


Electrification of the Chemical Industry

Workshop

"Developing the supply chain for electrolysis"


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Program for the afternoon

- Goal of the workshop
- Research on PEM electrolysis at TNO– the key challenges
- The market for electrolysis
- The role of the supply chain
- A brief introduction in the PEM electrolyser
- Interactive session: your feedback/input
- Conclusions of the workshop

This workshop is financed from the Ampere project, which received funding from the Ministry of Economic Affairs and Climate through RVO under contract TWAS11700



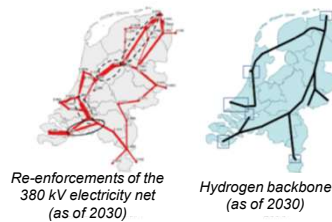
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On the role of hydrogen

Future Energy system security of supply

- Increased share of electricity in the energy mix will put stress on the electricity network
- Capacity of the national electricity net is limited:
 - Max capacity NL electricity net: **20 GW**
 - Max capacity NL gas distribution net: **350 GW**
- Stop on large scale solar PV in specific areas due to limited capacity of the local/regional electricity net
- Import of energy absolutely necessary



Source: Gasunie/Tennet; Infrastructure outlook 2050, November 2018



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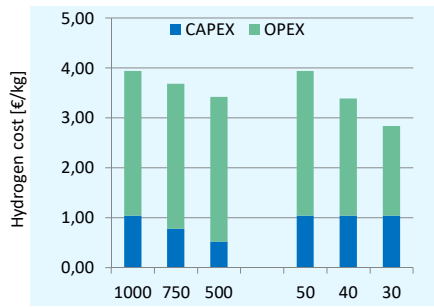
Bringing down the cost of hydrogen

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Bringing down the cost of hydrogen

Below graph shows the cost of hydrogen produced by electrolysis for different specific investment costs (left) and electricity price levels (right). It shows that at 8000 hours of operation annually the cost of the hydrogen is dominated by the electricity cost.



Conclusion: Two major cost factors:

- Capital cost for the electrolyser
- Energy cost is dominant @ 8000 operating hours

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]

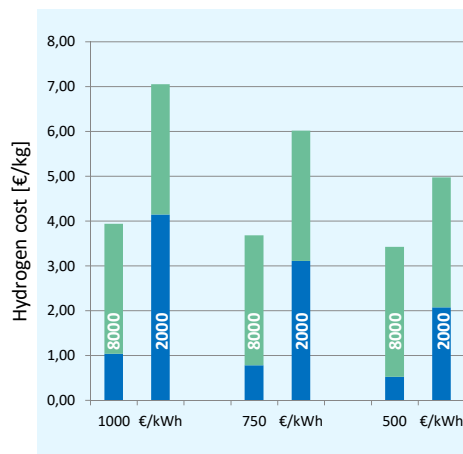


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Bringing down the cost of hydrogen

Below graph shows the cost of hydrogen produced by electrolysis a different cost levels for different yearly operating hours^[1].



Conclusion: With flexible operation the capital cost of the electrolyser becomes much more important.

To reduce cost of hydrogen:

- Improve efficiency
- Reduce electrolyser cost

← Operating hours per year

^[1] not taken into account in this example is the fact that lower operating hours will lead to a lower electricity price: all calculations are for 50 €/MWh



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Bringing down the cost of hydrogen

Why are the cost of the electrolyser (still) high?

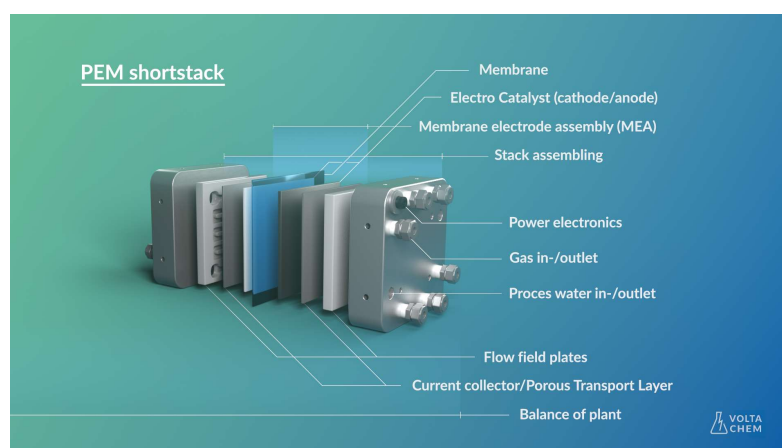
- Demanding conditions require **expensive materials**
 - Membrane, catalyst, electrodes
- Electrolysis is not yet a **high-volume market**
 - Immature supply chain for electrolyser
 - Labour intensive manufacturing processes
 - Limited standardization of system design



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Bringing down the cost of hydrogen



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Bringing down the cost of hydrogen

$\text{H}_2\text{O} \rightarrow \frac{1}{2}\text{O}_2 + 2\text{H}^+ + 2\text{e}^-$ (Anodic reaction)
 $2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2$ (Cathodic reaction)

Contact resistance due to Ti-oxidation
 Anode poisoning by Ti-species
 Blocking of ion exchange sites by ion impurities
 Cathode particle growth due to oxygen cross-over at power shut-down
 Electrolyte thinning by radical attack: peroxide due to O₂-cross-over

Porous Transport Layer
 Anode Catalyst Layer
 Proton exchange membrane
 Cathode Catalyst Layer
 Porous Transport Layer

More detail in the presentation by Paige Shirvanian

Brightman E. et al., Electrochemistry Communications, 52, 1-4, (2015)

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Bringing down the cost of hydrogen

The trade-off between cost, efficiency and lifetime.

Example: Membrane thickness ↑

- Improves durability
- More material use, higher cost
- Higher losses, lower efficiency

Example: Operating temperature ↑

- Rapid degradation, lower durability
- Higher efficiency
- Higher power density, lower cost


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The supply chain

Our work at TNO

Approach to shorten "time to market" for implementation of novel components

Understanding degradation and testing	Harmonised procedures and reference cell	Creating network with suppliers	Develop improved components	Validate in stack
<ul style="list-style-type: none"> • Understand degradation mechanisms + stressors • Accelerated stress test procedures (AST) • Specify, design and construct test stations 	<ul style="list-style-type: none"> • Define standardized testing conditions and protocols: Performance and AST • Standardized test cell 	<ul style="list-style-type: none"> • Open, non-exclusive relationship with OEM's • Current supply chain • Potential novel suppliers • Trust building 	<ul style="list-style-type: none"> • Testing of components in reference cells • Accelerated stress testing • Design cycle 	<ul style="list-style-type: none"> • Validate on full scale cells • Evaluate potential improvement
Key activities				


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The innovation challenges

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The Innovation challenges

- Materials, components and architectures for the electrolyser (durability at lower cost)
- Effective scale-up to the industrial scale hydrogen plants
- Low-cost manufacturing processes for the intermediate market
- Opportunities for demonstration and early market development for electrolysers

← Our focus today



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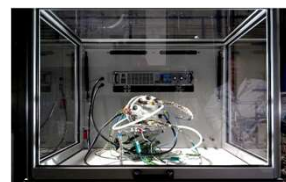
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The innovation challenges

Developing **novel materials and components**:

- Manufacturing of *manufacturing of membrane electrode assemblies* (MEA's)
- Standardized reference cell and test stations for duration testing
- Characterisation (during operation, post-test)
- In development:
 - Harmonized testing protocols for PEM cell testing (JRC)
 - Accelerated stress testing (AST)

Capabilities to test innovative materials & components



Understanding degradation and testing

Harmonised procedures and reference cell

Creating network with suppliers

Develop improved components

Validate in stack

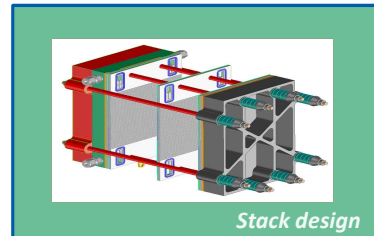
Innovation challenges

Scale-up of electrolyser stack technology

- Challenges in scaling up include fluid dynamics, dimensional stability of larger cells, temperature control, sealing, reproducibility of manufacturing methods

Why is it important?

- Understanding performance limiting mechanisms through experimentation and verification at the cell/component level.
- Development of (conceptual) stack designs to possible operating conditions, assess cost and performance impact



Innovation challenges

Goal of the MW test centre is to understand the potential and barriers in scale-up of different types of electrolysers



- Driven by potential users of the technology: Shell, Nouryon (formerly AkzoNobel), Yara (fertilizer), Gasunie, organised by ISPT
- Location: Entrance (Hanzehogeschool, Groningen)
- ≈ 4M€ investment in facilities to test short-stack, full-scale cells



Innovation challenges

Goal of the MW test centre is to understand the potential and barriers in scale-up of different types of electrolyzers

- Testing of full-scale cells and short stacks for PEM and alkaline electrolyser technology
- Alkaline: short stack/system will be acquired (Nouryon)
- PEM: building a open architecture stack: not optimized/state-of-the-art but known architecture (TNO)
- Key step between materials and electrochemical studies (Faraday lab) and application and design studies



- Develop a conceptual design and a transparent cost estimation methodology for a GW-scale electrolyzer plant, ready for start-up in 2030 and that delivers H₂ at cost below current H₂ manufacturing technologies.

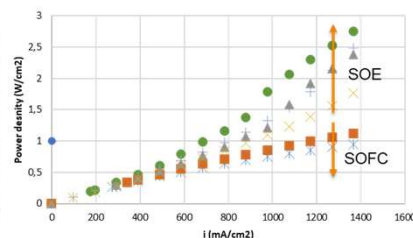
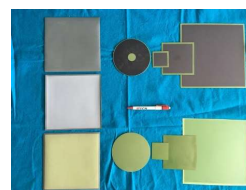
} GW study



Innovation challenges

Solid oxide electrolysis

- › Revisited SOFC manufacturing technology
- › Testing of "old" solid oxide cell in dual mode
-> state-of-the-art performance (!)
- › Currently manufacturing new cells (with existing equipment)
- › Building infrastructures for manufacturing cells and stacks



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Innovation challenges

Faraday Lab Capabilities

Testing of cells (including durability):

- Increasing number of PEM test stations (3 → 6) and novel test stations for SOC's
- Test equipment for redox flow batteries, base-acid separation

Manufacturing capabilities:


- From catalyst powder to electrochemical cells (up to 30x30 cm²)
- Preparation of deposition pastes from (electrocatalyst) powder
- Deposition technologies for active layers (tape casting, screen printing)
- Sintering equipment (different steps)
- Characterization equipment (proton conductivity, fluor emissions, RDE, etc.)

Scale-up / industrial application

- 50 kW test unit for PEM / Alkaline
- Design studies
- Short stack with full-scale cells and system for the HydroHub (250-500 kW)

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6 M€ investment



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Durability as key challenge

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Durability as key challenge

Brightman E. et al., Electrochemistry Communications, 52, 1-4, (2015)

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Harmonisation of testing & characterisation

Accelerated stress testing

AST PROTOCOL	In-situ analysis	Ex-situ analysis
<p><u>Variation T:</u> 60, 70, 80, 90 °C J = 1.5 A/cm² P_{an} = 2 bar P_{cat} = 10 bar Test time = 800-1200 hours</p>	<p><u>V(t) vs T:</u> 60, 70, 80, 90 °C</p>	<p><u>EIS, J-V:</u> Ohmic losses Polarisation losses</p> <p><u>Gas analysis:</u> increase in gas cross over</p> <p><u>Water analysis:</u> Fluor release</p> <p><u>Post test analysis:</u> Electrolyte thickness Catalyst particle growth Contact resistances</p>
<p><u>Variation pO₂ (anode):</u> 2, 5, 8 bara T = 80 °C P_{an} = 2 bar P_{cat} = 10 bar Test time = 800-1000 hours</p>	<p><u>V(t) vs pO₂ (anode):</u> 2, 5, 8 bara</p>	
<p><u>Variation J:</u> J-high: 3 A/cm² J-cycle: 0-3 A/cm² T = 80 °C P_{an} = 8 bara P_{cat} = 10 bar Test time = 600 hours</p>	<p><u>V(t) vs J:</u> J-high: 3 A/cm² ; J-cycle: 0-3 A/cm²</p>	

Total testing time: 2000 – 3000 hours

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