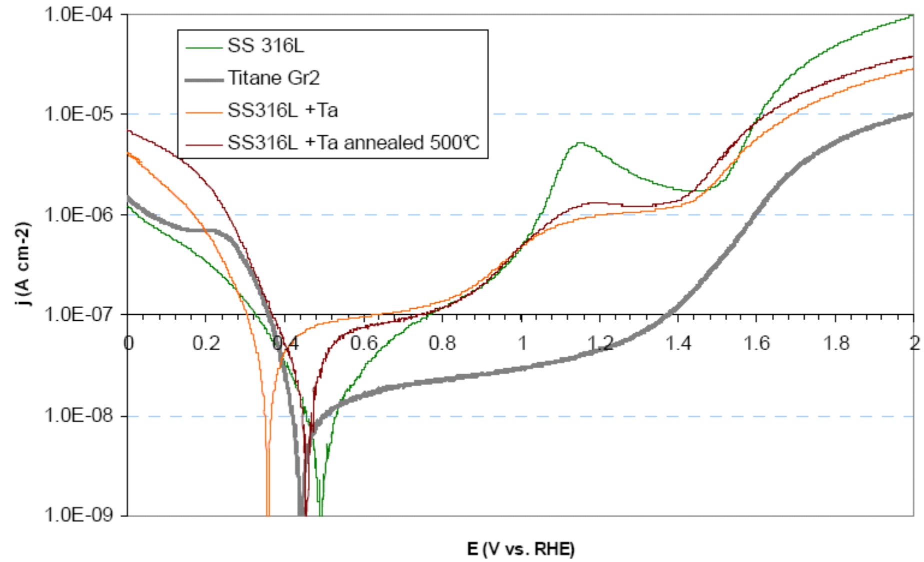
Tantalum coated stainless steel

- Tantalum coated by electrodeposition in ionic liquids
- A second sample of Ta coated SS316L was annealed at 500°C under air before testing

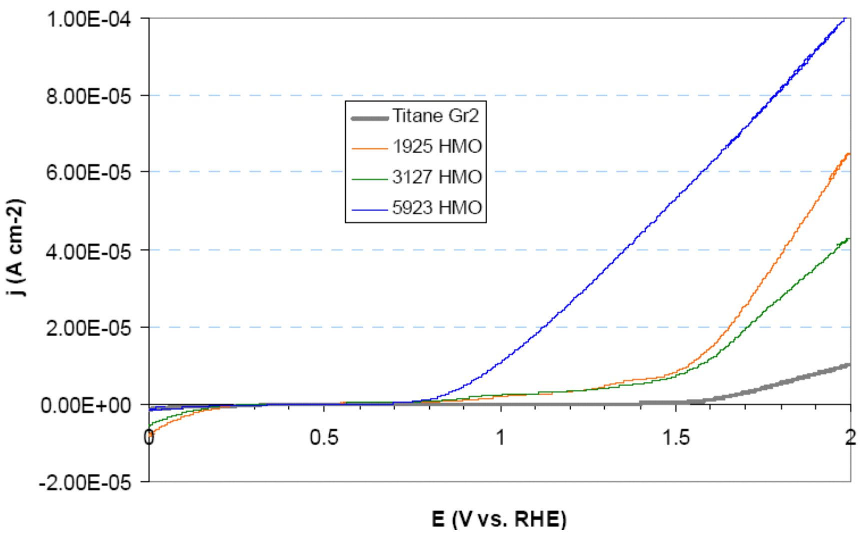


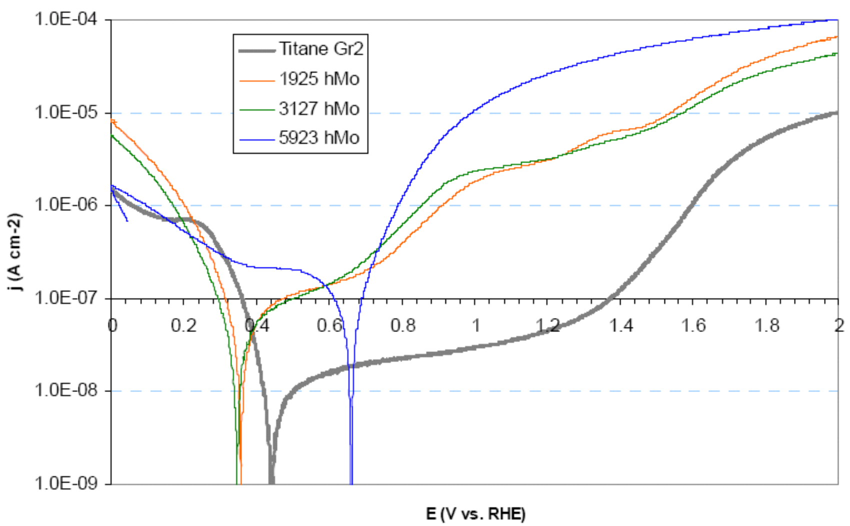


	316 L	316L+Ta	316L+Ta Annealed	Ti Gr2	DOE Objective
Corrosion current at 2V vs. RHE (µA/cm²)	63,4	41,8	99,6	10	< 16

Hastealloys

	Fe (Wt%)	Ni (Wt%)	Cr (Wt%)	Mo (Wt%)	Mn (Wt%)
Cronifer 1925	0,47	0,25	0,19	0,06	0,01
Nicrofer 3127	0,32	0,31	0,27	0,06	0,02
Nicrofer 5923	0,01	0,59	0,23	0,16	-

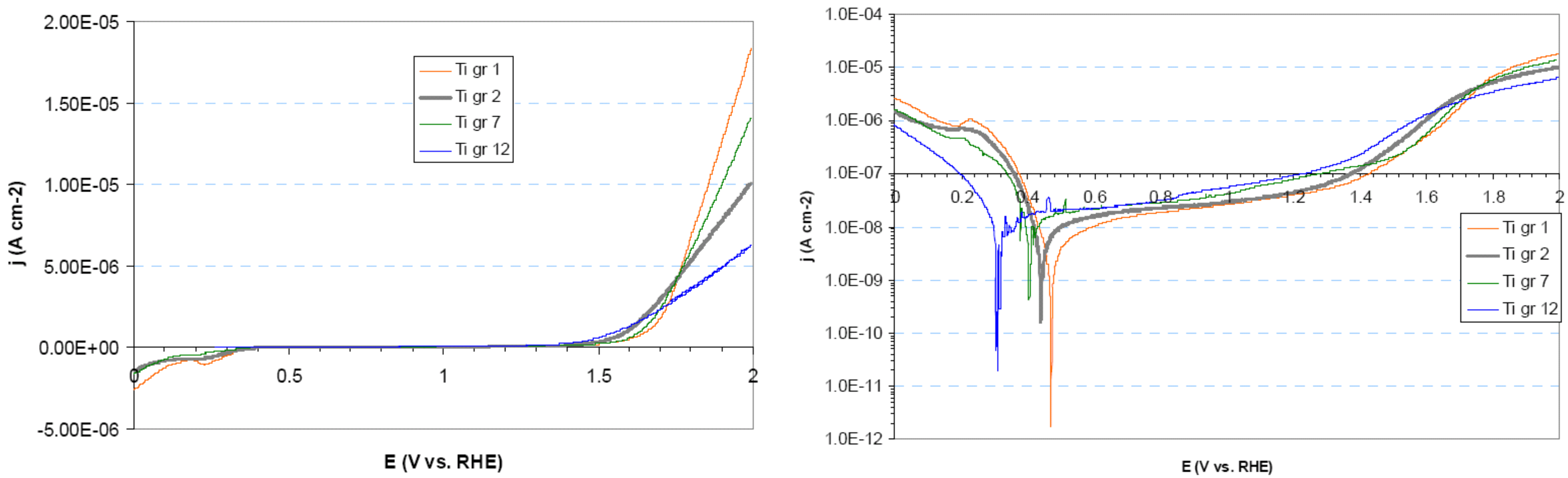




	1925	3127	5923	Ti Gr2	DOE Objective
Corrosion current at 2V vs. RHE (µA/cm²)	63,4	41,8	99,6	10	< 16

Titanium grades

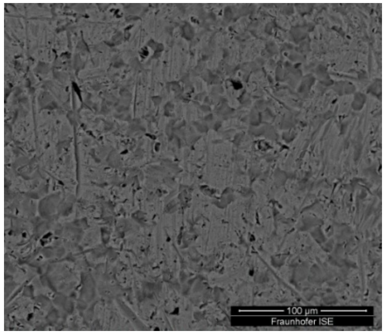
	C (Wt%)	Fe (Wt%)	H (Wt%)	N (Wt%)	O (Wt%)	Pd (Wt%)	Mo(Wt %)	Ni(Wt%)
Grade 1	0,1	0,5	0,015	0,05	0,4	-	-	-
Grade 2	0,1	0,3	0,015	0,05	0,35	-	-	-
Grade 7	0,1	0,3	0,015	0,05	0,35	0,2	-	-
Grade 12	0,1	0,3	0,015	0,05	0,35	-	0,3	0,8



	Grade 1	Grade 2	Grade 7	Grade 12	DOE Objective
Corrosion current at 2V vs. RHE (µA/cm²)	15,4	10	14,1	6,3	< 16

SEM and EDAX analysis for Ti Gr.2

As received



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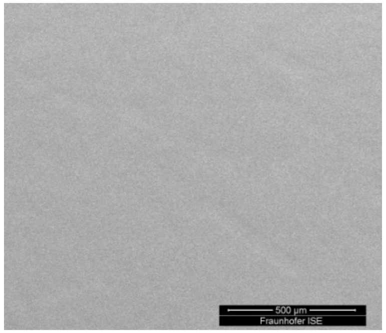

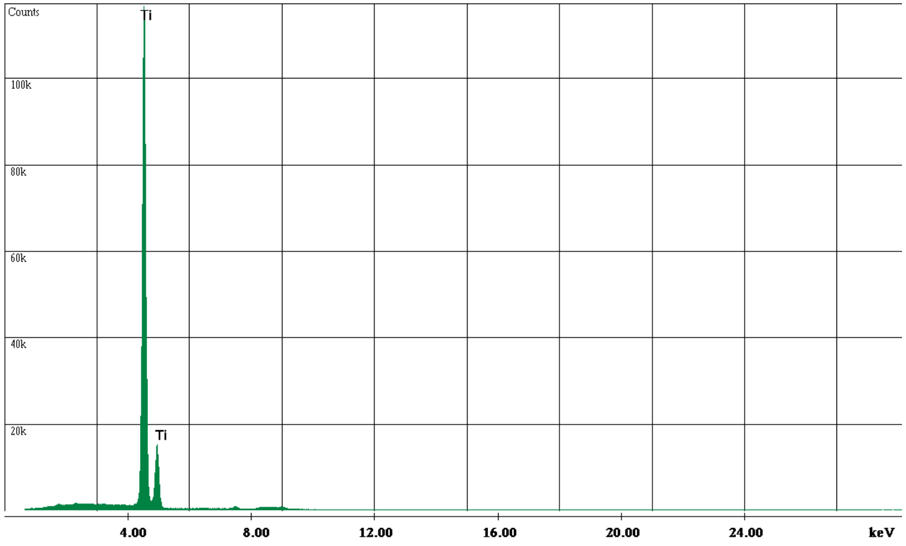

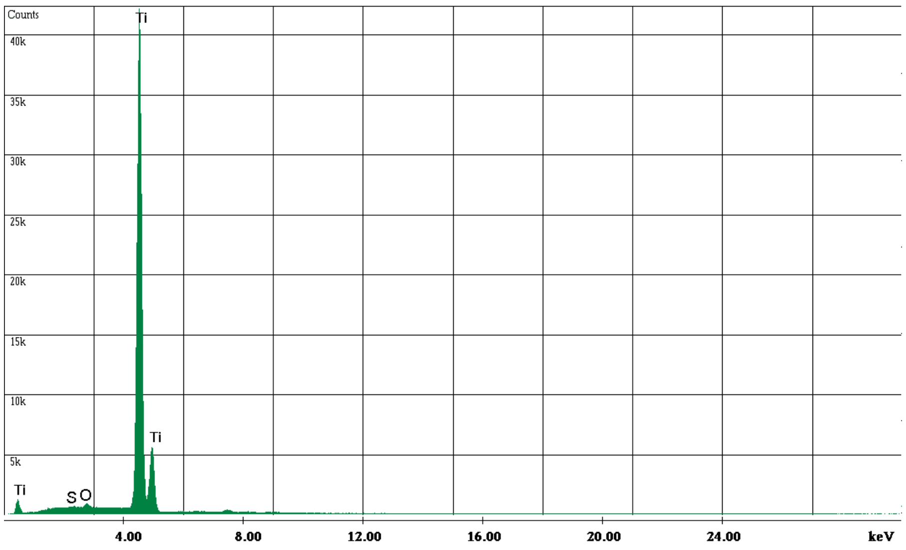

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Trade-off

- Basically, all titanium grades meet the corrosion resistance target !
- Material cost become major trade-off criterion
- Availability also taken into consideration
- Concerns about the possibility of nickel leaching into electrolyser water and to the environment
- Likelihood of leaching not studied
- Titanium grade 2 is chosen as the preferred material for used as bipolar plate, due to corrosion resistance and relatively low cost
- Bipolar plates without machined channels

Approximate material cost ratio*

	ASTM Grade	Cost ratio
Unalloyed Ti	2	1,00
Ti-0,3Mo-0,8Ni	12	1,12
Ti-0,15Pd	7	1,90
Ti-0,06Pd	16	1,38
Ti-0,1Ru	26	1,15
Ti-3Al-2,5V	9	1,25
Ti-3Al-2,5V-0,05Pd	18	1,60
Ti-3Al-2,5V-0,1Ru	28	1,38
Ti-6Al-4V	5	1,22
Ti-6Al-4V-0,05Pd	24	1,57
Ti-6Al-4V-0,1Ru	29	1,34

***Source: R.W Schutz et al. 1996**

Performance of conventional Vs. advanced design

- Laboratory test cells, both 25 cm² active area
- Sintered Ti Gr.2 discs as current collectors
- Fumatech EF-40 (230µm) MEA
- Increased electronic conduction
- Higher contact surface area

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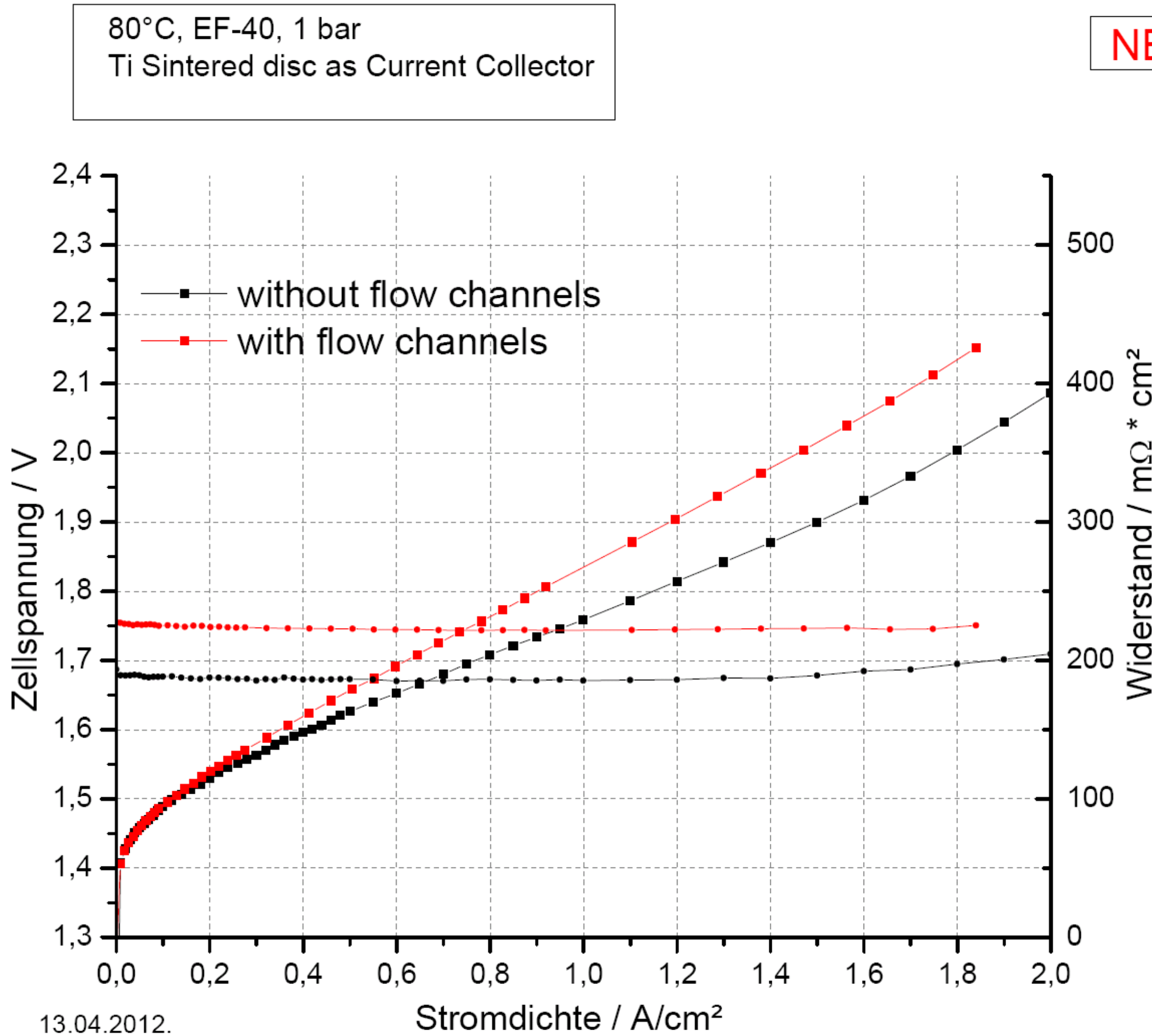

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Outlook

- *In-situ* tests with short stacks, 5 cells and then 10 cells
  - 150 cm² cell active area
  - 1,8 V nominal cell voltage
  - 1 A/cm² current density
  - Up to 30 bar operating pressure
- Characterisation after up to 1000 hours of operation
- Concerns about hydrogen embrittlement of titanium
- Questions about titanium self ignition
- Further investigation on other coating configurations and surface modifications

Thank you for your attention !!

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