PEM WATER ELECTROLYZER: WHAT'S NEXT?

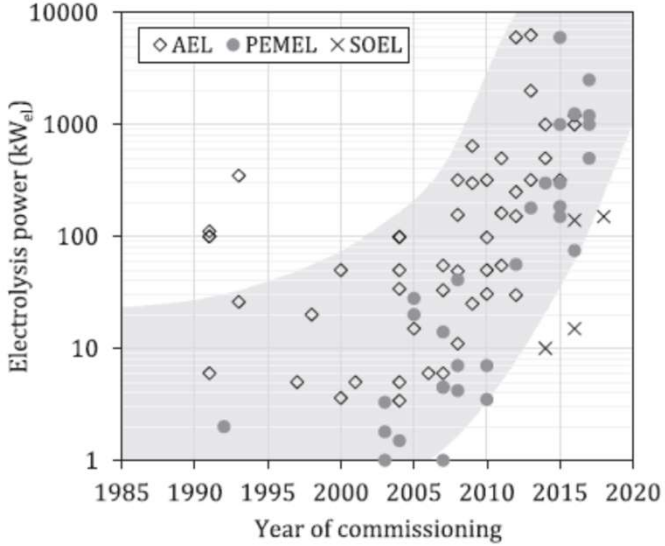
Opening of the ‘first Dutch” 50 kW water electrolyser system | Dr. F.P.F. van Berkel

ECN › TNO innovation for life

CONTENT

- PEMWE: Current status
- Cost of hydrogen production by PEMWE
- Cost perspective for PEMWE components
- Approach/positioning of TNO
- Conclusion

PEM WATER ELECTROLYZER: CURRENT STATUS



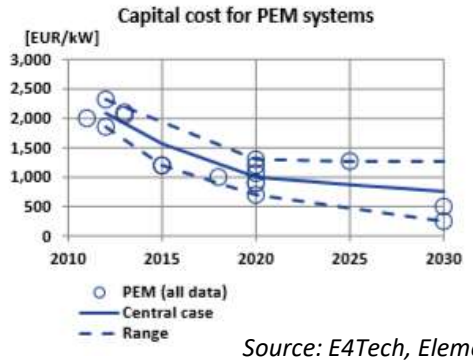
Source: Alexander Buttler, Hartmut Spliethoff
Renewable and sustainable Energy Reviews 82 (2018) 2440-2454

Installed Electrolysis power

- > 1 MW electrolysis systems:
  - Siemens
  - Hydrogenics
  - ITM

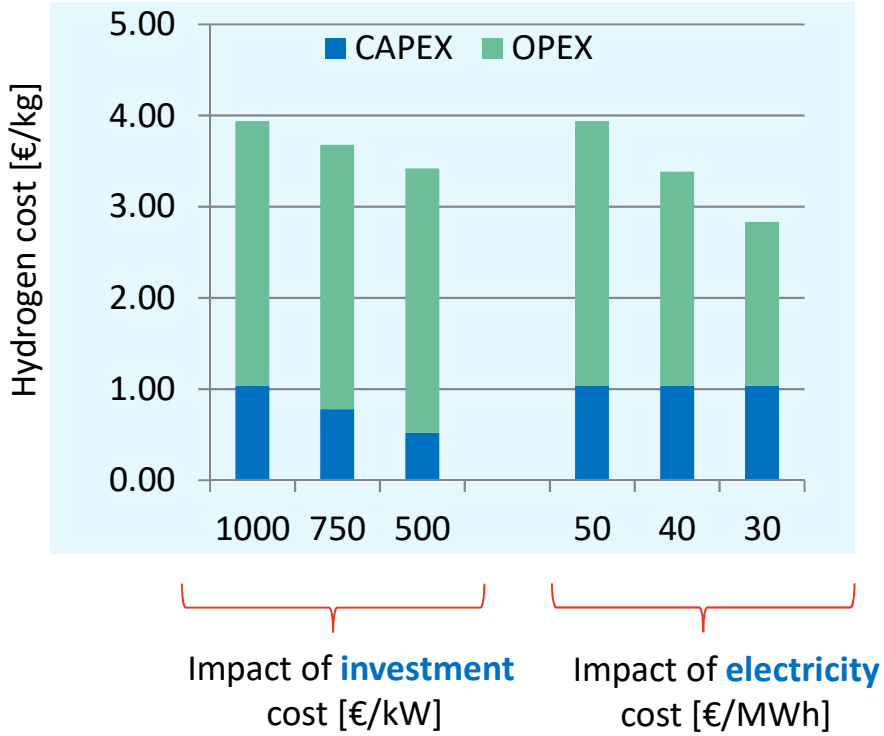
Large PEMWE-scale….but need for cost reduction

Target (2030) < 2€ /kg H_2



Source: E4Tech, Element Energy 2014. FCH-JU

PEM WATER ELECTROLYZER: COST OF HYDROGEN

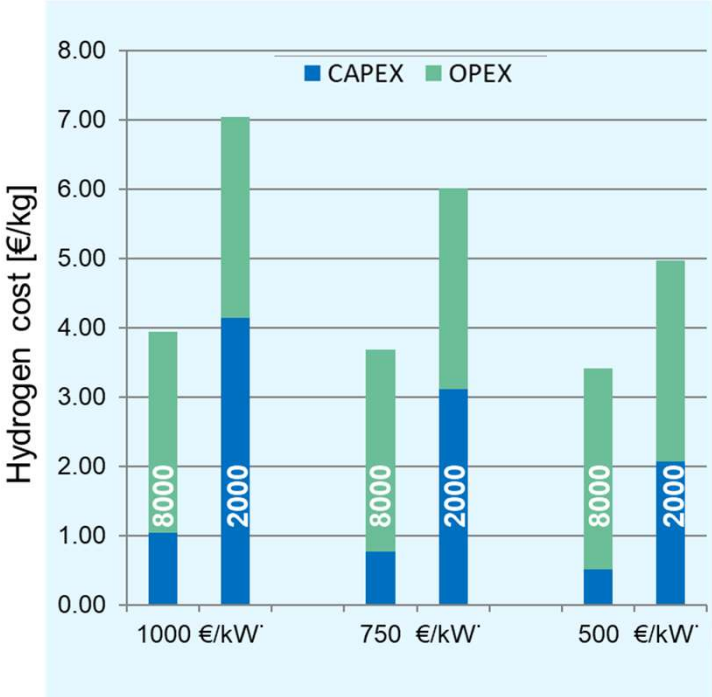


Two mayor cost factors:

- 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%

PEM WATER ELECTROLYZER: COST OF HYDROGEN

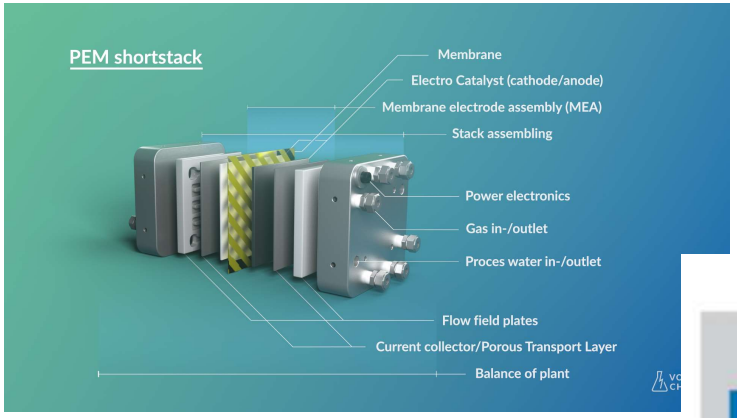


Flexible operation requires strong decrease of the capital cost of the electrolyser

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

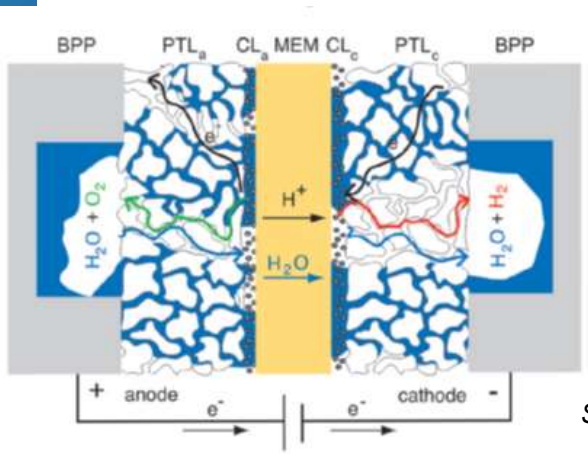
Operating hours per year

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)



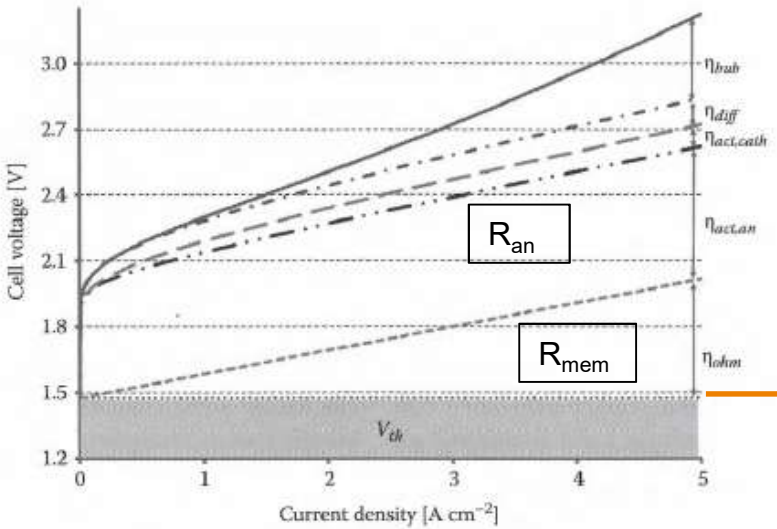
Anode: $H_2O \rightarrow 2H^+ + 1/2O_2 + 2e^-$

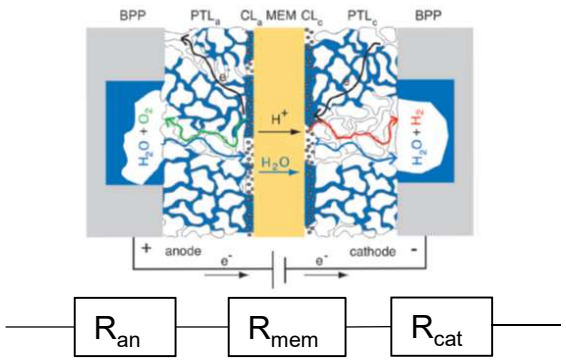
Cathode: $2H^+ + 2e^- \rightarrow H_2$

Source: JES, 164 (2017) F387

PEM WATER ELECTROLYZER: COST REDUCTION

- Cost reduction: OPEX





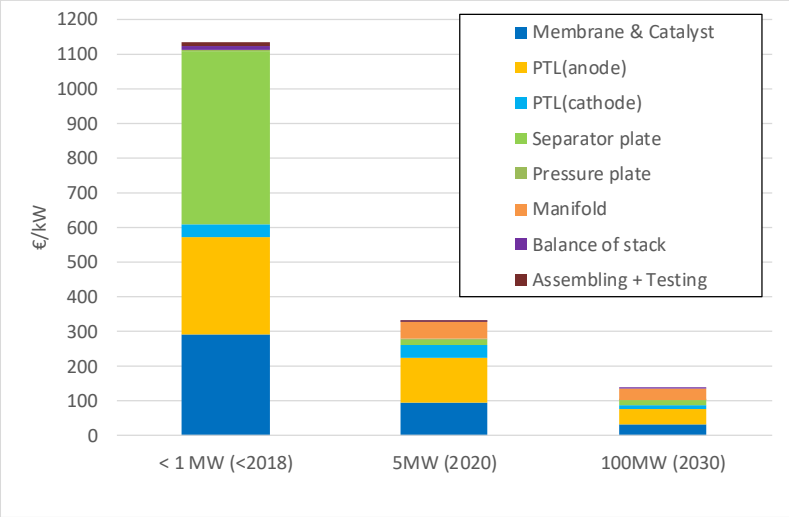
Efficiency increase

Efficiency 100%: $H_2O \rightarrow H_2 + ½ O_2$

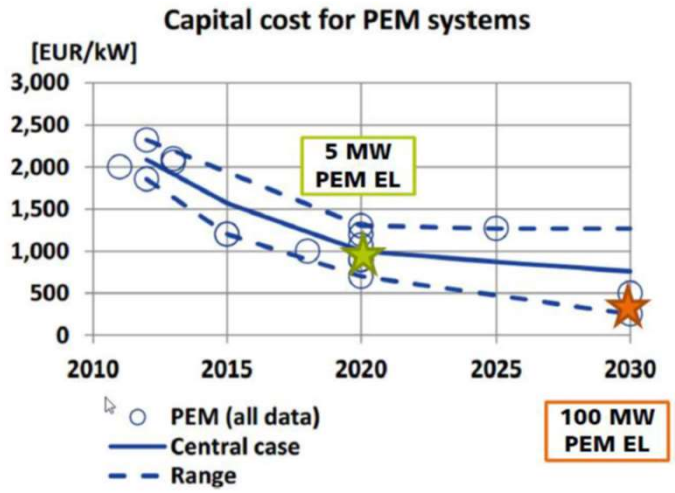
Reduction of internal losses: Membrane, Anode catalyst

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

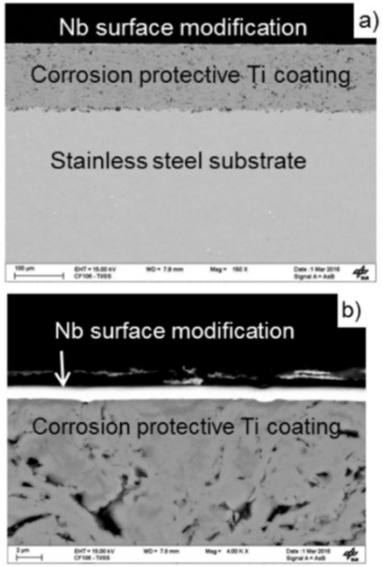


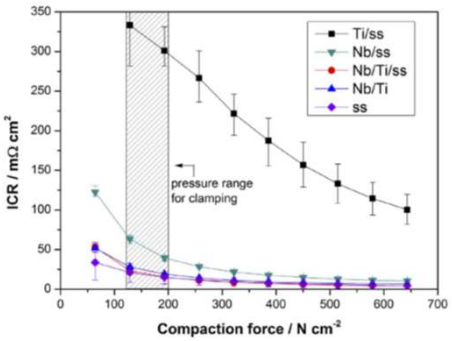
	5 MW (2020)	100 MW (2030)
System CAPEX (€/kW)	960	350
Stack CAPEX (€/kW)	330	135
Energy efficiency (%)	69	84

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, …

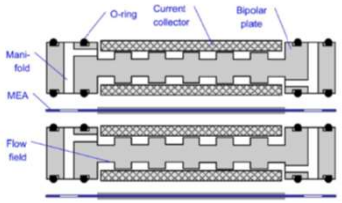
Conv.	*Gen. 1*	*Gen. 2*
500 €/kw	*80 €/kw*	*47 €/kw*
2012	*2022*	*2030*

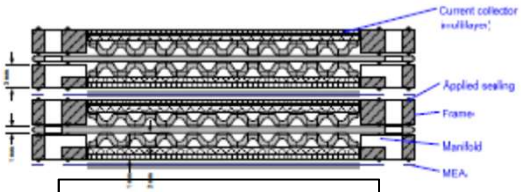




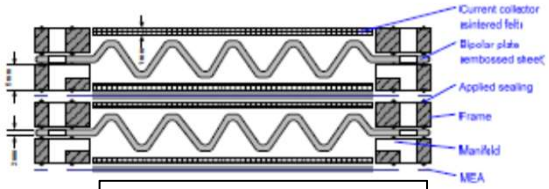
Source: Sci Rep 7 (2017) 44035

Conv.





Gen. 1: BPP/Manifold



Gen. 2: BPP/Manifold

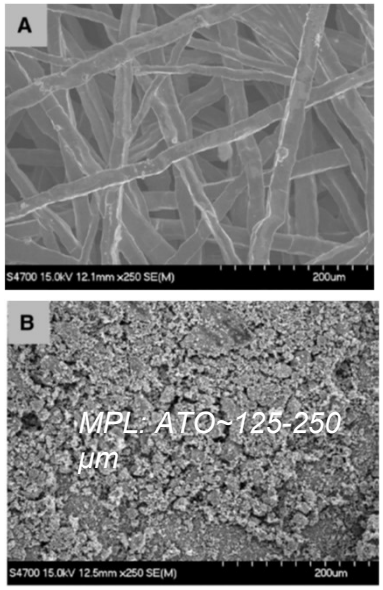
COST REDUCTION: POROUS TRANSPORT LAYER

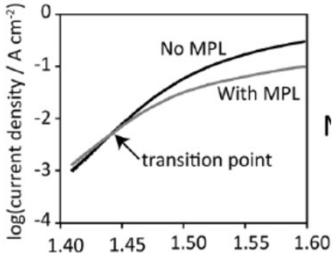
A-PTL: Status: ~280 €/kW
- Ti-based (~200 micron thick)
  - Ti-cloth/fibers (Bekaert)
  - Sintered Ti-powders (Mott Corp.)

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

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

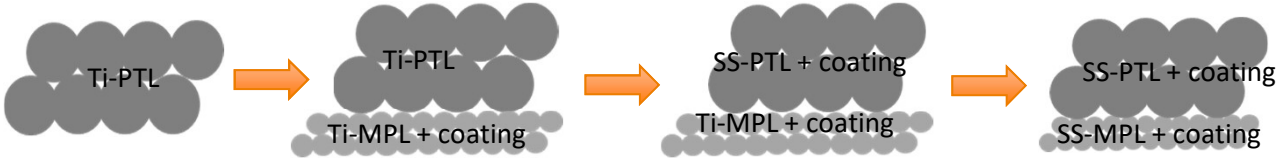
Ti-PTL No MPL	*Ti-PTL C-Ti-MPL*	*C-SS-MPL C-Ti-MPL*	*C-SS-MPL C-SS-MPL*
280 €/kw	*200 €/kw*	*100 €/kw*	*< 45 €/kw*
2016	*2020*	*2022*	*2025*





J Appl Echem 47(2017)1137

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

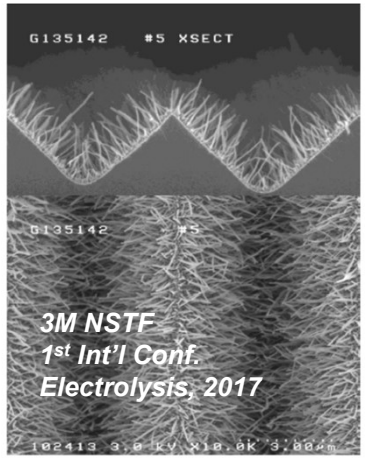
A-CAT Status:
- State-of-Art commercial: Ir/IrO_x-NP
  - Commercial stacks: 2-3 mg/cm^2

Back-of-the-envelope calculation
- Ir price: 42000 €/kg
  - Catalyst cost ~ 0.084 €/cm^2
  - Performance 3 W/cm^2 → 26 €/kW

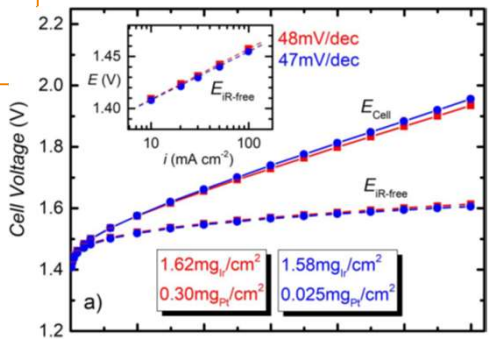
Aim: Low cost (< 2 €/kW),
- robust, highly active, durable
  - Abundant → non-PGM-based

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

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: $AgCeCrO_3$
  - TM Bronze: $A_xM_yO_z$
  - Nitrogen-doped carbon (NDC)



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



Source: JES 165(2018)F305

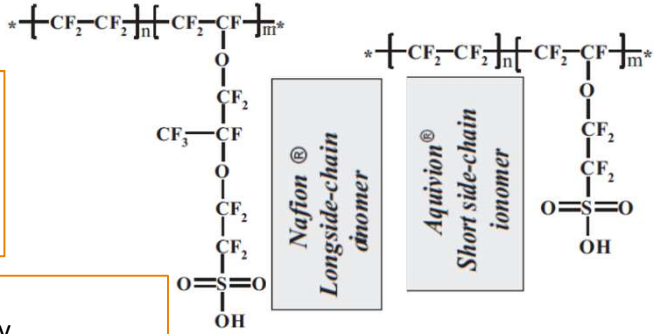
COST REDUCTION: MEMBRANE

Status: Nafion (Dupont)
- PFSA-based

Back-of-the-envelope calculation
- Nafion: 115 (127 µm) , 117 (183 µm)
- Price : 1833 €/m^2 , 2222 €/m^2
  - @ 3 W/cm^2 typical performance
    - Nafion Cost: 60-120 €/kW

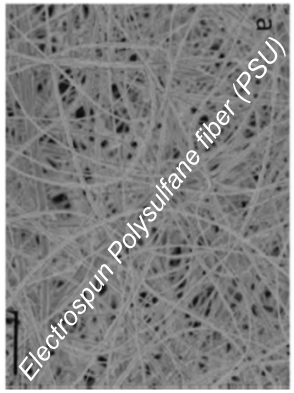
Aim: Low cost (< 20 €/kW),
- Chemical & Mechanical Robustness/Durability
  - ΔP~100 bar!, T ~ 90 C, pH < 0
- Gas crossover↓, Conductivity ↑

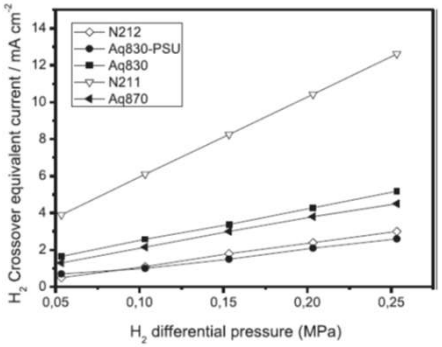
Source: J. Mem. Sci. 466(2014)1



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

PFSA -Nafion/ -Aquivion	*Thin PSFA -Reinfored mem Recomb. Cat.*	*Hydrocarbon*
60-120 €/kw	*30-50 €/kw*	*< 20 €/kw*
2019	*2022*	*2028*





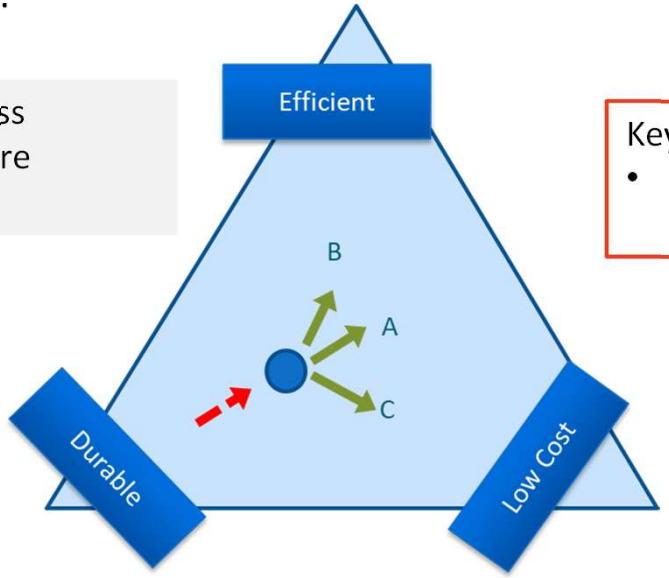
Source: J. Mem. Sci. 570(2019)69

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.

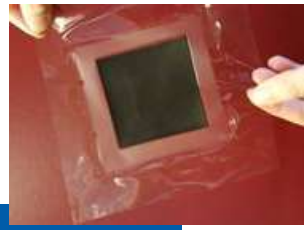
A - Decrease membrane thickness
B - Operate at higher temperature
C - Use lower catalyst loadings



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 cm^2



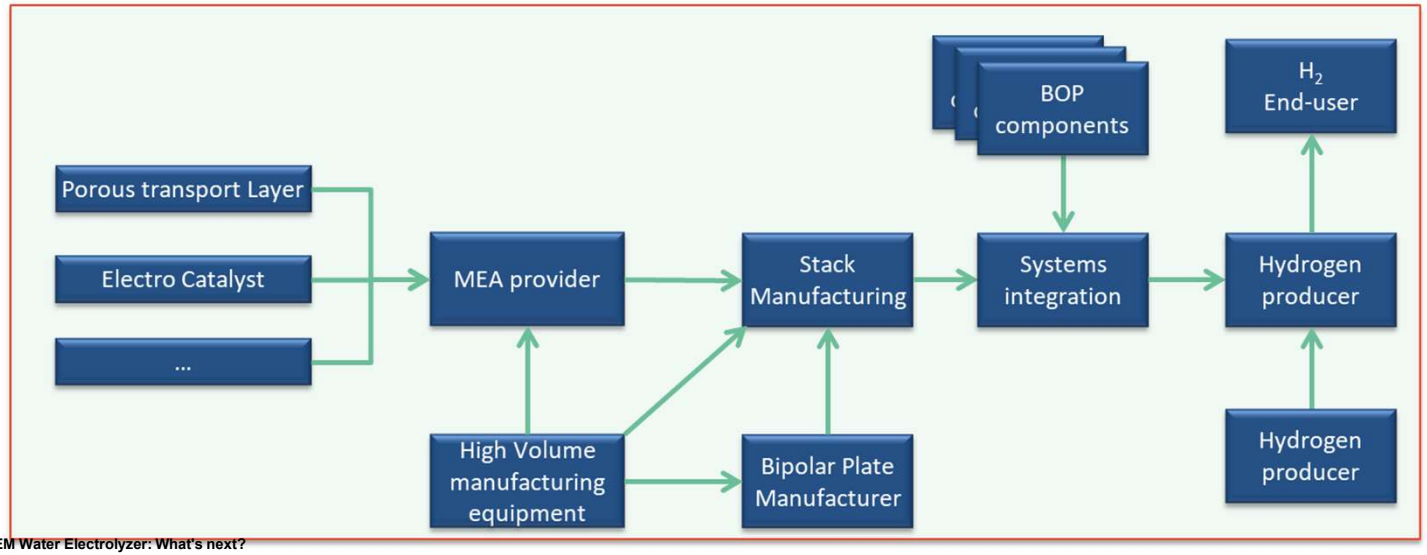
- Testing infrastructure for performance and lifetime testing (Faraday lab):
  - Single cell-level: lab- to bench-scale
  - Small stacks up to 50 kW
  - Large stacks up to 1 MW-level

- 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

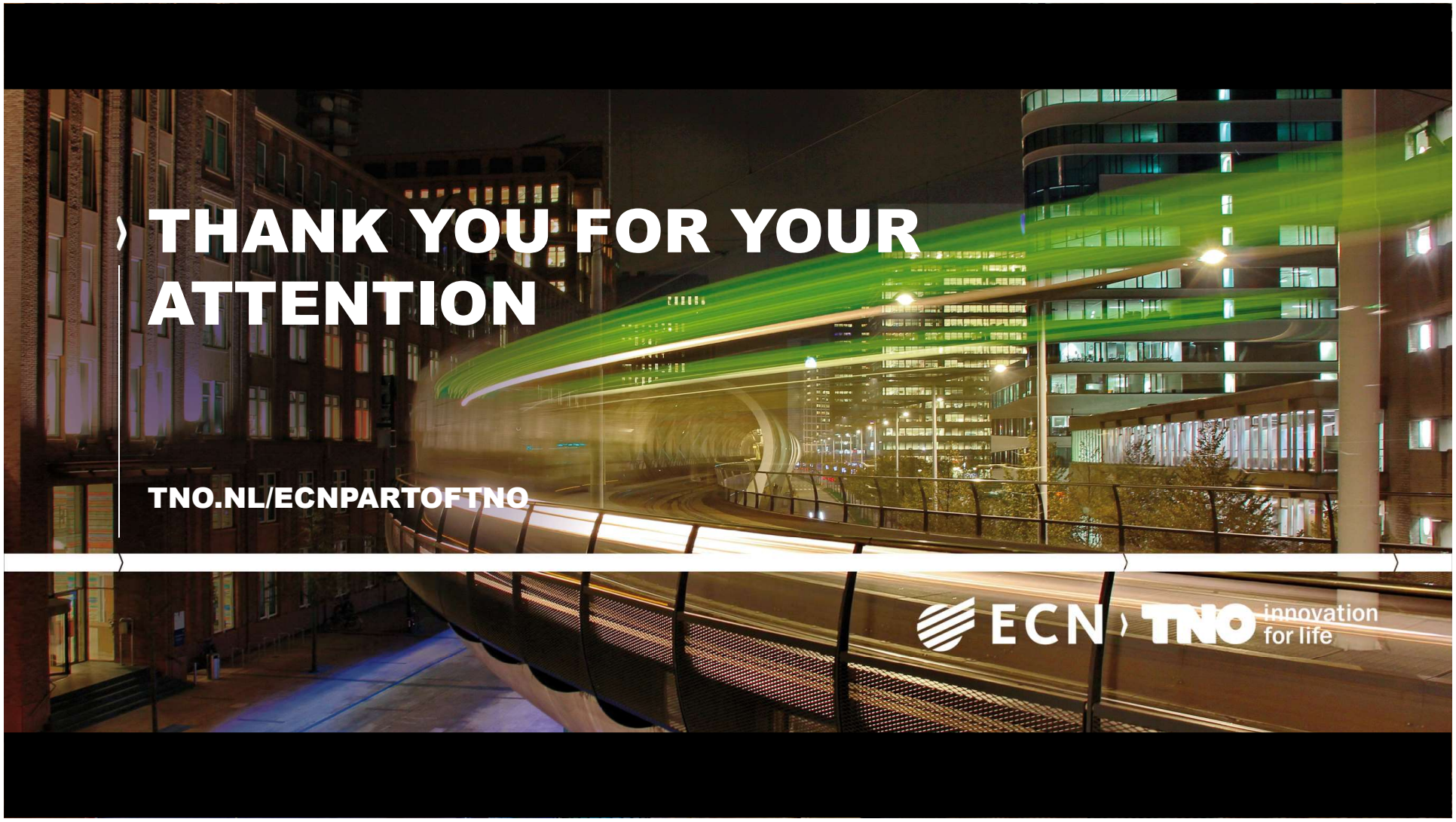


CONCLUSIONS: WHAT'S NEXT?

- Reduction of cost of hydrogen by PEMWE electrolysis:
  - Target 2030: < 2 euro/kg H_2
  - 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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TNO innovation for life