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French Corrosion Institute

Réduction des coûts des électrolyseurs PEM par une approche anti-corrosion

Dr. Michel Prestat

Institut de la Corrosion, Brest, France

French Corrosion Institute in brief

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French Corrosion Institute

Technopole of Brest
(headquarters, 35 coworkers)

Lyon
(7 coworkers)

Saint-Etienne
(15 coworkers)

Institut de la Corrosion (IC)
French Corrosion Institute

- SME, non-profit R&D institute
- Founded in 2002
- 57 employees
- Mostly industrial R&D and commissions + low-TRL (academic) projects
- 80% funding from industry + 20% public funding (national/regional agencies, EU)

Activities in many industrial fields: marine corrosion, aerospace, steel, oil&gas, coatings, infrastructures, automotive industry, corrosion sensors, low-carbon energies…

Hydrogen-related activities:
- transport & storage
- hydrogen embrittlement
- **water electrolysis**

Proton exchange membrane water electrolyzer (PEMWE)

- **Working principle**

Contents lists available at ScienceDirect
Journal of Power Sources
journal homepage: www.elsevier.com/locate/jpowsour

Review article

Corrosion of structural components of proton exchange membrane water electrolyzer anodes: A review

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M. Prestat, J. Power Sourc. 448 (2023) 227563 (open-access)

PTL: porous transport layer, 100-500 µm thick

M: polymer electrolyte membrane (acidic)
A,C: anode, cathode catalyst layers
PTL: porous transport layer (metal)
BPP: bipolar plates (metal), connect the single cells in an electrolyzer stack.

Operation time > 60000 hours (~ 7 years)

Electrochemical splitting of water for H_2 production:

Cathode: $2H^+ + 2e^- \rightarrow H_2$

Anode: $H_2O \rightarrow ½\ O_2 + 2H^+ + 2e^-$ (high potential)

Anode: corrosive environment for BPP & PTL

BPP: bipolar plates, with flow fields (channels).

→ Sensitive to metal pollution at ppm levels.

→ State-of-the-art material for BPP and PTL: titanium + precious metal (Au, Pt) coatings.

PEMWE stack material costs

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- **Corrosion-related cost issues in PEMWE**

Cost breakdown of PEM electrolyzer stack (in %)

BPP+PTL: > 60% of the stack capital expenditures (CAPEX)

Corrosion-based limitation of PEMWE's economic competitiveness

M. Babic *et al.*, J. Electrochem. Soc. 164 (2017) F387

Pristine anode PTL Corroded anode PTL

Unprotected titanium: PTL corrosion (oxidation)

D.G. Bessarabov et al., Performance Degradation, in: PEM Water Electrolysis, Academic Press, 2018.

Noble coatings do not systematically satisfy: Delamination of PTL platinum coatings at 3 A/cm^2.

C. Rakousky *et al.*, Electrochim. Acta 164 (2017) F387

Capex reduction-driven challenges based on corrosion approach:

→ Replacing titanium by stainless steels (or other metals)

→ Ensuring corrosion resistance (durability) using cost-effective coatings.

Ongoing projects: PROTIS, low TRL, 2023-2026

- **Thin films for protection of stainless steel PTL**

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lemta
Laboratoire Energies & Mécanique Théorique et Appliquée

Empa
Materials Science and Technology

LinkedIn: PROTIS project

State-of-the-art: thick Ti-Nb coatings by vacuum plasma spraying (4-step process)

PROTIS: one-step deposition of thin films

Stiber *et al.*, Energy Environ. Sci., 15 (2022) 109

Atomic Layer Deposition (ALD)

Electrodeposition

Physical vapor deposition (PVD)

Synthesis - nanostructure - corrosion protection relationships

Ongoing projects: PROTIS, low TRL, 2023-2026

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• Thin films for protection of stainless steel PTL

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lemta — Laboratoire Energies & Mécanique Théorique et Appliquée

Empa Materials Science and Technology — Swiss Coordinator

- [EMPA] Synthesis of thin oxide coatings (PVD, ALD): TiO_x and others.
- [IC] Corrosion testing, electrodeposition, ex situ accelerated stress tests (AST).
- [LEMTA, Uni. Lorraine] PEM electrolysis, in situ AST, contact resistance measurements.

Corrosion testing:

- Monitoring by chronoamperometry, impedance spectroscopy…
- Post-mortem analysis: optical microscopy, SEM/EDX, Raman microscopy, scanning kelvin probe analysis…

PVD TiO_x

Synthesis of thin coatings:

- Influence of synthesis parameters on nanostructure.
- Optimization of substrate surface state.
- Chemical, electrical and microstructural character.

Picture credit: LEMTA

PEM water electrolysis:

- Implementation of coated PTL, evaluation of cell performance.
- Influence of temperature, gas pressure, clamping pressure…

Evan Blachier:
Stage BUT (4 mois) à l'IC

iut Lannion

École d'ingénieurs ensibs : Université Bretagne Sud

INGENIEUR ENSIBS - Génie Energétique et Génie Electrique Parcours Hydrogène

Ongoing projects: UNICORN, TRL 3-6, 2023-2026

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SINTEF

Coordinator

RISE

Institut Européen des Membranes

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Alleima

hystar

Ionomer Innovations Inc.

Activities:

- Coatings for stainless steel BPP: IEM (research), Alleima (industry)
- Corrosion testing: IC, RISE (research)
- Environmental-friendly polymer electrolyte (without PFAS): Ionomer Inn. (industry)
- Techno-economic analysis, life cycle analysis: RISE (research)
- End-users (PEM electrolysis): SINTEF (research), Hystar (industry)

No R&D activity on PTL, hence complementary to PROTIS

Picture credit: SINTEF

Ongoing projects: UNICORN (2023-2026), TRL 3-6

Picture credit: Hystar

Air-fed anode with thinner membranes: lower ohmic losses, higher current densities.

Picture credit: Inomer Innovations Inc.

Pemion® : hydrocarbon membrane free of PFAS

Alleima's continuous carbon coating line (~ 30 nm, PVD) for BPP: mass production

Picture credit: Alleima

Becker *et al.*, Energy Environ. Sci. 448 (2022) 227563.

Collaboration with COSTO project (2022 - 2026), low-TRL

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- **Anti-corrosion thin films for anodic structural elements (BPP, PTL) in PEMWE**

French funding program “PEPR Hydrogen”

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IC subcontractor + co-supervision of the Ph.D. thesis of Khaoula Chergui (Univ. Brest)

COSTO consortium:

- Univ. of Paris-Saclay (2 labs)
- Univ. of Brest
- Univ. of Rennes
- European Institute of Membranes (Montpellier)
- University of Paris Sorbonne

Coordinator: Univ. of Paris-Saclay

Protection of BPP using scalable thin-film techniques

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- **Thin TiOxNy films (PVD) for protection of stainless steel BPP**

Magnetron sputtering with Ti target and non-heated substrate.

Requirements:
* Chemically stable in near-neutral aqueous solution (possibly containing SO_4^{2-} and F^-).
* Good electrical conductivity and low interfacial contact resistance (ICR).
* Good adhesion to the stainless steel substrate (under steady-state and intermittent conditions)

Poster de Khaoula Chergui, doctorante à l'Université de Bretagne Occidentale (directeur de thèse: Dr. S. Rioual):

TiO_xN_y-based protective coatings for corrosion protection of 316L stainless steel bipolar plates under PEMWE anode-like conditions

Collaboration avec l'ISC Rennes et l'Institut de la Corrosion

Cost-shared R&D: Member Research Consortium (MRC)

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65 member companies

ARCOR

Association pour la Recherche sur la Corrosion et l 'Anti-Corrosion

Member Research Consortiums

Paints and linings for steel and related alloys structures in atmosphere and in immersion -

Oil & Gas production: metallic materials

Corrosion in Aerospace Industry

Corrosion and Cathodic Protection in Soils

Offshore, harbour and seawater systems

Corrosion properties of coil-coated steel products

Hydrogen Industry

- Adhesion fee: 6.5 k€/year (initial commitment of 3 years)
- R&D activities decided by the MRC members.
- 100% budget dedicated to R&D. No admin costs.
- Applied R&D for industry.
- Discount for commissions/consultancies/R&D studies.

MRC 13 (site of Saint-Etienne)

Airbus	Aperam	Akzo Nobel	Böhler Edel
GE Power	Geostock	GRT Gaz	Industeel
Sandvik	Shell	Storengy	Technip Energies
Technip FMC	Tenaris	Terega	Total Energies
Ugitech	Vallourec	DGA	Tata Steel
Bekaert	Ascometal	EDF	BakerHugues

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Under construction: New MRC on corrosion in low-temperature electrolyzers (& fuel cells). Contact: M. Prestat (site of Brest)

Plans for the near-future

Development of a MRC on low-temperature water electrolysis during 2024:
- Corrosion testing of BPP, PTL and coatings, development of novel protective coatings.
- Corrosion issues in balance of stack (e.g. rouging in stainless steel pipes).
- PEM, AEM, alkaline and seawater electrolysis technologies.
- Currently collecting expressions of interest of potential participants.

Anode: $4OH^- \leftrightarrow 2H_2O + O_2 + 4e^-$
Cathode: $4H_2O + 4e^- \leftrightarrow 2H_2 + 4OH^-$

Extension of R&D activities to **Anion Exchange Membrane (AEM)** water electrolysis:
- For ex situ corrosion testing, similar set-ups, mostly shifting the pH to alkaline values.

Extension of R&D activities to **seawater electrolysis**:
- Extensive experience of IC in marine corrosion.
- BPP/PTL protection and catalyst durability (long-term testing)
- Selection of materials for the balance of stack (based on corrosion resistance in marine environment).

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PROTIS: anr Swiss National Science Foundation

UNICORN: anr The Research Council of Norway Swedish Energy Agency

lemta Laboratoire Énergies & Mécanique Théorique et Appliquée
hystar
Alleima
SORBONNE UNIVERSITÉ
RI.SE
Empa Materials Science and Technology
UNIVERSITÉ DE LORRAINE
Institut des Sciences Chimiques de Rennes UMR CNRS 6226
UBO université de bretagne occidentale
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Merci pour votre attention !

Corrosion parameters: potential (and pH)

Becker *et al.*, J. Power Sources 448 (2020) 227563.

Becker *et al.*, Energy Environ. Sci. 448 (2022) 227563.

Local measurements within the PTL (2 mm thick Ti sinter) "far" (several 100 µm) from the catalyst layer (CL).
→ PTL (and thus the BPP) is decoupled from the applied current density (from the cell potential).
→ Misconception: BPP (and most of the PTL) does NOT have the same potential (ca. +2 V/SHE) as the anode.

For *ex situ* corrosion experiments:

→ BPP (and most of the PTL): corrosion potential (open-circuit potential) and near-neutral pH (4-6).

→ PTL/CL interface: potential around +2 V/SHE (typically for 2 A/cm^2) and acidic pH (~ 0-2).