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Development of Pt-free catalysts for polymer electrolyte membrane fuel cells

PhD Marek Mooste

Research Fellow

Tartu Hydrogen Days 2025

October 9–10 | Physicum & Chemicum

10.10.2025 Tartu

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Introduction

About the presenter:

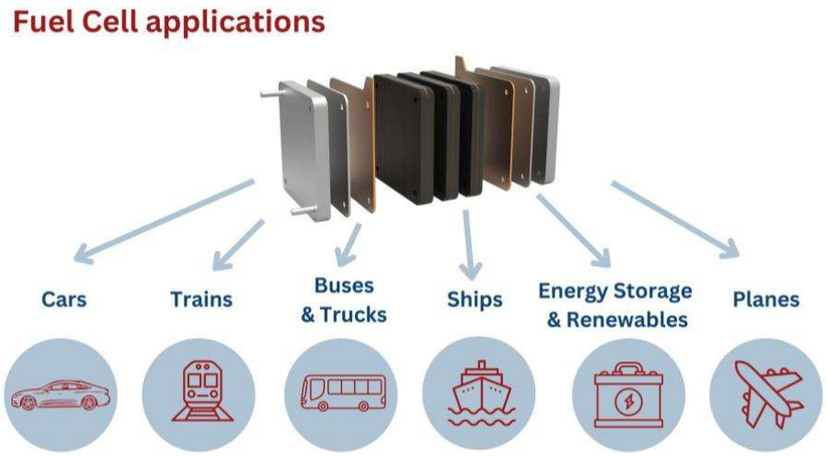
2019 University of Tartu, Ph.D. in Chemistry

2019–... University of Tartu, Faculty of Science and Technology, Institute of Chemistry
Research Fellow (1.00)

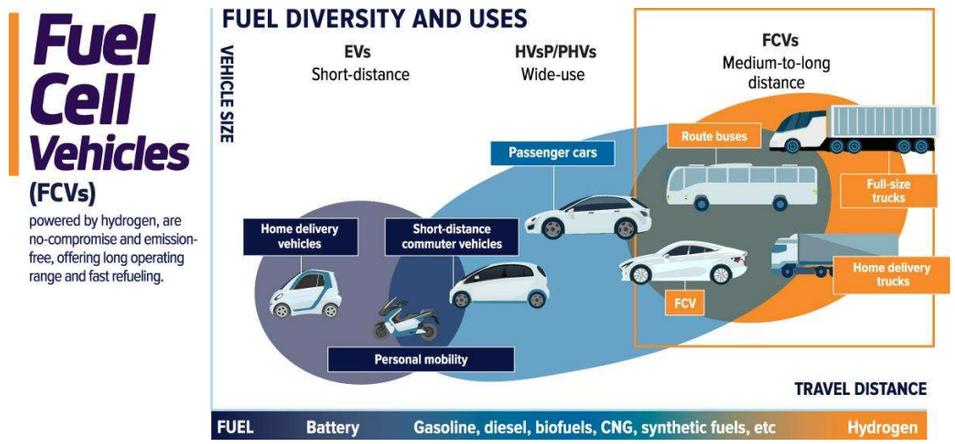
2022–2025 DLR Institute of Engineering Thermodynamics, Oldenburg, Germany
Guest Researcher (1.00)

Main research focus:

Development of Pt-free catalysts for polymer electrolyte membrane fuel cells



https://www.innovationnewsnetwork.com/graphite-hydrogen-fuel-cell-technologies/26736/



https://www.gasnet.com.br/conteudo/2588/FUEL-CELLS-From-promise-to-performance

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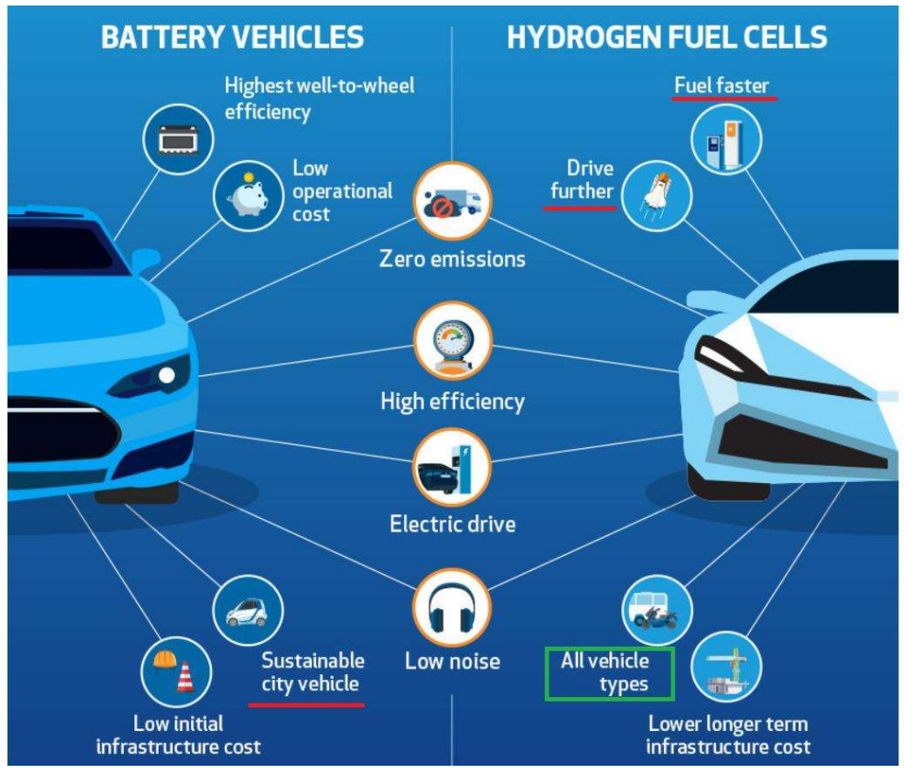
Polymer electrolyte membrane fuel cells
(PEMFC)

Relationship between the European Green Deal, green hydrogen, and fuel cells?

Fuel Cell Type	Common Electrolyte	Operating Temperature	Typical Stack Size	Advantages	Challenges
Polymer electrolyte membrane (PEM)	Perfluorosulfonic acid	<120°C	<1 kW–100 kW	Solid electrolyte reduces corrosion and electrolyte management problems Low temperature Quick start-up and load following	Expensive catalysts Sensitive to fuel impurities

Comparison of Fuel Cell Technologies

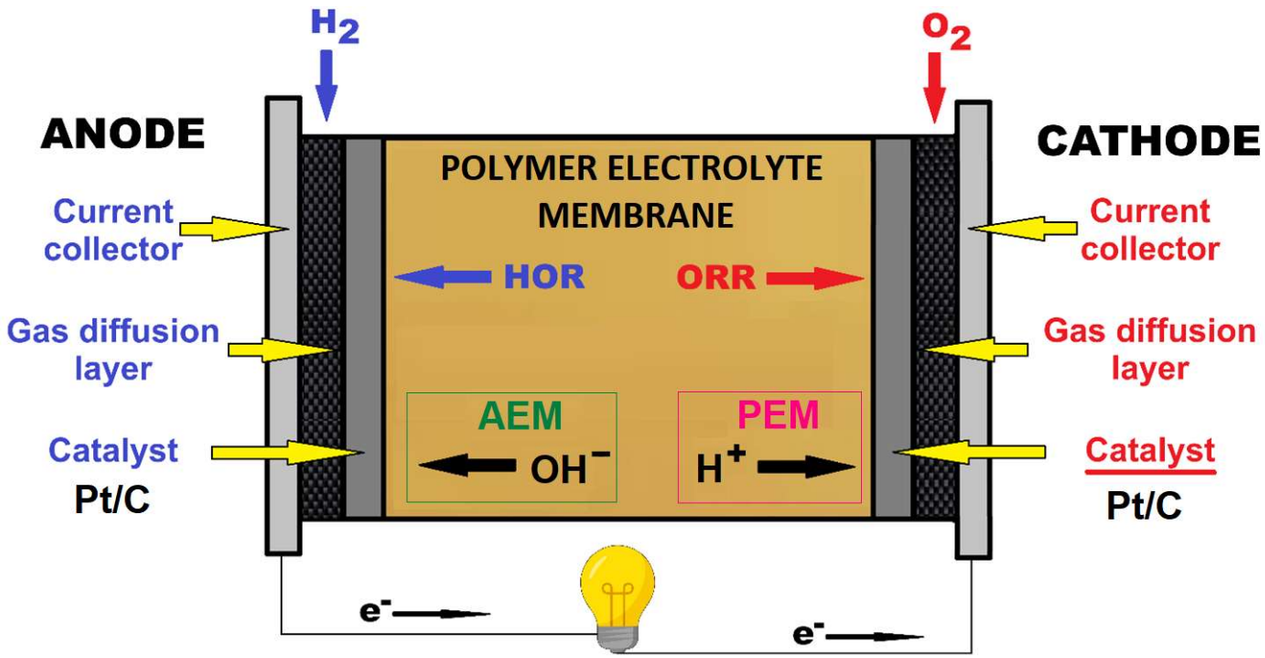
U.S. DEPARTMENT of ENERGY



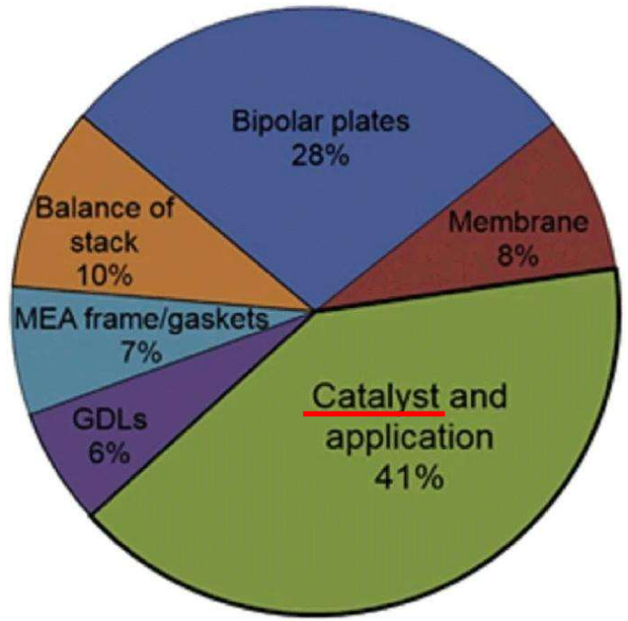
EV and FCV comparison

https://www.visualcapitalist.com/6-ways-hydrogen-and-fuel-cells-can-help-transition-to-clean-energy/

Polymer electrolyte membrane fuel cells
(PEMFC)



Scheme of a PEMFC with:
a) anion exchange membrane (AEM)
b) proton-exchange membrane (PEM)



Component cost breakdown at a production volume of 500,000 units/yr for the FC stack
https://doi.org/10.1007/s40243-019-0156-x

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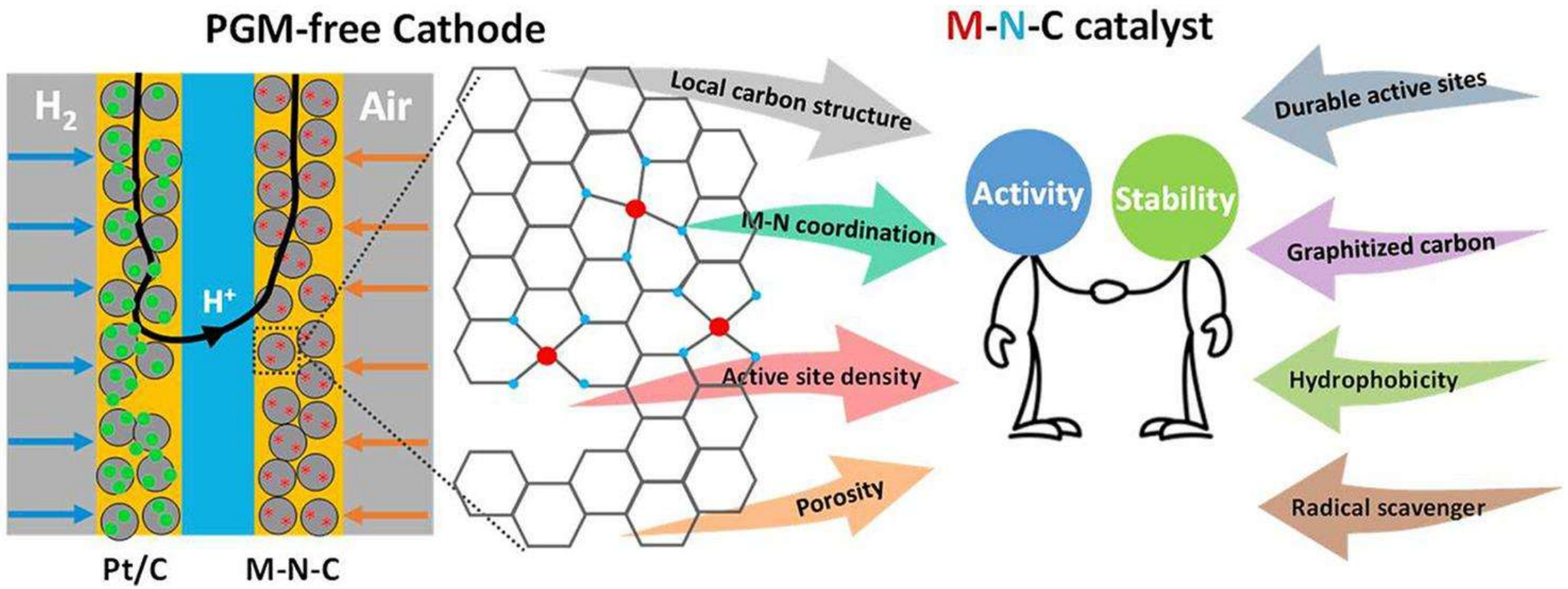
Pt-free catalysts for PEMFC

ACS MATERIAL®
Advanced Chemicals Supplier

60% Platinum on Carbon Catalyst (60% Pt/C)
$1,170.00 Package 5g



(Platinum Group Metal) PGM-Free Oxygen-Reduction Catalyst Development for PEMFC
https://doi.org/10.1021/accountsmr.1c00226

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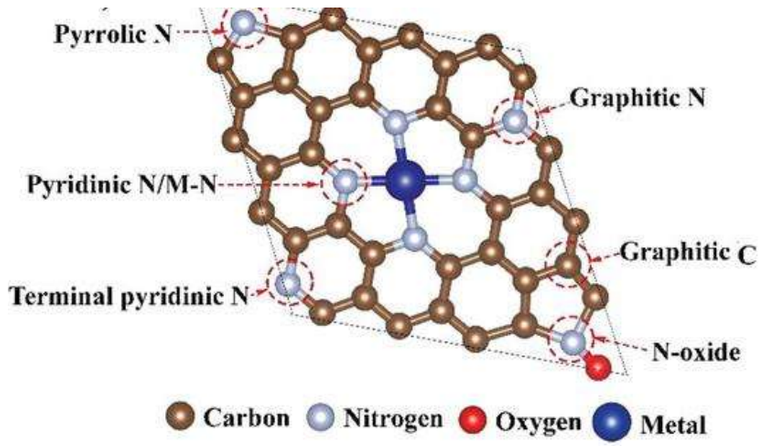
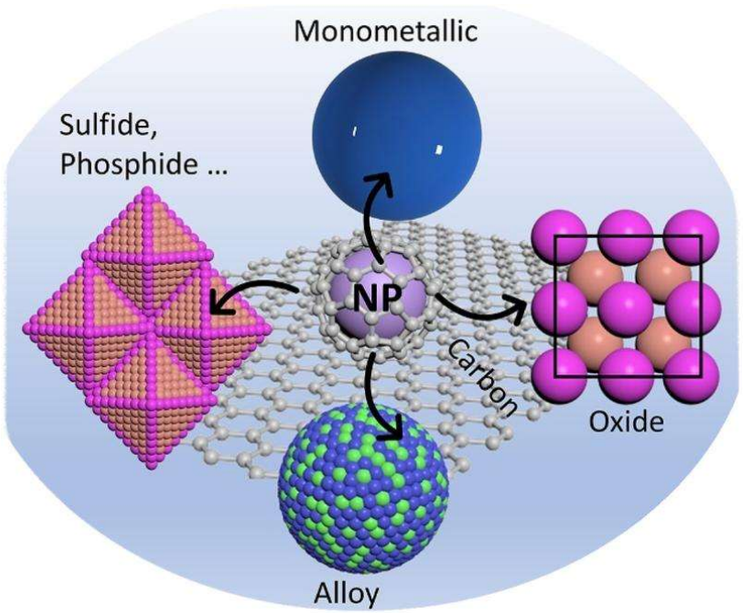
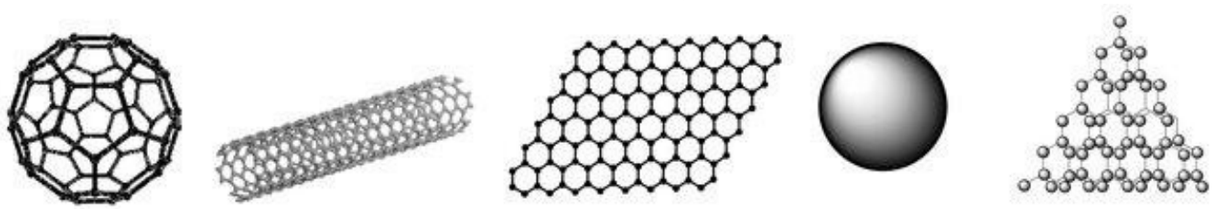
M-N-C catalysts for PEMFC

1) Active sites for oxygen reduction reaction (ORR)





2) Nanocarbon material to host (maximum amount of) active sites



DOI: 10.1002/aenm.201803689 DOI: 10.1002/eom2.12067 DOI: 10.7150/thno.4156

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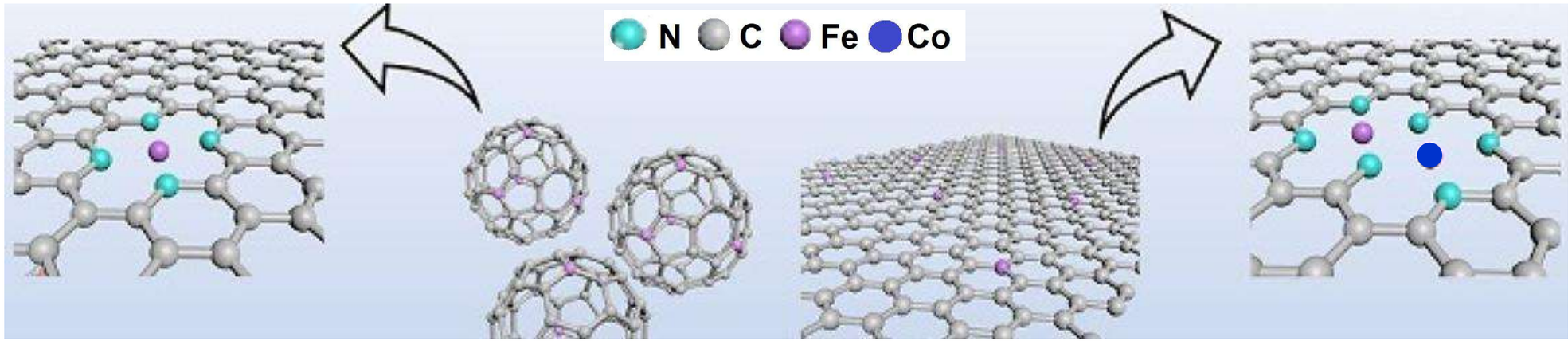
M-N-C catalysts for PEMFC

Dual metal M-N-C catalysts



- Dual-metal-atom catalysts, which have been proposed to be more efficient ORR catalysts than current benchmark Fe-N-C materials (**2 W cm^{-2} in AEMFC**).
- The co-existence of **Fe-Nx** and another **TM-Nx** in one catalyst has been recently proposed as a promising approach for the preparation of bifunctional catalyst materials that can meet the **requirement for industrial-scale production catalyst!**

DOI: 10.1002/adma.202102576 DOI: 10.1016/s1872-2067(20)63536-7 DOI: 10.1002/eom2.12067 DOI: 10.1038/s41560-021-00878-7

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M-N-C catalyst development

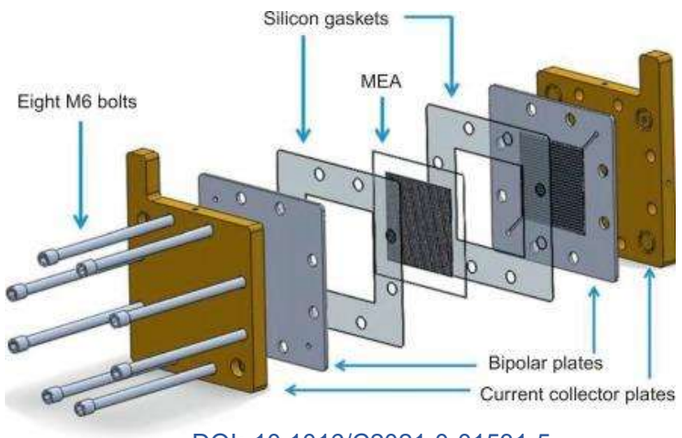
M-N-C catalyst development for AEMFC and HT-PEMFC

AEMFC benefits:

a) M-N-C show high activity towards ORR in alkaline conditions
b) **More affordable components** due to alkaline conditions

HT-PEMFC benefits:

a) **Lower purity hydrogen fuels** (e.g., hydrogen from methanol)
b) Simplified water management
c) Enhanced electrochemical kinetics
d) Efficient cooling due to high temperature (HT)



DOI: 10.1016/C2021-0-01531-5

A Greenlight Fuel Cell Test Station (G40 Fuel Cell System, Hydrogenics, Canada)

https://www.scribner.com/

Technology is already in use (incl. Estonia)

Example applications

Tallinn Opens First H_2 Station - Eesti Vesinikuühing

Estonia's First Public Hydrogen Refueling Station

By Ain Laidoja | 18.September 2025

Station Details: Green Hydrogen in Tallinn

Estonia's first public Hydrogen Refueling Station is located next to the Utilitas Vão combined heat and power plant and is operated by Alexela. Hydrogen refueling is now available in Estonia; previously, the closest option was in Riga (Latvia).

- Hydrogen: **Price: €14/kg**
- Hydrogen Type: **Green Hydrogen**
- Pressure: **350 bar**

A 700-bar station, intended for the broader consumer market, is expected to be completed at Peterburi tee 77 later this year. While 350-bar pressure is primarily used for refueling heavy-duty vehicles and buses, passenger cars generally require 700-bar pressure.

Hydrogen Refueling Station in Tallinn

You can now catch a hydrogen taxi on the streets of Tallinn.

The 2025 Mirai starts at $52,890

Toyota Mirai is a hydrogen fuel cell vehicle (FCV) based on PEMFC technology

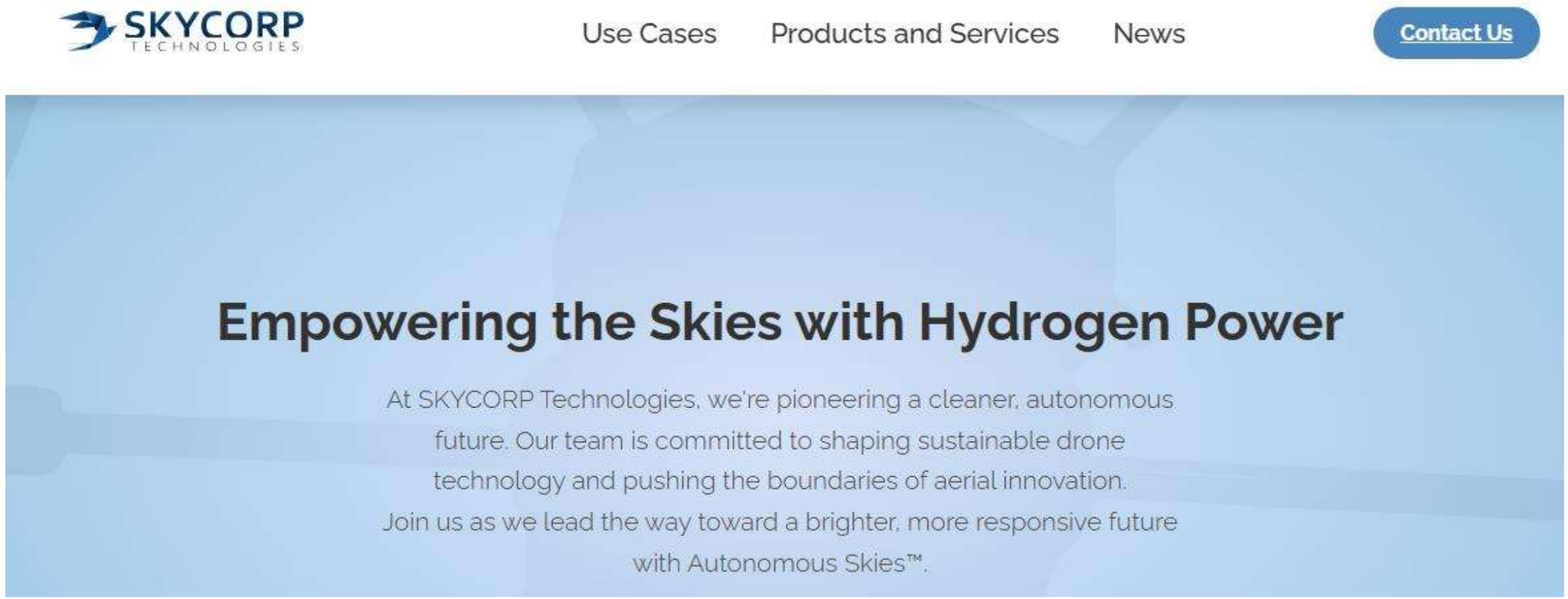
MODULE. STACK ASSEMBLY, FUEL CEL. **$ 33,802.89**

Part Number: 1A1H077010 ~~MSRP: $ 41,602.74~~

https://h2est.ee/en/estonias-first-public-hydrogen-refueling-station/

AEMFC with M-N-C?

PEMFC technology for drones



AEMFC with M-N-C?

https://www.skycorp.tech/

HT-PEMFC technology for aviation

Decarbonising flight

Dreams of powering the aviation industry towards net zero are closer to reality.

UNSW SYDNEY

The aviation sector accounts for around 5% of Australia's carbon dioxide emissions, but it is one of the most challenging sectors to decarbonise. And it's still growing.

While the industry considers improvements to engines and sustainable biofuels to reduce carbon emissions, the potential for hydrogen-powered aircraft has already been demonstrated through various prototypes since the 1950s.

Today, the industry has reignited hydrogen's potential, with Airbus planning to launch its first commercial hydrogen-powered aircraft by 2035. If they achieve this, and as the technology scales up, the aviation sector could potentially achieve net zero by 2050.

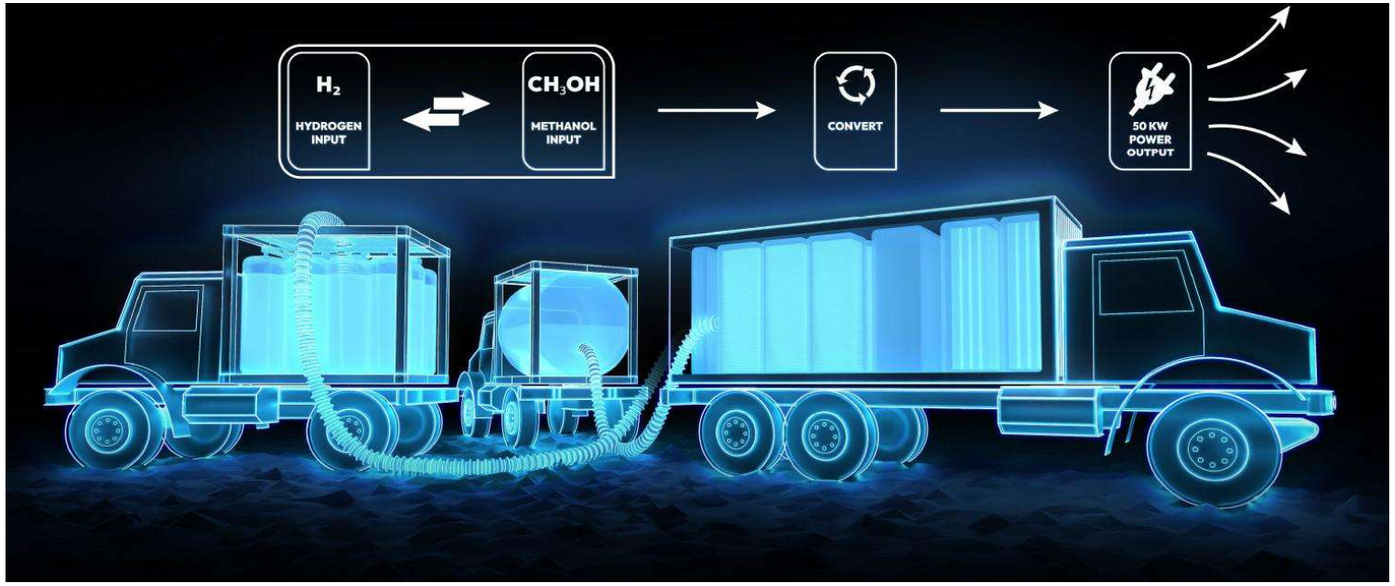
Dr Quentin Meyer from UNSW Sydney's School of Chemistry says hydrogen is "the ultimate clean energy source. This is because it produces no carbon emissions."

https://www.unsw.edu.au/science/about-us/creating-impact/decarbonising-flight

M-N-C?

PROJECT RESCUE

Securing Power Supply – Strengthening Resilience Against Natural Disasters.



Containerised **HT-PEMFC** system with a reliable 50 kW power output and dual-fuel capability for operation with methanol or hydrogen.

HORIZON JU Innovation Actions (Funding 5M €)

Advanced fuel cell system capable of operating on 100% hydrogen as well as methanol. Designed to deliver 50 kW of continuous electrical power and up to 100 kW peak power.

https://project-rescue.eu/

M-N-C?

CONSORTIUM

DLR Deutsches Zentrum für Luft- und Raumfahrt
German Aerospace Center

ADVENT

CERTH
CENTRE FOR RESEARCH & TECHNOLOGY HELLAS

DTU

PROACT

Technisches Hilfswerk

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Conclusions

- For European Green Deal policy and (green) hydrogen economy fuel cell development is needed
- PEMFC are attractive due to low operational temperature, easy start-up (FCVs)
- PEM-based PEMFC main shortcomings:
  - Efficient and affordable cathode catalyst for ORR (1)
  - Need for high purity H_2 (2)
  - Expensive materials due to the acidic environment (3)
- Development of Pt-free catalysts for polymer electrolyte membrane fuel cells
  - AEMFC:
    - M-N-C catalysts (Mn-N-C@CNT), maximum power density ≈ 1 W cm^{-2} (1)
    - Alkaline environment (3)
  - HT-PEMFC
    - M-N-C catalysts (CoFe-N-CNT/PDC), maximum power density ≈ 0.120 W cm^{-2} (1)
    - High tolerance to H_2 impurities (2)

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Aknowledgements

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METROSERT

TAL TECH VIRUMAA KOLLEDŽ

eis enterprise estonia

Universität Bremen

Advanced CERAMICS

DLR Deutsches Zentrum für Luft- und Raumfahrt German Aerospace Center

DAAD Deutscher Akademischer Austauschdienst German Academic Exchange Service

Estonian Research Council

THANK YOU FOR YOUR ATTENTION!

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