Titanium coatings deposited by thermal spraying for bipolar plates of PEM electrolysers

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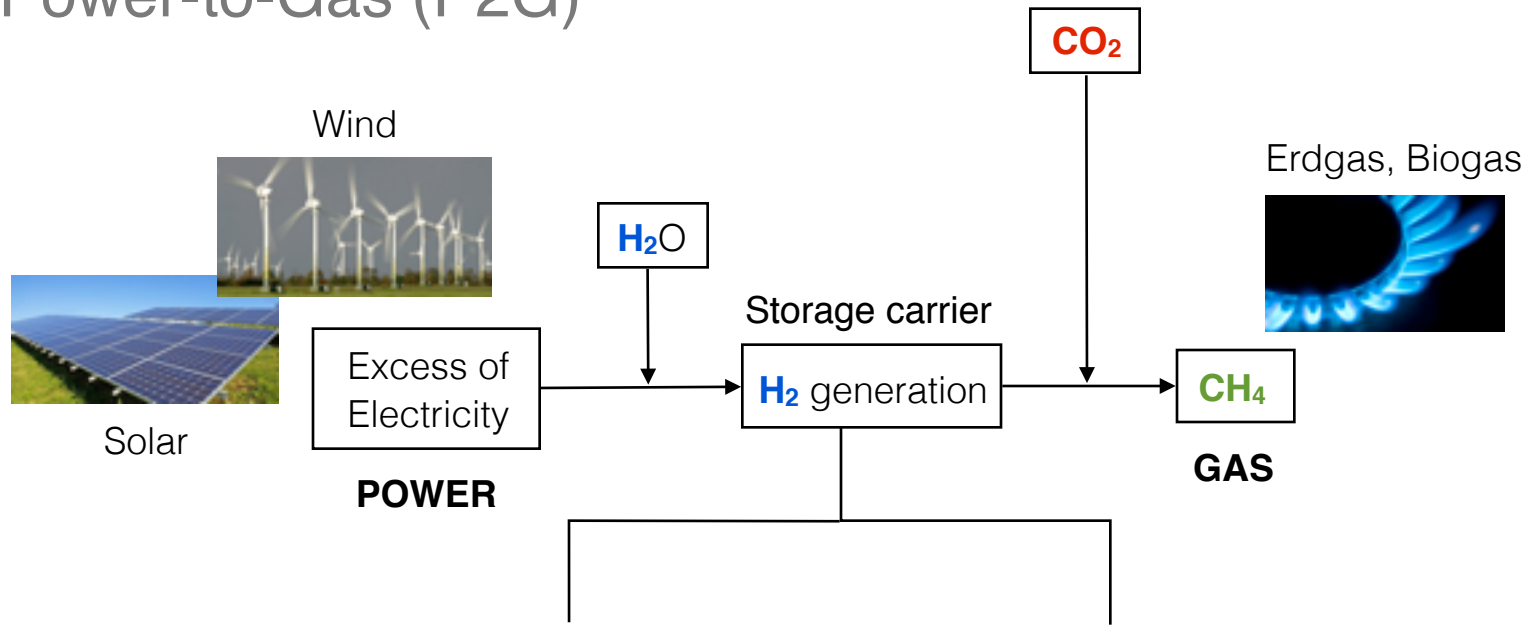
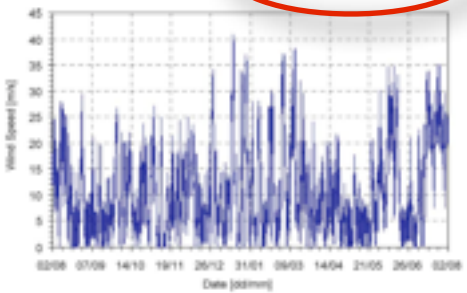
Power-to-Gas (P2G)



Wind profile: **Intermittent**



Alkaline electrolysis

- Liquid electrolyte (KOH)
- Additional compressor
- < 0.7 A cm^{-2}
- Slow response
- Cheap

PEM electrolysis

- Uses only DI water
- No additional compressor
- >10 A cm^{-2} (expected)
- Rapid response (dynamic operation)
- Expensive… **for the time being**

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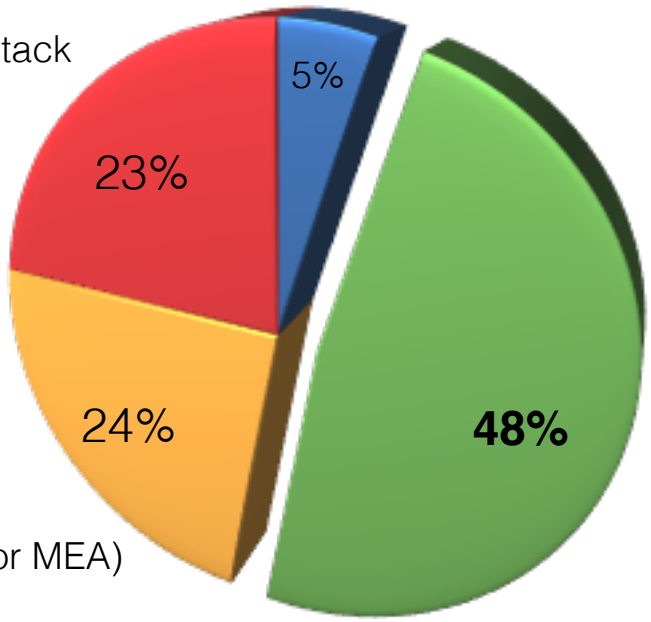
Cost of a PEM electrolyser stack



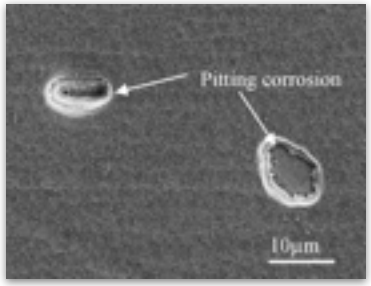
Stainless steel in a PEM electrolyser?

Bipolar plates and current collectors made of **Titanium**

M. Carmo, D.L. Fritz, J. Mergel, D. Stolten, International Journal of Hydrogen Energy 38 (2013) 4901.

Strategy for coating stainless steel

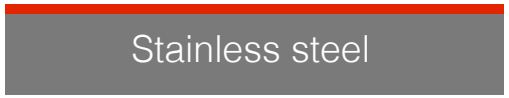
PVD coating of TiN



Y. Wang, D.O. Northwood, Journal of Power Sources 191 (2009) 483.

Coatings for PEM fuel cells:

Standard approach:



I 1 μm

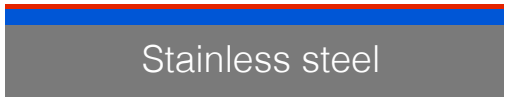
Coating 1 Coating 2

Corrosion resistant and conductive coating on stainless steel

The Fe^{2+} released from corrosion poison the CCM

Coatings for PEM electrolysers:

Our approach:



I< 50 μm

Coating 1: Titanium coating by thermal spraying

Coating 2: Surface modification of Titanium

Cost reduction?

- **PEMFC**: PVD coatings alone meet the DOE requirements.
- **PEM electrolysers**: current Ti bipolar plates have to be coated to reduce the passivation.

Dramatic cost reduction for **large area** bipolar plates ⟶ **Megawatt** scale

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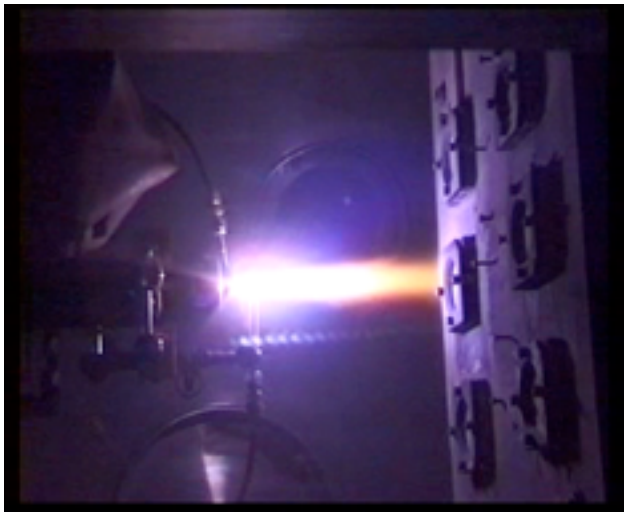
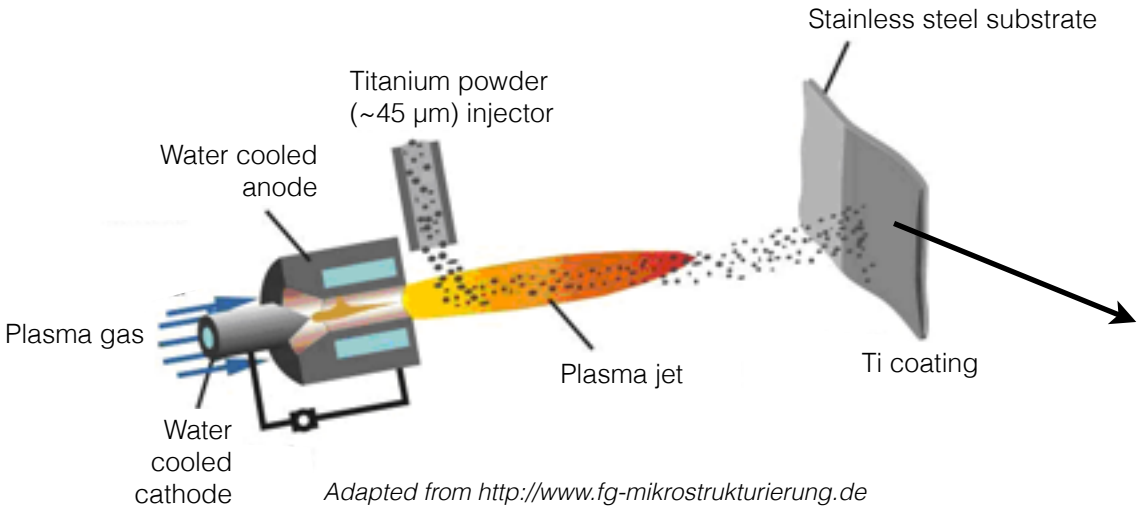
Thermal spraying

Applications at the DLR:

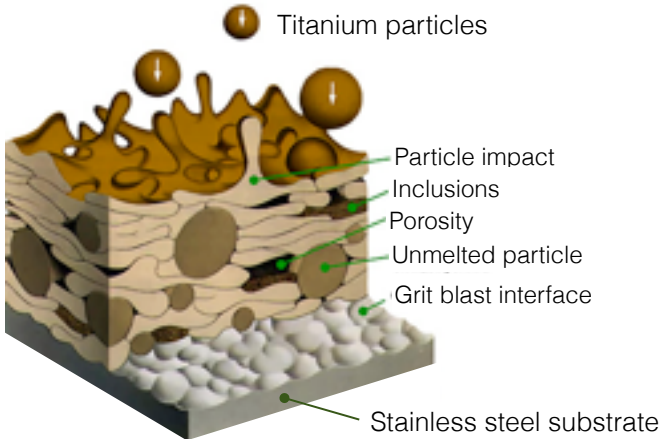
- SOFC components
- Catalyst for alkaline electrolysis
- Bipolar plates of PEM electrolysers

Vacuum Plasma Spraying (VPS)





Adapted from http://www.fg-mikrostrukturierung.de



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Deposition parameters for Ti coatings on Crofer® 22 APU

	Input				Output
Sample	Powder feeder rate g min^{-1}	Plasma enthalpy (h) MJ kg^{-1}	Z mm	V mm s^{-1}	Leak rate mbar l cm^{-2} s^{-1}
CF-29	18	9.09	350	600	53
CF-30	11.7	11.1	350	600	117
CF-31	11.7	12.61	350	600	63
CF-32	11.7	14.62	350	600	48
CF-40	11.7	14.6	320	350	8.4
CF-41	11.7	14.62	320	350	12.6
CF-42	11.7	14.65	320	350	88.8
CF-56	11.7	14.6	320	350	8.4
CF-57	11.7	14.66	320	350	10.5
CF-105	11.7	21.27	320	350	4.3

Vessel Pressure:	50 mbar
Anode type:	M3-6mm
Injector:	Internal
Track separation:	10 mm
Number of layers:	8
Substrate temperature:	250 °C

Plasma enthalpy

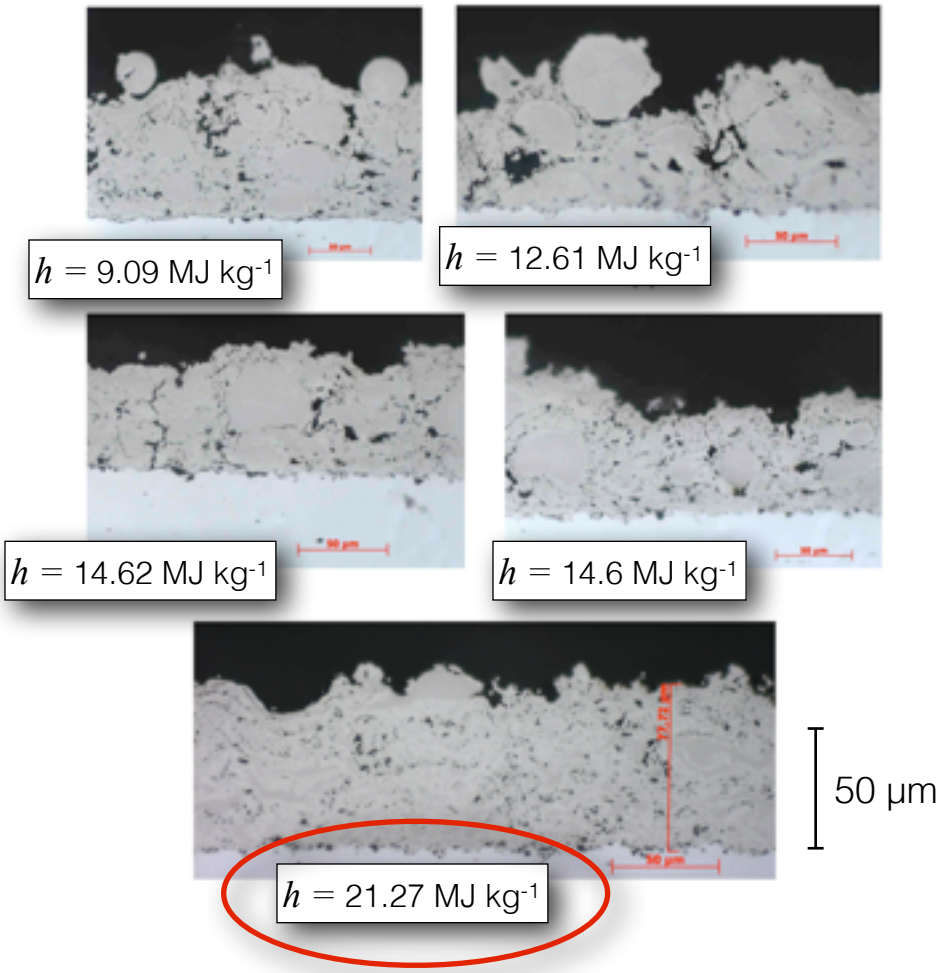
$$h = P_{\text{eff}} / m_{\text{g}}^{\circ} \ (\text{MJ kg}^{-1})$$

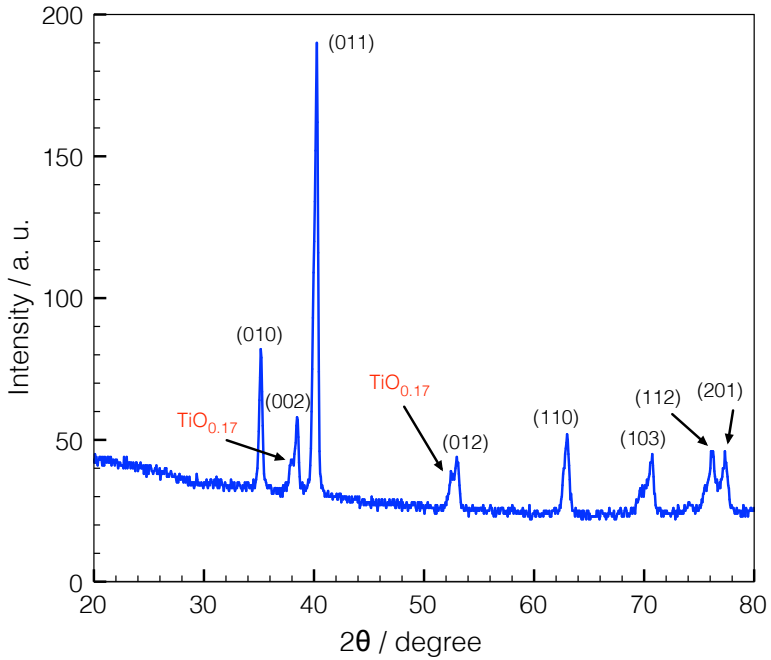
Power dissipated in the gas (kW)

Plasma gas flow rate (kg s^{-1})

P. Fauchais, J. Phys. D: Appl. Phys. 37 (2004) R86.

Coating development

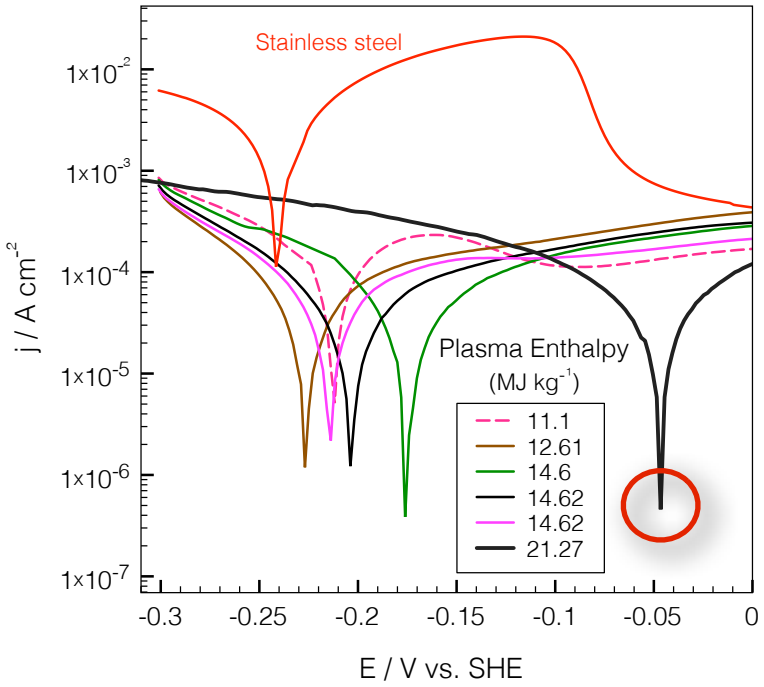


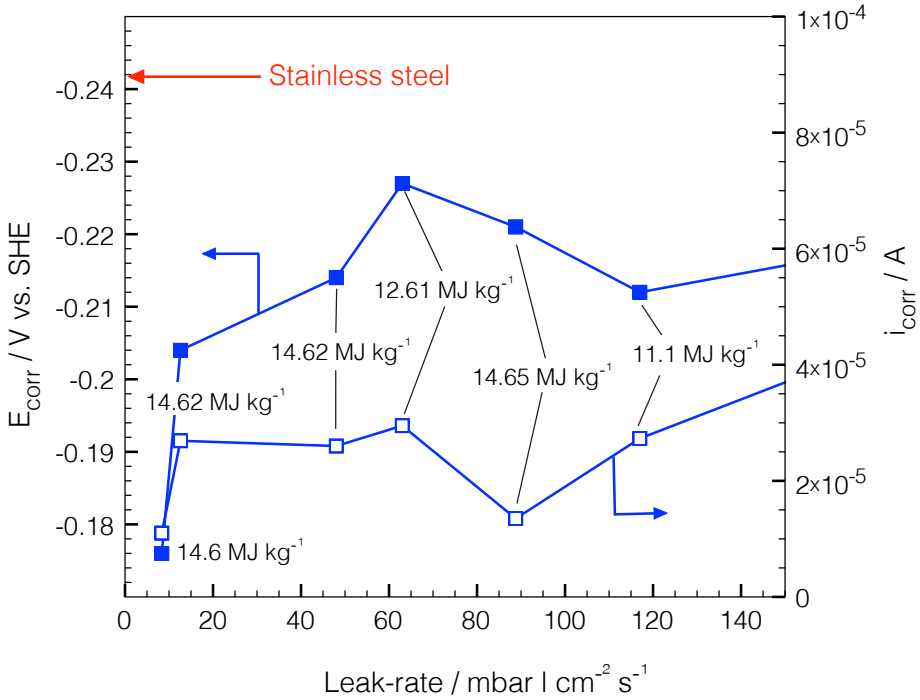


- Dense coatings of Ti were produced with high plasma enthalpies.
- Pure Ti-α was obtained as the deposition was performed in vacuum.

Electrochemical characterization

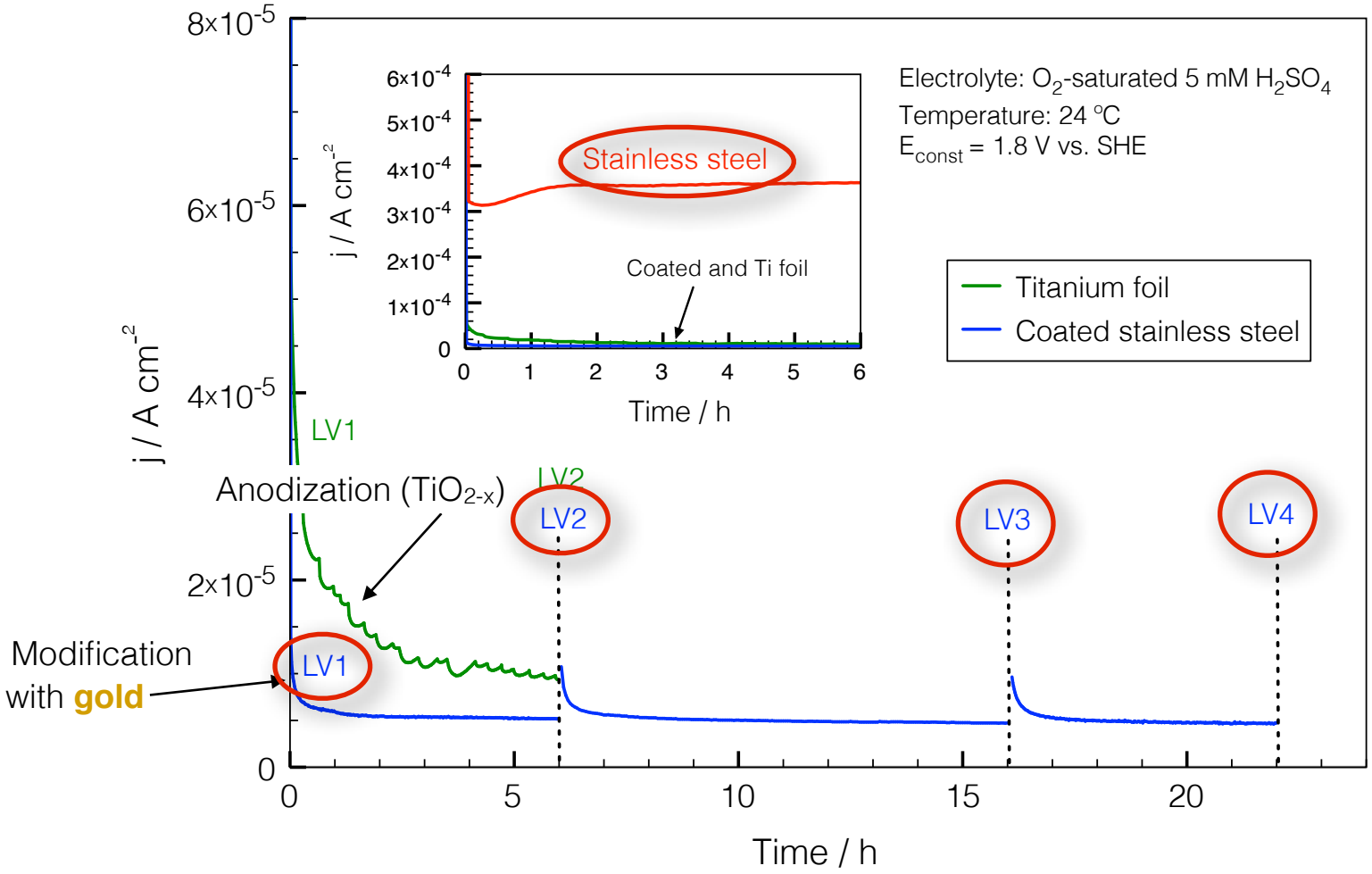
Experimental conditions: O_2-saturated 0.5 M H_2SO_4, temperature: 24 °C, scan rate: 5 mV s^{-1}





- Ti coatings deposited with high plasma enthalpies showed lower corrosion currents (i_{corr}) and higher corrosion potentials (E_{corr}) than stainless steel.

Further improvement of the coating (patent pending)



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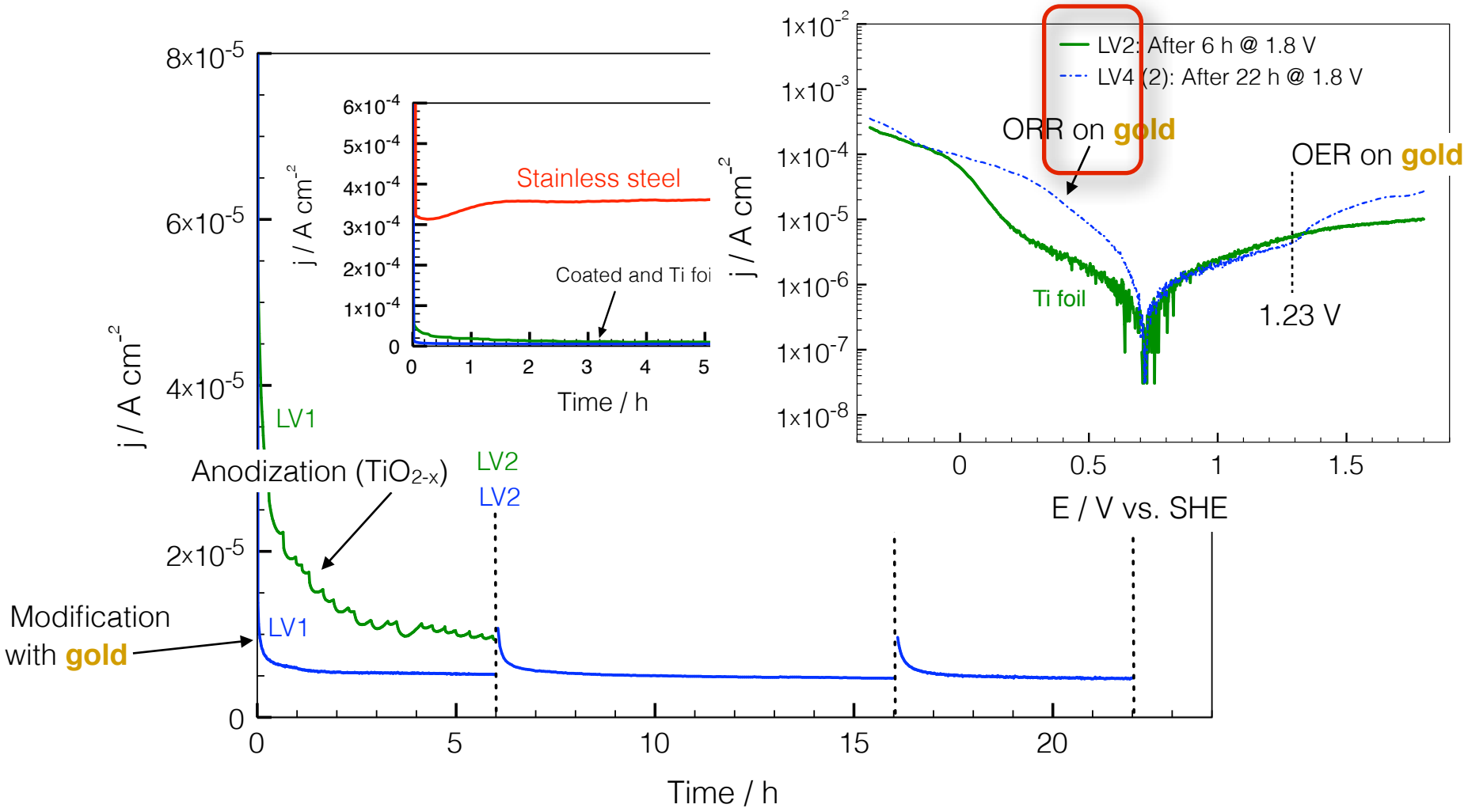

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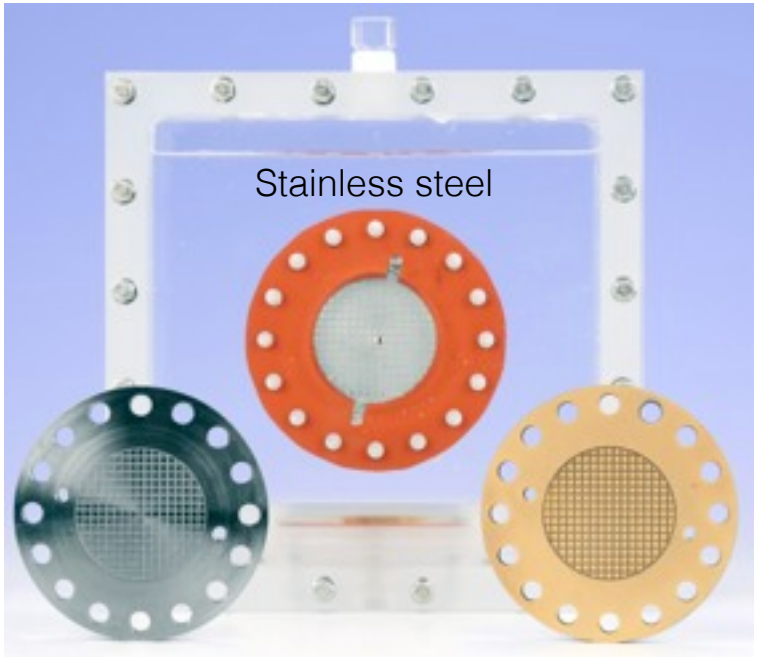
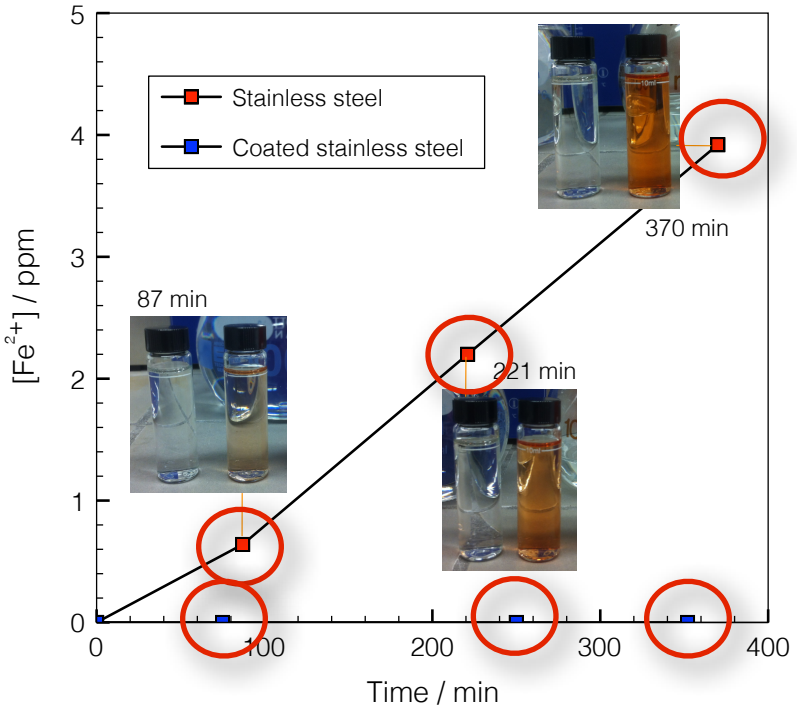
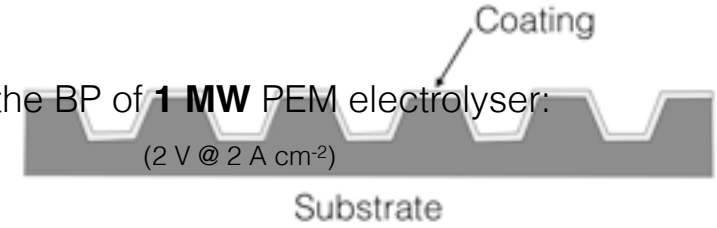
Corrosion demonstrator (measurement of Fe^{2+})



Titanium Coated stainless steel



Cost of coating the BP of **1 MW** PEM electrolyser:



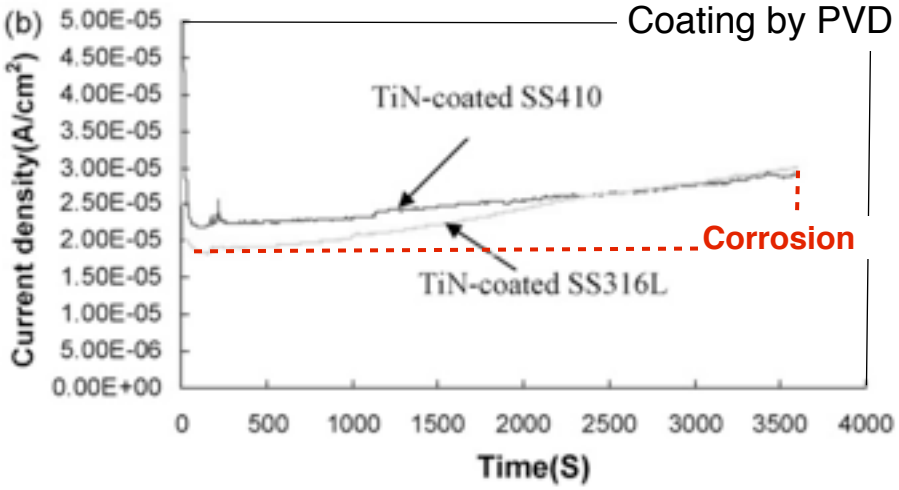
1000 cm^2 = 2.3 € / bipolar plate

+ diverse costs. The stainless steel with flow channels is not included.

One-to-one comparison (AST for bipolar plates)

Simulated cathode of a PEMFC:

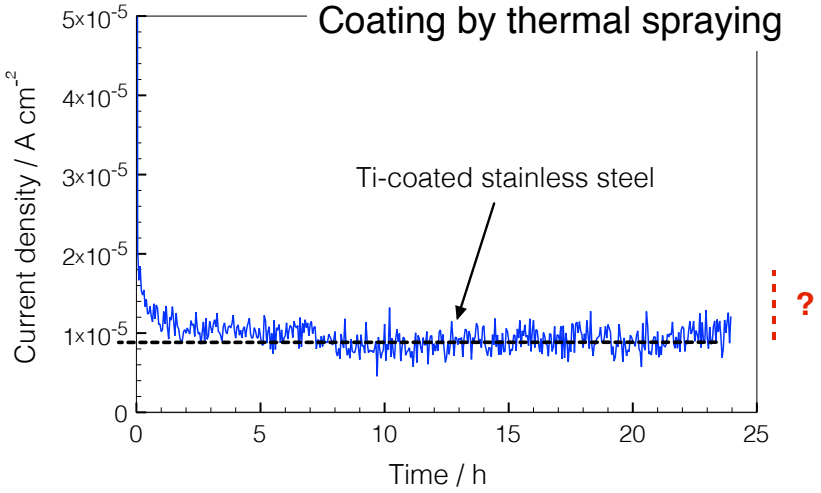
- Electrolyte: O_2-saturated 0.5 M H_2SO_4 (pH =0)
- Temperature: 70 °C
- E_{const} = 0.84 vs. RHE
- Duration of the experiment: 1 hour



Y. Wang, D.O. Northwood, Journal of Power Sources 191 (2009) 483.

Simulated anode of a PEM Electrolyser:

- Electrolyte: O_2-saturated 0.5 M H_2SO_4 (pH =0)
- Temperature: **80 ºC**
- E_{const} = **2 V** vs. RHE
- Duration of the experiment: **24 hours**



- No pinholes (SEM not shown).
- No corrosion of the substrate.

Conclusions

- There is an urgent need to reduce the cost of PEM electrolysers for Power-to-Gas applications. The bipolar plates are very expensive.
- Dense Ti coatings were produced by plasma spraying (with high h) on stainless steel substrates.
- The coatings were evaluated in simulated conditions: O_2-saturated 0.5 M H_2SO_4, 80 ºC, E_{const} = 2 V.
- Further improvement of the coating resulted in full protection of the substrate over extended periods of time (demonstrated!).
- The cost of coating stainless steel bipolar plates of 1000 cm^2, for the MegaWatt range, is estimated in 2.3 € per piece.

Thank you for your attention