PEM WATER ELECTROLYZER: WHAT'S NEXT?

Opening of the “first Dutch” 50 kW water electrolyser system | Dr. F.P.F. van Berkel
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- PEMWE: Current status
- Cost of hydrogen production by PEMWE
- Cost perspective for PEMWE components
- Approach/positioning of TNO
- Conclusion
PEM WATER ELECTROLYZER: CURRENT STATUS

Installed Electrolysis power
• > 1 MW electrolysis systems:
  - Siemens
  - Hydrogenics
  - ITM
Large PEMWE-scale....but need for cost reduction
Target (2030) < 2€ /kg H₂

Source: Alexander Buttler, Hartmut Spliethoff
Renewable and sustainable Energy Reviews 82 (2018) 2440-2454

Source: E4Tech, Element Energy 2014. FCH-JU
PEM WATER ELECTROLYZER: COST OF HYDROGEN

Two mayor cost factors:
• Capital cost for the electrolyser system
• Energy cost

Base case (BC)
- Investment cost 1000 €/kW
- Depreciation 15% /year
- O&M 2% /year
- Electricity price 50 Euro/MWh
- Operating hours 8000 hours
- Efficiency 60%

Impact of investment cost [€/kW] Impact of electricity cost [€/MWh]
PEM WATER ELECTROLYZER: COST OF HYDROGEN

Flexible operation requires strong decrease of the capital cost of the electrolyser

To reduce cost of hydrogen:
• Improve efficiency
• Reduce electrolyser cost

Operating hours per year
PEM WATER ELECTROLYZER: COMPONENTS

PEMWE components:
- Membrane (MEM)
- Anode Catalyst (CL_a)
- Cathode Catalyst (CL_c)
- Porous Transport Layer (PTL_a, PTL_c)
- Bipolar plates (BPP)

Anode: \( \text{H}_2\text{O} \rightarrow 2\text{H}^+ + 1/2\text{O}_2 + 2\text{e}^- \)

Cathode: \( 2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2 \)

Source: JES, 164 (2017) F387
PEM WATER ELECTROLYZER: COST REDUCTION

Cost reduction: OPEX

Efficiency increase

Efficiency 100%: $\text{H}_2\text{O} \rightarrow \text{H}_2 + \frac{1}{2} \text{O}_2$

Reduction of internal losses: Membrane, Anode catalyst
PEM WATER ELECTROLYZER: COST REDUCTION

› CAPEX: Cost projection and breakdown

*Based on: Smolinka, T.; Wiebe, N.; Thomassen, M., Cost break down and cost reduction strategies for PEM water electrolysis systems, 6th European PEFC & Electolyser Forum, Lucern, Switzerland, 2017*

**System CAPEX (€/kW)**
- 5 MW (2020): 960
- 100 MW (2030): 350

**Stack CAPEX (€/kW)**
- 5 MW (2020): 330
- 100 MW (2030): 135

**Energy efficiency (%)**
- 5 MW (2020): 69
- 100 MW (2030): 84
COST REDUCTION: BIPOLAR PLATES

Status: 450-500 €/kW (2012)
- Ti- or SS-plate (2-3 mm) with PGM-coating + flow field (Milling)

Aim: Reduce cost to < 40 €/kW (2030)

Approach:
- Thin/frame, combine corrugated plate/frame
- Ultra-thin novel coatings on SS
  - TM/C,N,B; Nb, Zr, ...

<table>
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<tr>
<th>Conv.</th>
<th>Gen. 1</th>
<th>Gen. 2</th>
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<tbody>
<tr>
<td>500 €/kw</td>
<td>80 €/kw</td>
<td>47 €/kw</td>
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<td>2012</td>
<td>2022</td>
<td>2030</td>
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Source: Sci Rep 7 (2017) 44035
**A-PTL: Status:** ~280 €/kW
- Ti-based (~200 micron thick)
  - Ti-cloth/fibers (Bekaert)
  - Sintered Ti-powders (Mott Corp.)

**Aim:** Lower cost < 44 €/kW, robust PTL

**Approach:**
- Use coated SS (INCOME project)
- Use graded porosity
  - Micro-Porous Layer (MPL)

<table>
<thead>
<tr>
<th>Year</th>
<th>Ti-PTL</th>
<th>Ti-PTL No MPL</th>
<th>C-SS-MPL</th>
<th>C-SS-MPL No MPL</th>
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<tr>
<td>2016</td>
<td>280 €/kw</td>
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<td>2020</td>
<td>280 €/kw</td>
<td>200 €/kw</td>
<td>100 €/kw</td>
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</table>

**C-PTL/MPL:**
- Based on PEMFC
  - Carbon paper/cloth
  - US Drive/DOE Roadmap
    - ~ 1 - 3 $/kW
  - Smolinka EU-study:
    - 36 → 10 €/kW
COST REDUCTION: ANODE/CATHODE CATALYST

A-CAT Status:
- State-of-Art commercial: Ir/IrO₅-NP
- Commercial stacks: 2-3 mg/cm²

Back-of-the-envelope calculation
- Ir price: 42000 €/kg
  - Catalyst cost ~ 0.084 €/cm²
  - Performance 3 W/cm² → 26 €/kW

Aim: Low cost (< 2 €/kW), robust, highly active, durable
- Abundant → non-PGM-based

Approach:
- Low-Ir content
  - PTL/MPL fine-tuning
  - Alloy/Core-shell Ir w/TM’s (IrNi)
  - Catalyst/support (e.g. IrOx/TiO₂)
    - Electronic/Lattice
    - Thin film catalysts (e.g. NSTF)
    - Not NP, High TOF
- Non-PGM-based
  - Silver-based: AgCeCrO₃
  - TM Bronze: AₓMᵧO₂
  - Nitrogen-doped carbon (NDC)

Ir/IrOx-NP | Low Ir/IrOx | Non-PGM
---|---|---
26 €/kw | 3-5 €/kw | < 2 €/kw
2019 | 2022 | 2028

C-CAT Status:
- PEMFC based (Pt-NP/C)
- Loading ↓ → ~No performance loss
- Cost ~ 4 €/kW

Source: JES 165(2018)F305
COST REDUCTION: MEMBRANE

**Status:** Nafion (Dupont)
- PFSA-based

**Back-of-the-envelope calculation**
- Nafion: 115 (127 µm), 117 (183 µm)
- Price: 1833 €/m², 2222 €/m²
  - @ 3 W/cm² typical performance
  - Nafion Cost: 60-120 €/kW

**Aim:** Low cost (< 20 €/kW),
- Chemical & Mechanical Robustness/Durability
  - ΔP~100 bar!, T ~ 90 C, pH < 0
- Gas crossover↓, Conductivity ↑

**Approach:**
- Thin-PFSA → Gas crossover
- Short side chain PFSA
- Composite/Reinforced membranes
  - Graphene, TMO-NP’s, etc.
  - Recombination Catalyst
    - From PEMFC
    - Loss in eff%
- Hydrocarbon membranes (F-free: AMPERE)
  - Improve conductivity/durability
  - Multiple side-chains

**Source:** J. Mem. Sci. 466(2014)1

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<td>Aquivion</td>
<td>-Reinforced mem</td>
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<td>Recomb. Cat.</td>
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<table>
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<th>Hydrocarbon</th>
<th>60-120 €/kw</th>
<th>30-50 €/kw</th>
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<td>2019</td>
<td>2022</td>
<td>2028</td>
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**Source:** J. Mem. Sci. 570(2019)69
COST REDUCTION: LIFETIME

Key economic parameters – a complex trade-off

- There is a strong trade-off between cost, efficiency and lifetime.
- A change in the design or operation of an electrolyser generally has impact on all three main parameters.

A - Decrease membrane thickness
B - Operate at higher temperature
C - Use lower catalyst loadings

Key objective of our R&D:
- Reduce cost of components while maintaining durability
COST REDUCTION: TECHNICAL APPROACH

- Implementation of novel components in PEMWE on single cell level (Faraday lab)
  - Manufacturing facility for Membrane-Electrode Assemblies up to 50x50 cm²

- Testing infrastructure for performance and lifetime testing (Faraday lab):
  - Single cell-level: lab- to bench-scale
  - Small stacks up to 50 kW
  - Large stacks up to 1 MW-level

- Test protocols:
  - Performance testing (Efficiency, lifetime)
  - Accelerated stress testing in-situ and ex-situ
  - Harmonisation of test protocols (JRC, IEA-annex)
COST REDUCTION: SUPPLY CHAIN

Why focus on the supply chain?
- Large part of added value in chain – willingness to invest based on future business
- Specific know-how available, but limited access to electrolyser knowledge
- Shorten time-to-market by involving suppliers from start
CONCLUSIONS: WHAT’S NEXT?

› Reduction of cost of hydrogen by PEMWE electrolysis:
  › Target 2030: < 2 euro/kg H₂
  › Enhance efficiency
  › Reduce cost of components

› Reduction of cost of PEMWE Electrolysis components (Cooperation with industry and academia):
  › Membrane (Thin, alternative materials (non-fluor)
  › Anode catalyst (Ir-reduction or alternatives)
  › Anode Porous Transport Layer (Stainless steel, micro-porous layer)
  › Bipolar plates (Stainless Steel, Thin plates, corrosion resistant layers)

› TNO facilitates in component implementation, performance and lifetime testing, PEMWE demonstration
THANK YOU FOR YOUR ATTENTION

TNO.NL/ECNPARTOFTNO