On the road to sustainable propulsion: material and operation strategy development for PEFCs

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Agenda

Challenges in the deployment of fuel cells

- Durability
- Product maturity

R&D activities at CEET

- Fuel cell operation optimisation
- Material and martial manufacturing development

Fuel Cell Durability

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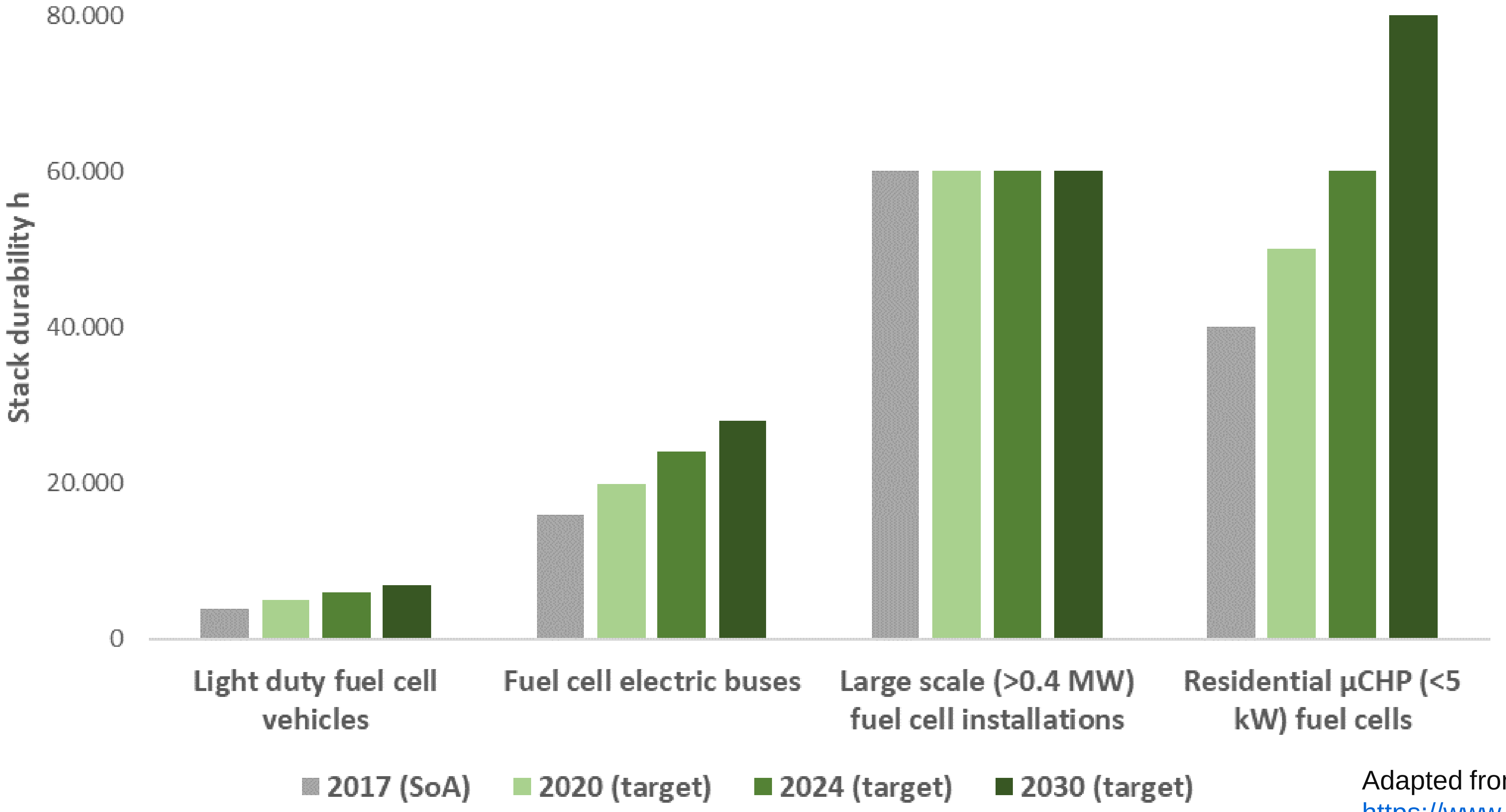
Fuel cell durability



Adapted from:
https://www.fch.europa.eu/soa-and-targets

Causes of degradation in PEFCs

→ Impurities, contaminants

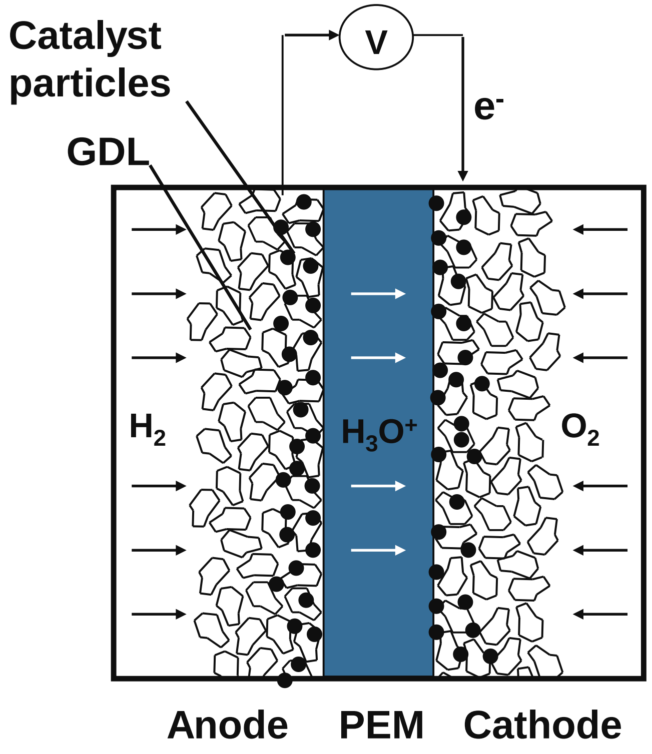
Electrode Degradation

- High temperatures
- High humidity
- High potentials
- High gas crossover
- Gas starvation

Membrane Degradation

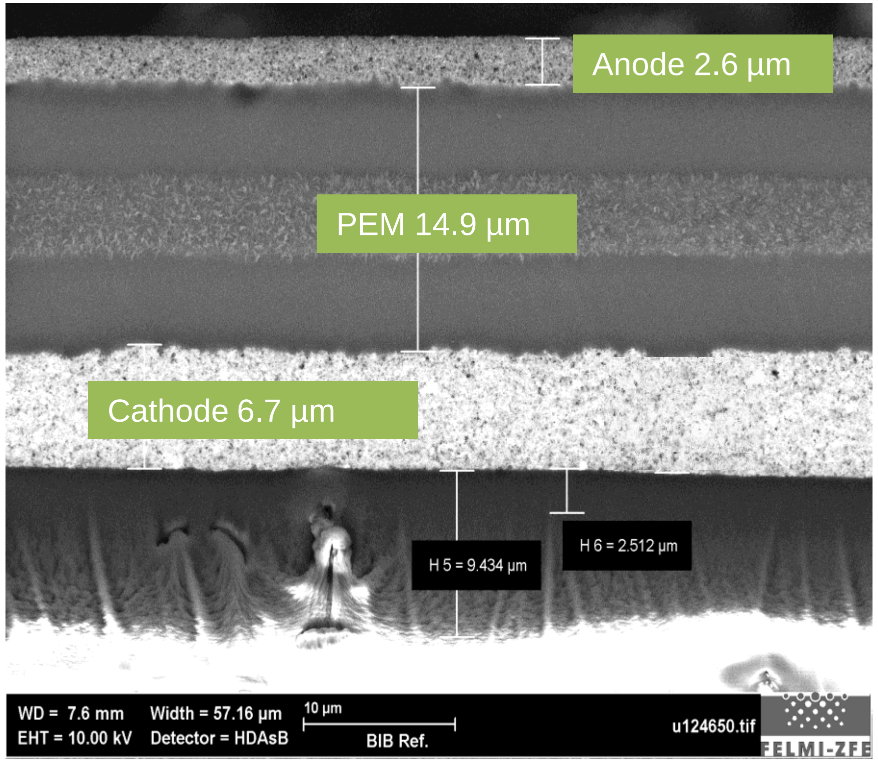
- **Mechanical degradation** due to stress and strain by alternating humidification temperatures
- **Chemical degradation** due to high temperatures and the presence of radicals

Principle of a PEFC

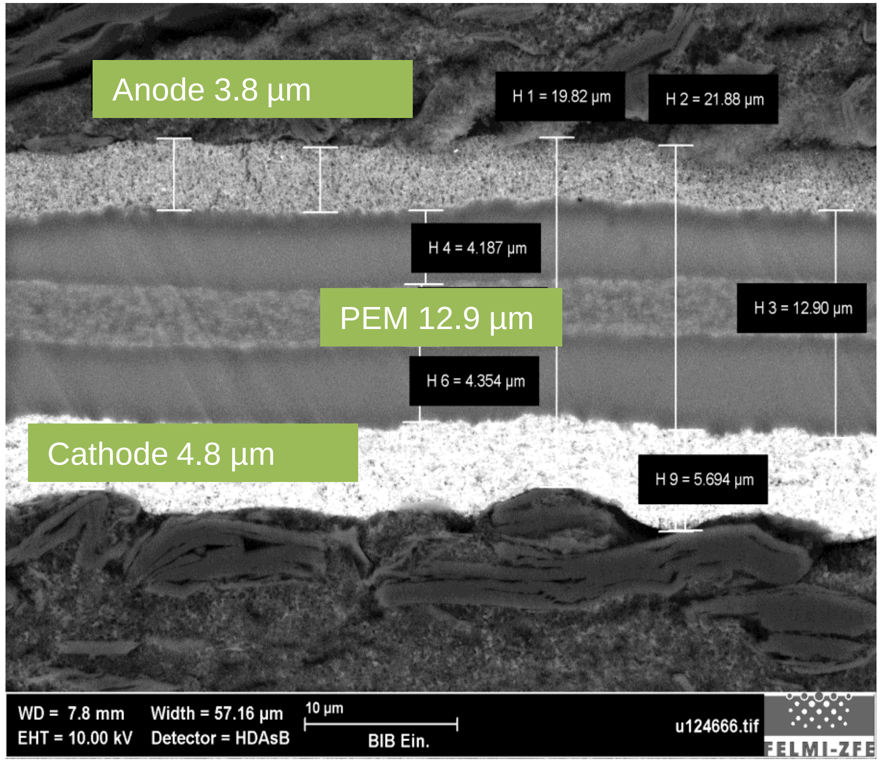


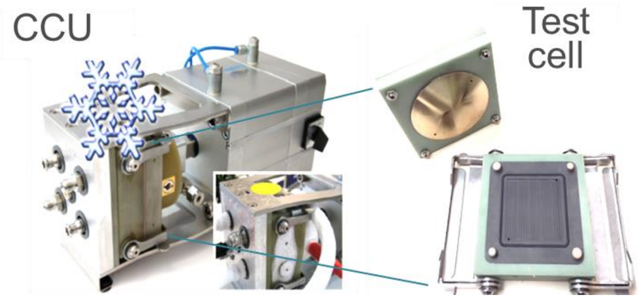
Fuel cell durability during cold start

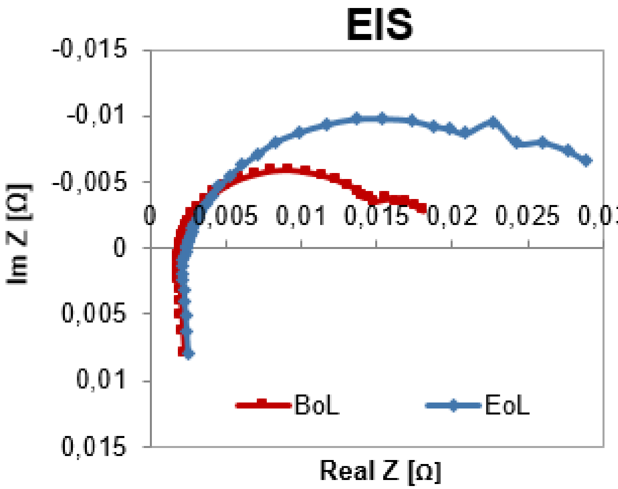
Reference MEA



Aged MEA







Membrane electrode assembly after 45 freeze/thaw cycles with different purge and current density variations.

Kocher et al., 2021

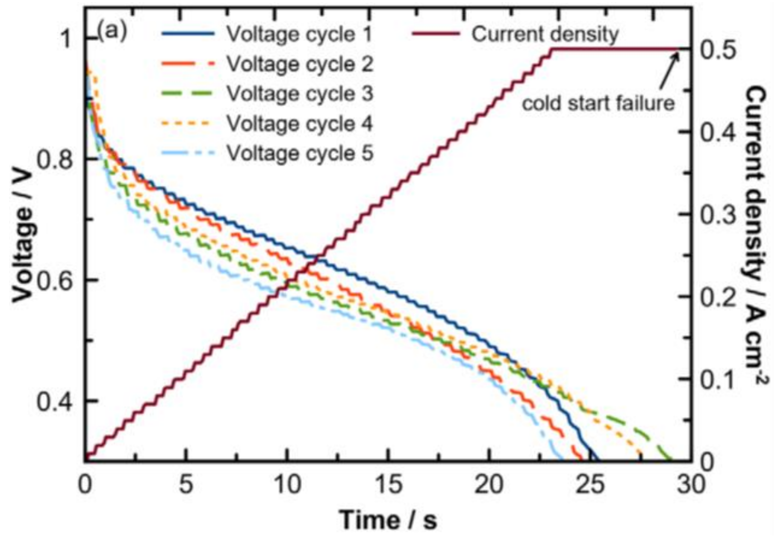
Fuel cell durability during cold start

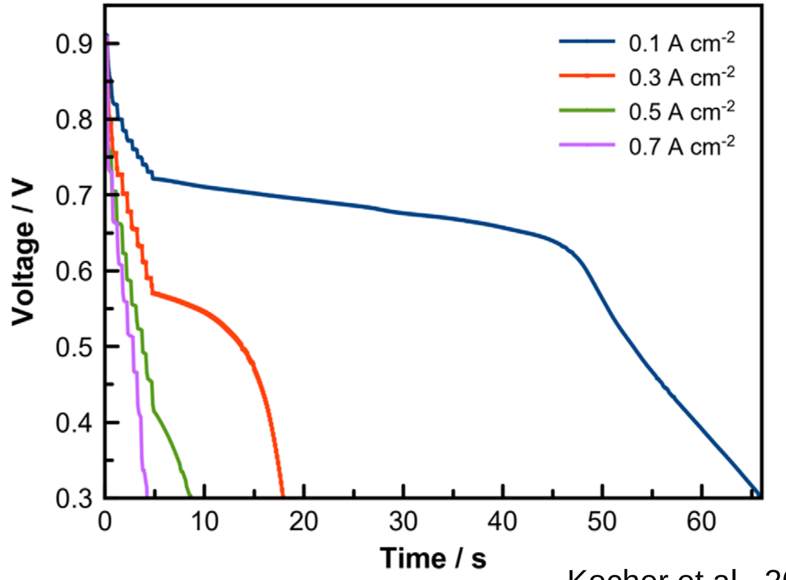
Analyzed Operating Parameters

- Current ramping
- Dry gas purge (prior to cold start)
- Start-up current density

Membrane Degradation

- **Reactant starvation** due to ice formation in CL and GDL
- **Mechanical degradation** due to stress and strain by alternating temperatures and humidification



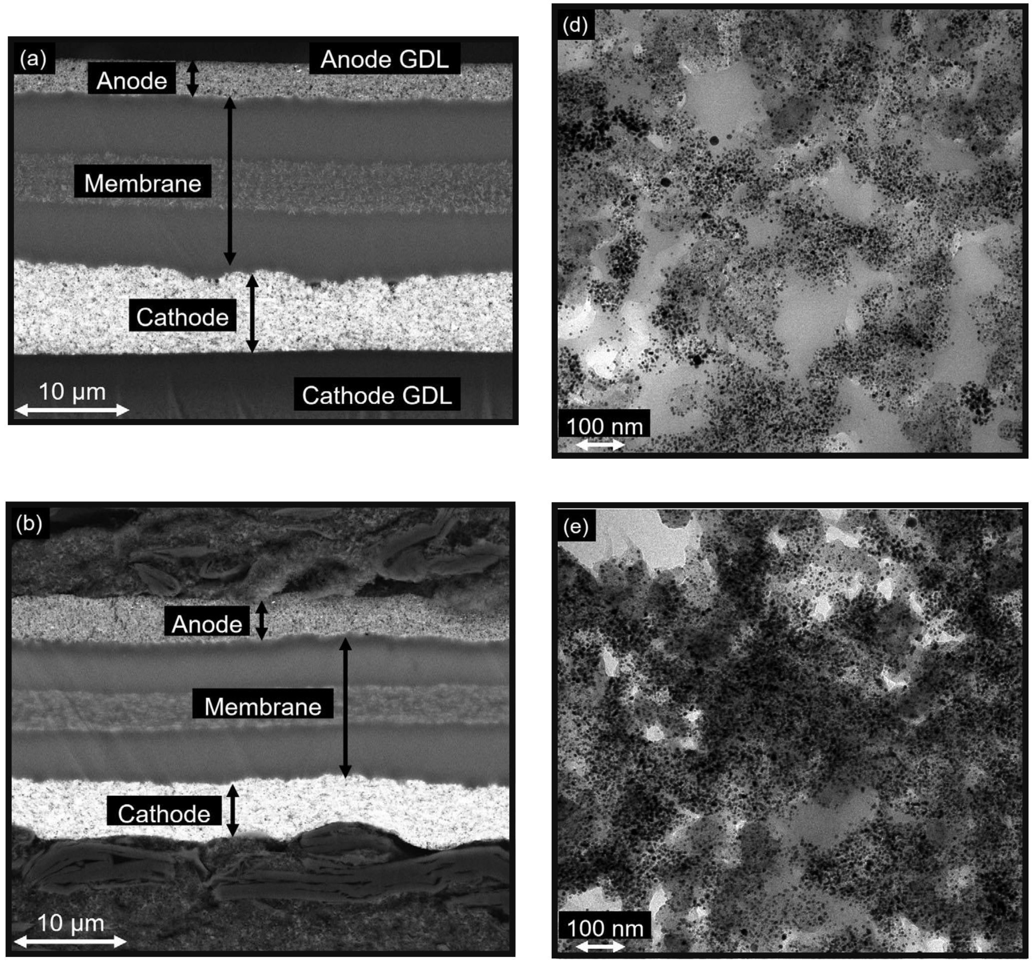


Kocher et al., 2021

Fuel cell protection during cold start

Effects - reversible & irreversible degradation
- Pt – dissolution / Pt – agglomeration
- *Membrane degradation*

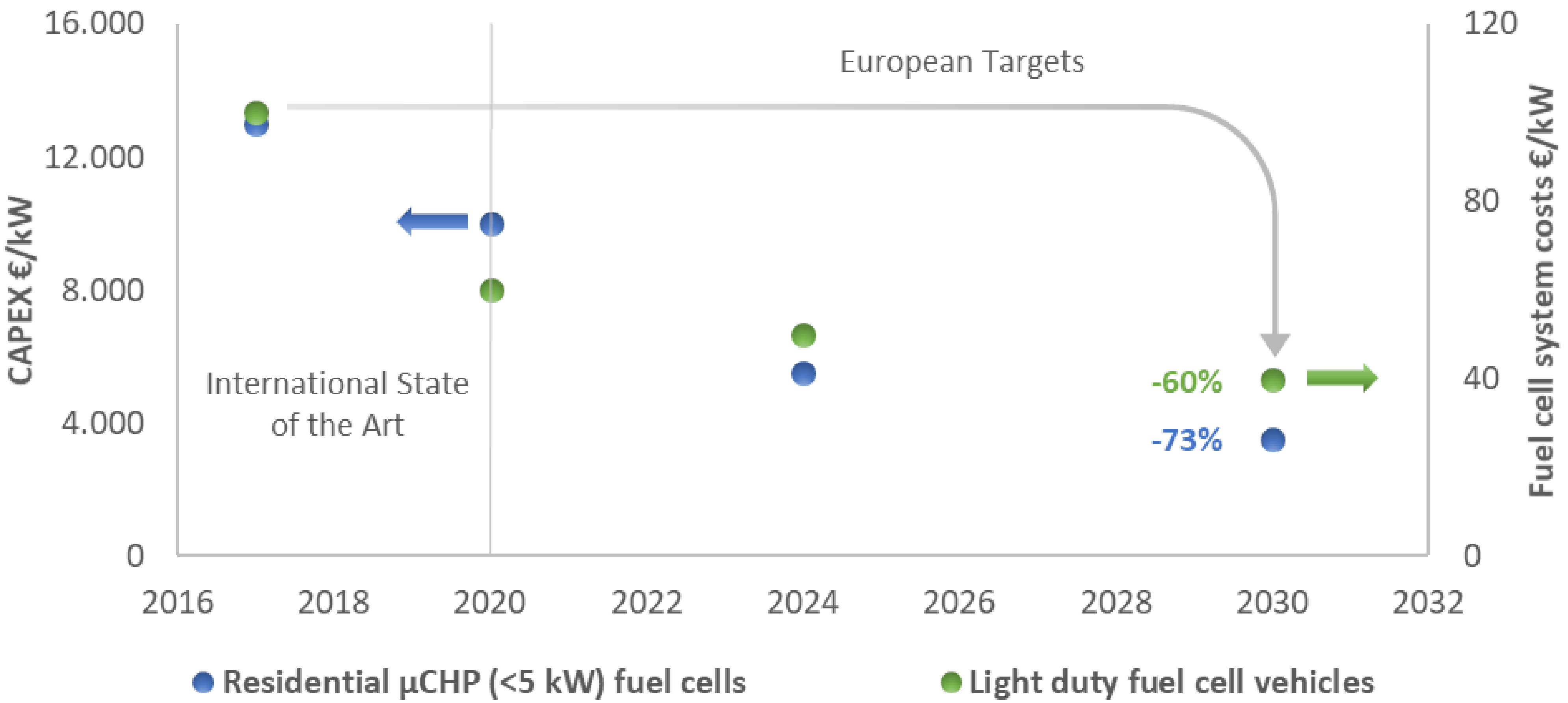
Operating Strategies
- Gradual current increase
  - Reduced water production
  - Increased water soaking and distribution time
- Dry purge
  - Controlled cell humidity
  - Reduced water in cell and CL
- Low current density
  - Lower water production
  - Better water distribution



Kocher et al., 2021

Fuel Cell Cost and Production Maturity

Fuel Cell Costs



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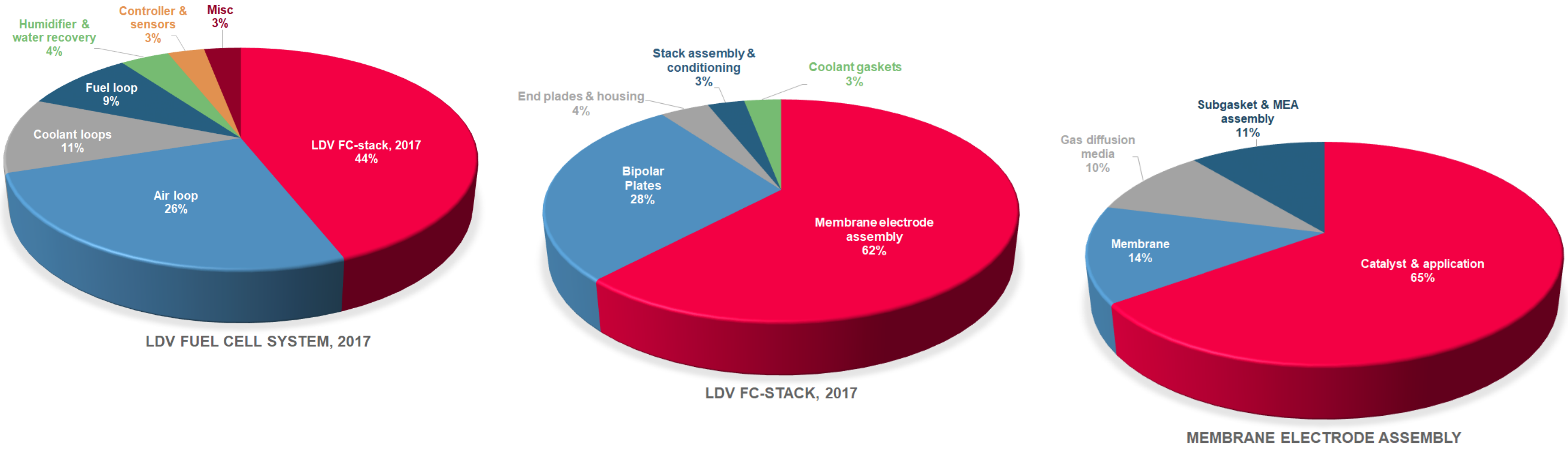
Fuel Cell Costs



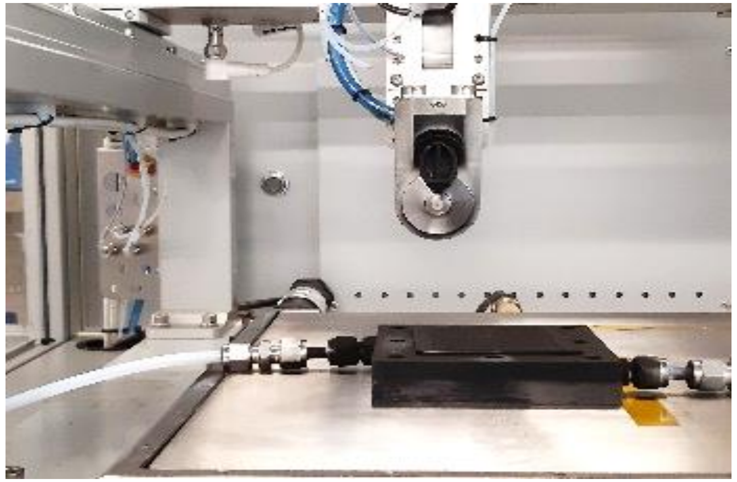
Predicted price for 2025: 43 $/kW (100k sys/yr) and 36 $/kW (500k sys/yr)

Ultimate target: 30 $/kW

Adapted from:
DOE Hydrogen and Fuel Cells Program Record, 2017
Thompson et al., J. of Power Sources, 2017

Technical challenges in reducing electrode costs

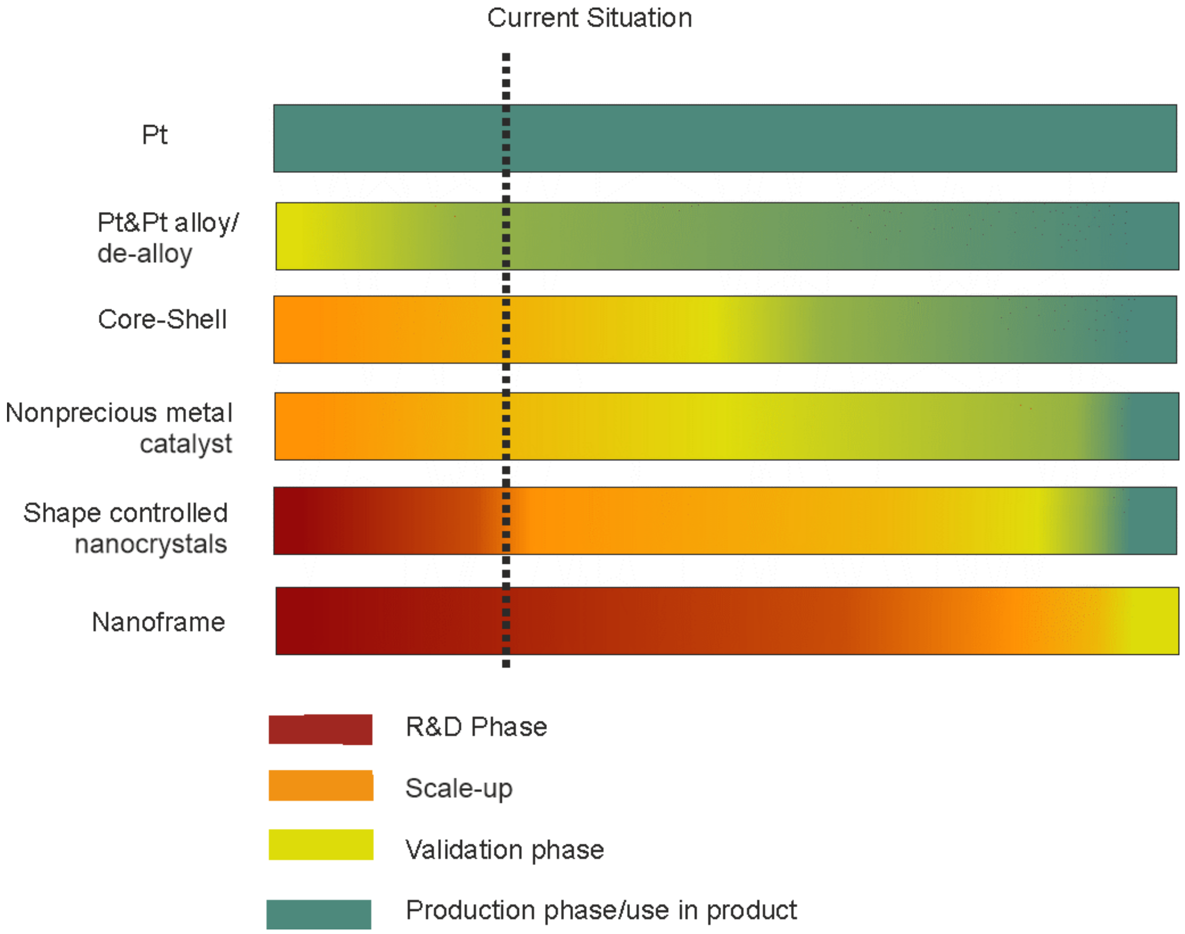
- Platinum price will rise with increasing demand
- Assessment of possible effects of alloying (non-Pt) metals to other components and mitigation strategies
- Optimisation of active layer is cost and time intensive



[1] Yoshida, T. et al., Electrochem. Soc. Interface (2015), 24 (2), 45–49.
[2] Papadias D. D et al.,. *J. Electrochem. Soc*. (2018) 165 (6), F3166–F3177.
[3] Ahluwalia R. K, et al., *J. Electrochem. Soc*. (2018) 165 (6), 3316–3327.
[4] Bodner M., et al., *Int. J. Hydrogen Energy (2019)* 44 (25), 12793–12801
[5] Kongkanand A., *J. Phys. Chem. Lett. (2017)*, 7 (7), 1127–1137

Status of electrocatalyst development

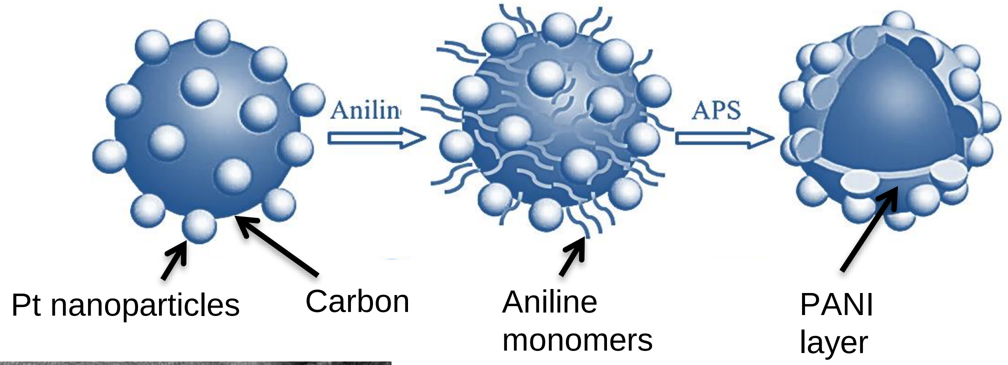
- Reduction of Pt-content in the metal particles of the catalyst
- For Pt-alloy / de-alloy and core-shell it is crucial to stabilize the less noble metal at operational conditions
- Shape Controlled Nanocrystals and Nanoframe catalysts are far away from application

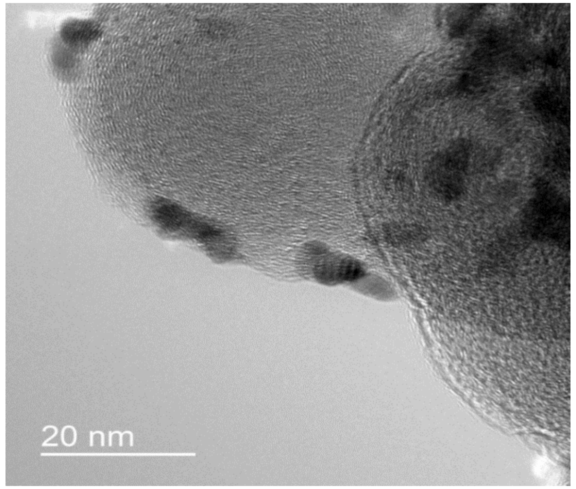


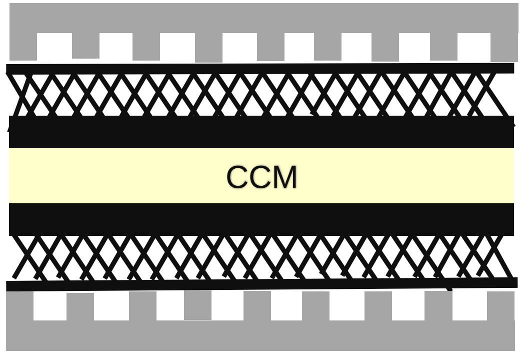
Adapted from:
Banham, D. and Ye, S., ACS Energy Lett. (2017), 2 (3), 629–638

Development of new electrode materials

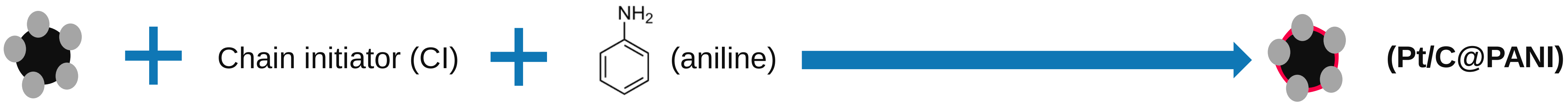
- Development of a polyaniline-coated carbon substrate for increased lifetime
- Mechanically produced MEA
- Increase in catalyst activity and lifetime (RDE)
- Implementation of ex-situ results (RDE) in fuel cells



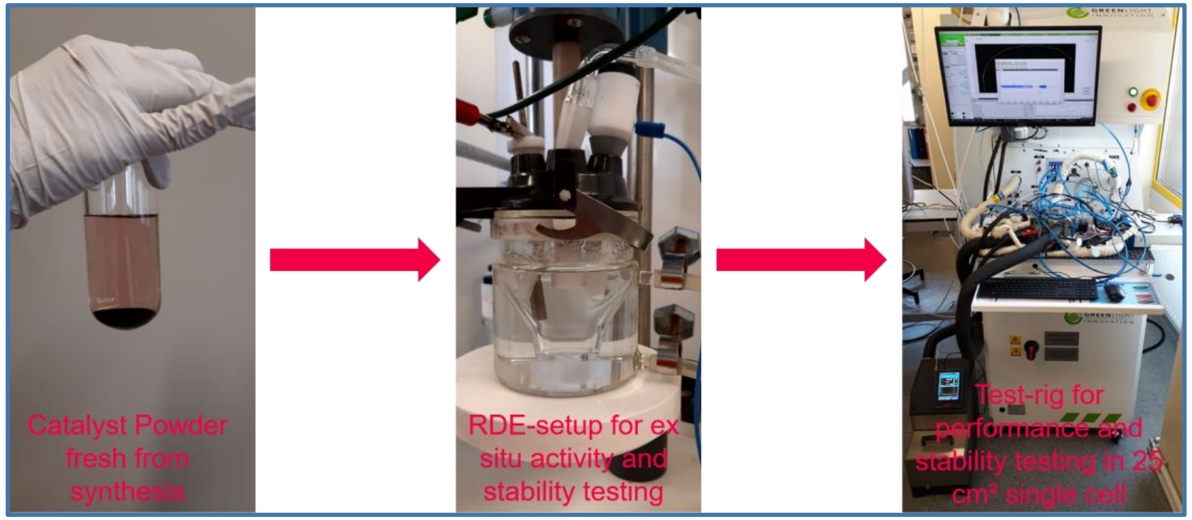




Synthesis and characterization of polyaniline coated carbon toward highly durable PEMFC catalysts

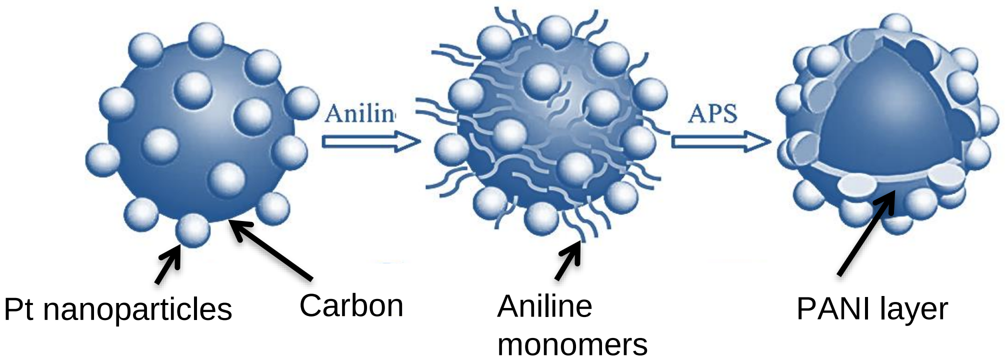


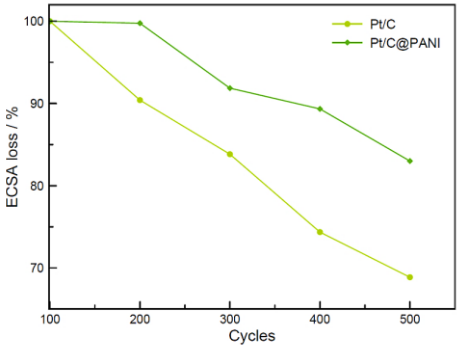
- Wet chemical polymerization of aniline
- Direct use of finished catalysts or coating of carbon followed by platinum deposition
- Ex-situ characterization on RDE and in-situ characterization in 25 cm² single cell
- Durability of the catalyst increased by protecting the carbon

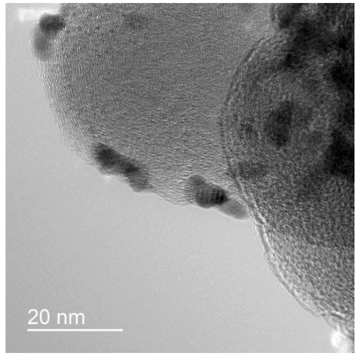


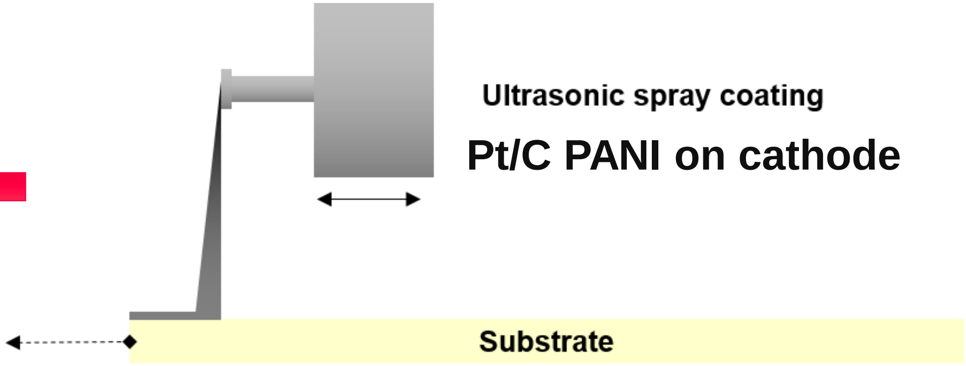
K. Kocher, C. Bender and V. Hacker, *EP3667785A1*
M. Grandi, B. Marius and V. Hacker, *DocDays Graz*, Austria 2021

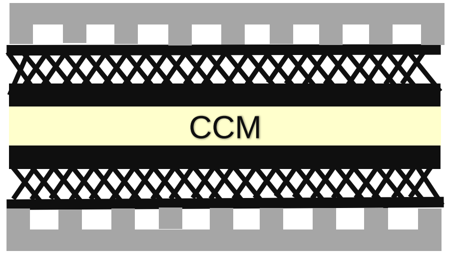
Polyaniline coated carbon support for longer life-time



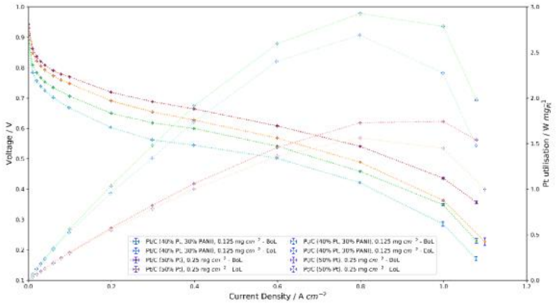






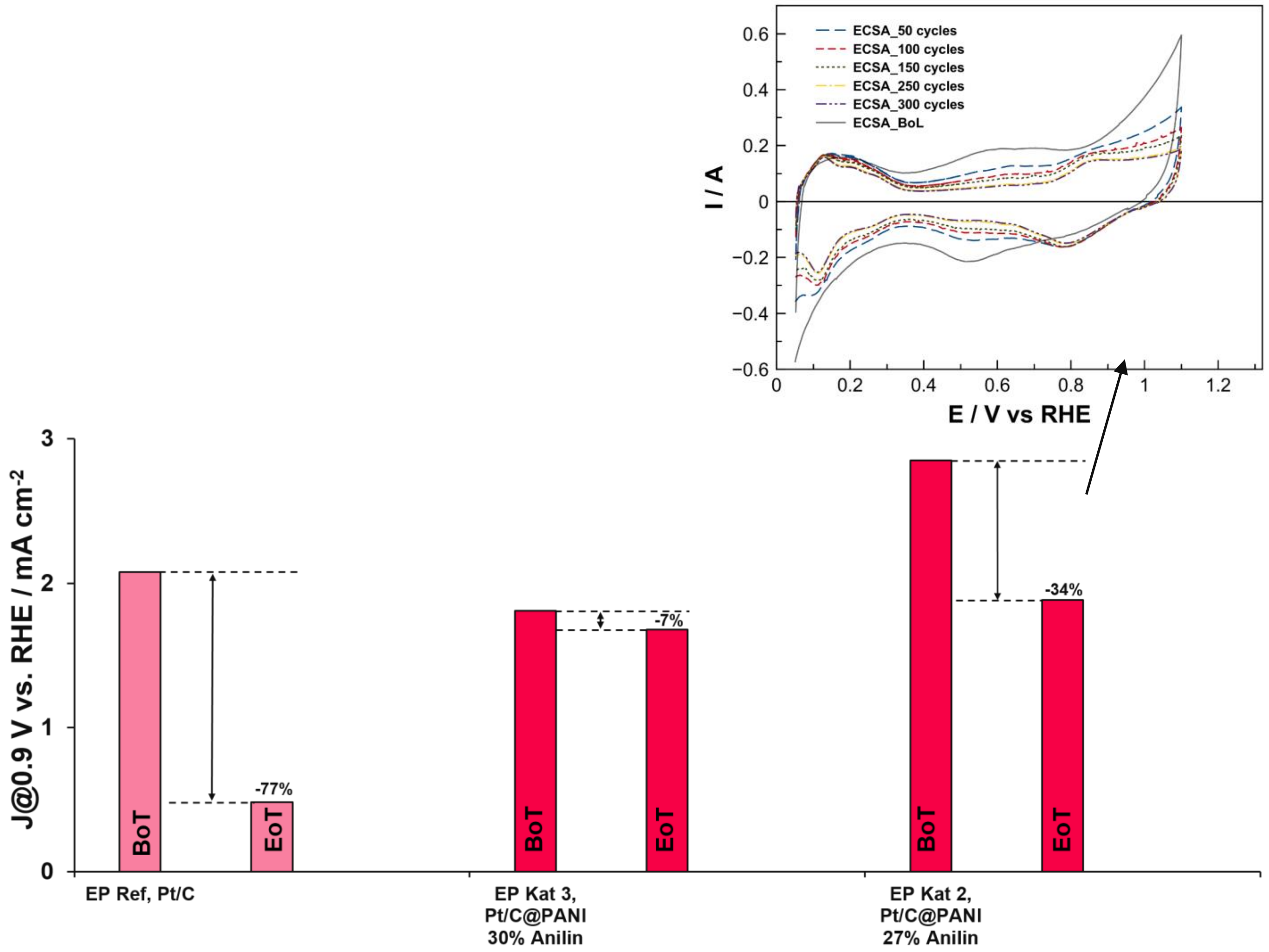


Accelerated Stress Test



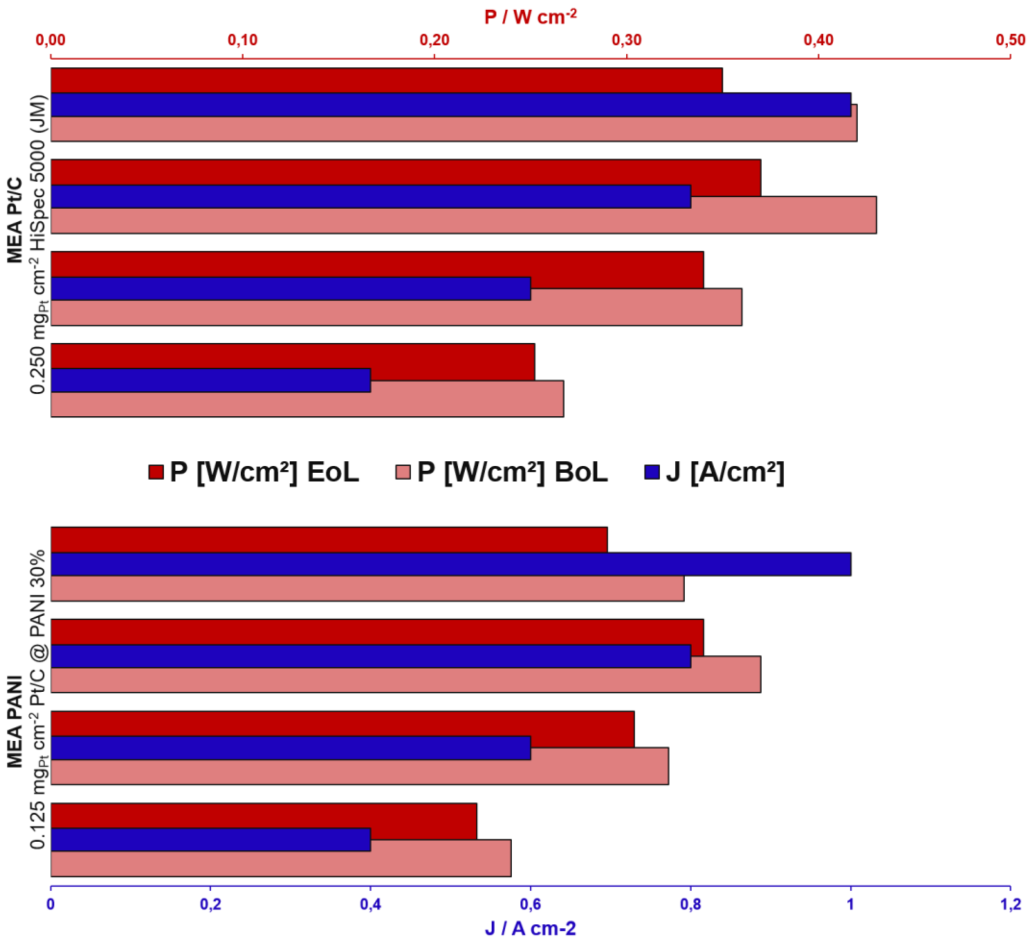
Ex-situ accelerated stress testing on the RDE

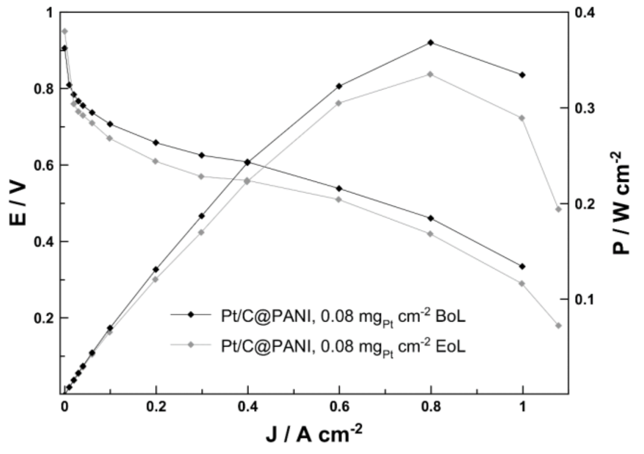
- ORR measurements before and after cycling 300 times between 0.05 and 1.2 V vs RHE at 50 mV sec^{-1}
- Measurement of ECSA (0.05-1.1 V) every 50 cycles and ORR measurement before and after AST
- Comparison with commercial Pt/C catalyst HiSpec 4000 (JM)
- Highest stability achieved with 30% aniline with slight activity decrease
- Highest activity achieved with 27% aniline with still considerable stability increase

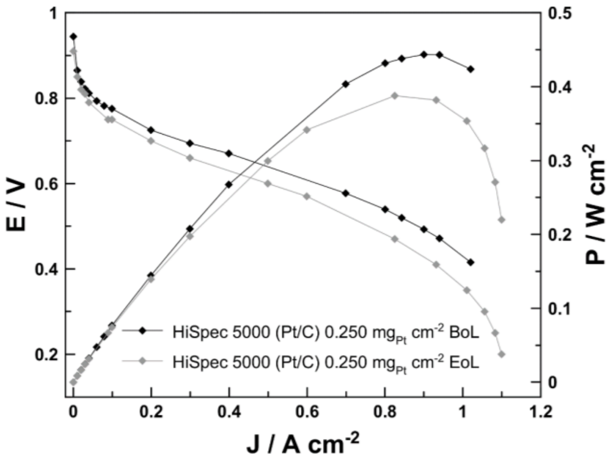


M. Grandi, B. Marius and V. Hacker, *DocDays Graz*, Austria 2021

In-situ accelerated stress testing of Pt/C@PANI catalyzed MEA





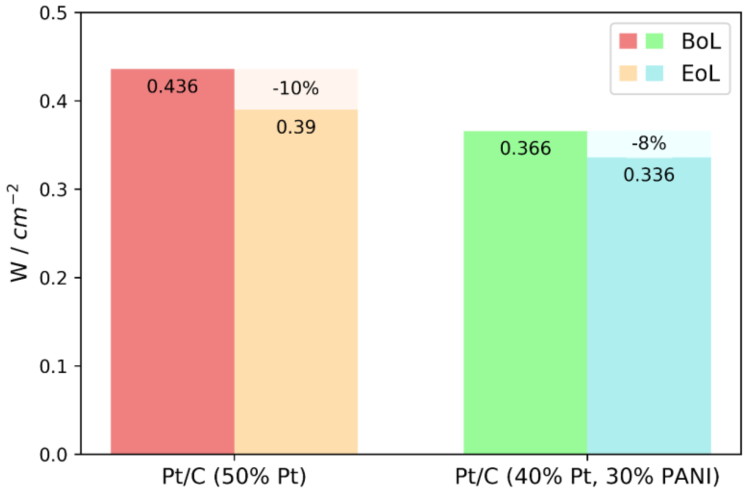


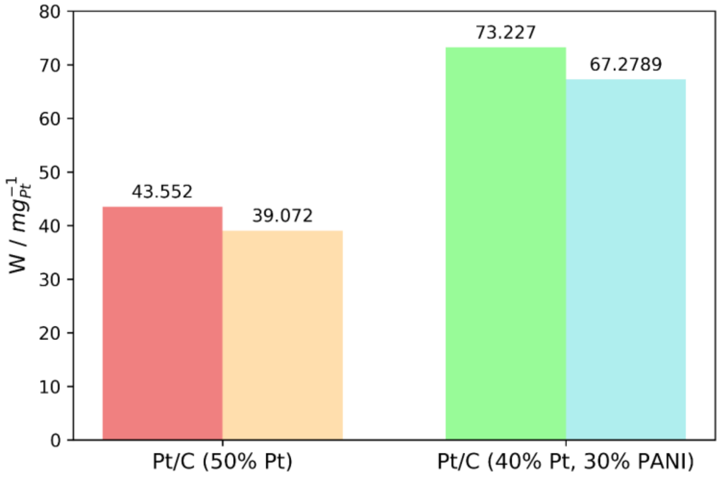
- 4 to 6 % less power loss after AST with PANI modified catalyst.
- AST Protocol: Catalyst degradation cycle of the U.S. DOE [2]

[1] M. Grandi, B. Marius and V. Hacker, *DocDays Graz*, Austria 2021
[2] https://www.energy.gov/sites/default/files/2017/05/f34/fcto_myrdd_fuel_cells.pdf

Polyaniline coated carbon support for longer life-time

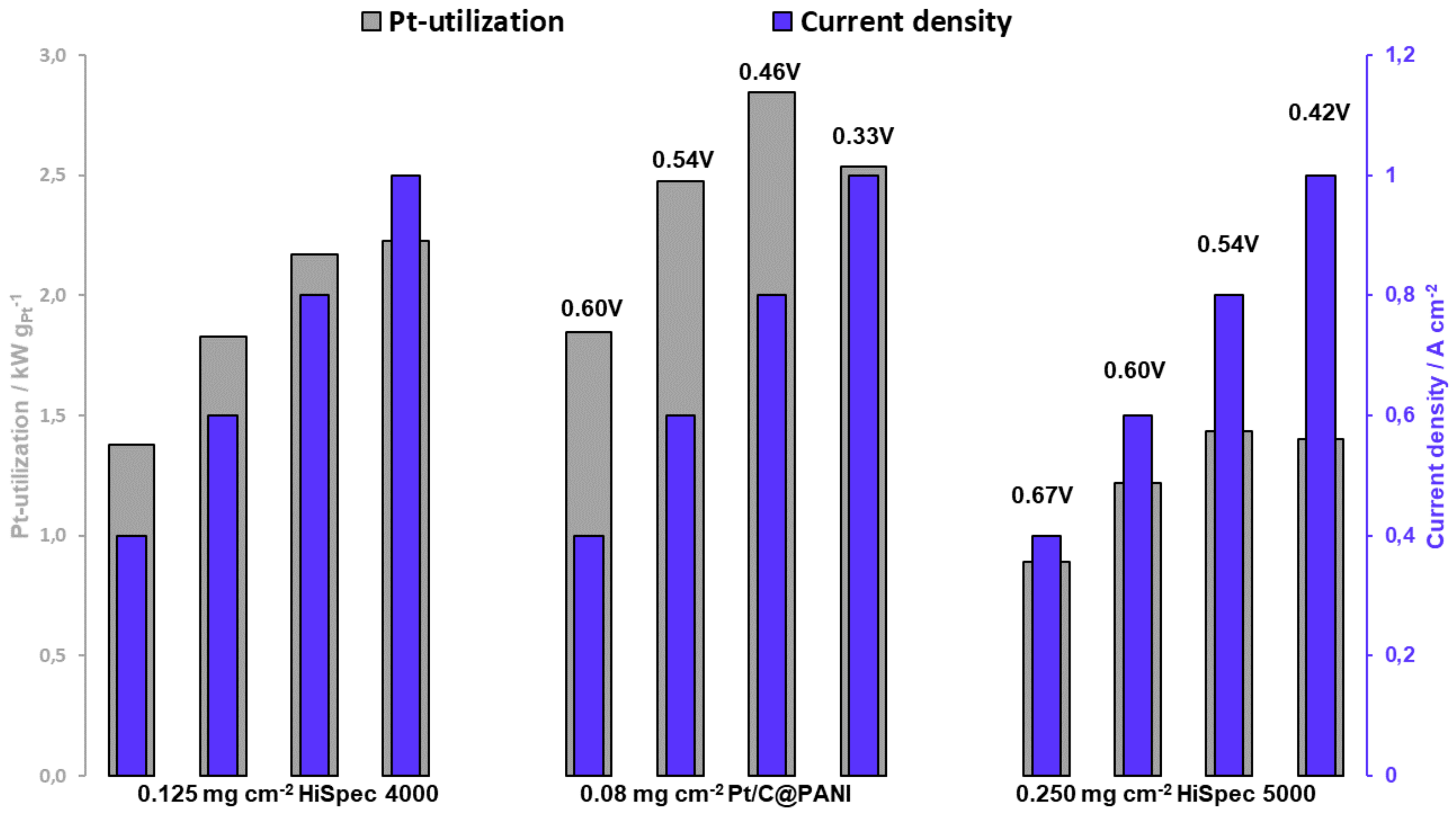
- **Pt/C-PANI** had an overall **performance loss of 8%**
- **Pt/C** reference had an overall **performance loss of 10%**
- Further reduction of loss is expected by use of Pt/C-PANI on the anode
- MEA with PANI coating yields higher Pt-utilisation





Higher Pt – utilization in the MEA by use of PANI coated carbon supports

- Increased platinum utilization of Pt/C @ PANI catalyzed MEA
- Can lead to considerable material cost reduction
- At 0.6 V: 1.4 vs 1.7 vs 1.2 kW g^{-1} for HiSpec 4000 (JM), Pt/C @PANI and HiSPec 5000 (JM) respectively



M. Grandi, B. Marius and V. Hacker, *DocDays Graz*, Austria 2021

Conclusions

- Durability challenges and targets are depending on the application
- The severity of critical events such as cold start can be reduced by choosing the adequate strategy

- Many of the costs are linked to catalyst and manufacturing
- Entirely new catalyst concepts are for the most part at early stages
- New, innovative treatment methods promise faster implementation and
  - Increase the durability by 4-6% (and potentially up to 70%)
  - Improve the catalyst utilization by 30%

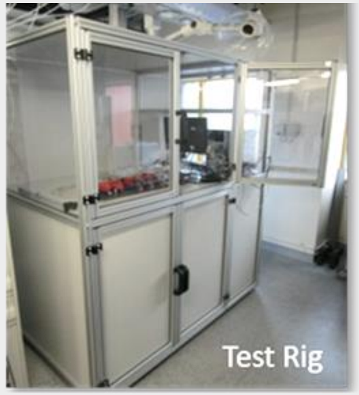
HyTechonomy - Hydrogen Technologies for Sustainable Economies

Problem and Research need

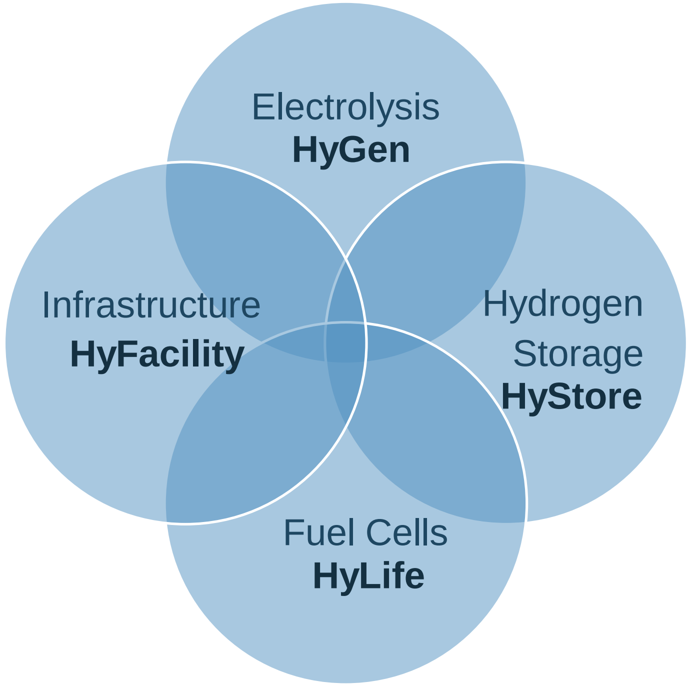
- Validation of degradation in PEMWEs (HyGen)
- Research of hydrogen storage systems and identify optimisation potentials by sector coupling (HyStore)
- Advanced characterization of fuel cell degradation mechanisms (HyLife)
- Optimisation of multi- parameter systems from research up to real operation (HyFacility)

Goals

- Technological innovations of PEM electrolysis regarding cell, stack & system level (HyGen)
- Identification of appropriate materials and alloys for hydrogen storage (HyStore)
- Analysis and definition of degradation processes in PEM fuel cells (HyLife)
- Systematic optimisation of systems technology and individual components (HyFacility)



Key Technologies – Subprojects



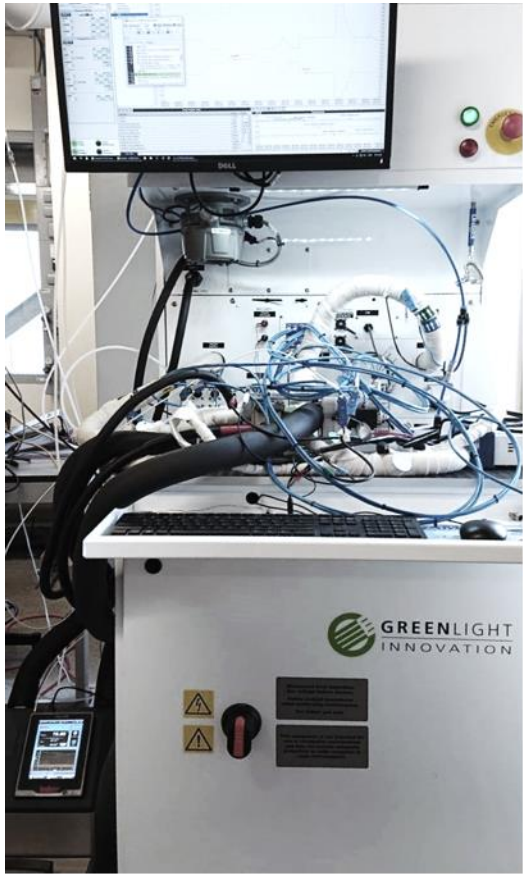
PROTECT - Performance Recovery Strategy & Advanced Control for Efficient Fuel Cell Operation

Highlights:

- Advanced fuel cell control & characterization
- Long-term testing with fully automated, industrial PEM fuel cell test station
- Suitable for strategy simulation of PEM-FCs in automotive applications

Research and development:

- Control strategies for efficient PEM-FC operation
- Validation of PEM-FC cold start behavior due to various operation parameters
- Advanced electrochemical characterization techniques



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