FUSION FUEL™

Redesigning PEM electrolysis: Introduction to the HEVO technology

Electrochemical White Paper | No.1

Hydrogen: The Most Wanted Molecule for the Energy Transition

Between 2020 and 2021, the International Energy Agency (IEA) saw a 5% increase in demand for hydrogen (91 Mt in 2020 to 94 Mt in 2021), mainly driven by refineries and chemical industries, which represent around 900 Mt of CO2 emissions. Hydrogen for mobility applications (40 kt in 2022), although a small portion of total hydrogen use today, saw a 60% increase in demand year on year which highlights the strong interest in the transition of propulsion systems for the mobility sector. The greatest consumers are China, the USA, followed by the Middle East, Europe and finally India. However, less than 1% of that hydrogen is considered "low emission" hydrogen, and a significant change to hydrogen production methods worldwide is imperative [1].

The Perfect Match: Renewable Energy and Hydrogen Production

Renewable energy can be stored in the form of hydrogen (chemical energy), the so-called green hydrogen. This hydrogen can be considered an energy carrier: it can be converted into useful forms of energy, can be redistributed, and even be converted back to electrical power using fuel cells, for example, without carbon dioxide emissions. The hydrogen wide application range includes process heat, power supply, cooling, heating, feedstock in fertilizer and gas processing industry, reducing agent and various industrial uses [2].

Knowing that the most abundant source of hydrogen is water, water splitting seems to be the logical choice to obtain hydrogen. Among many hydrogen production methods, eco-friendly and high purity hydrogen can be obtained from PEM water electrolysis processes, which is the base technology creating Fusion Fuel´s green hydrogen.

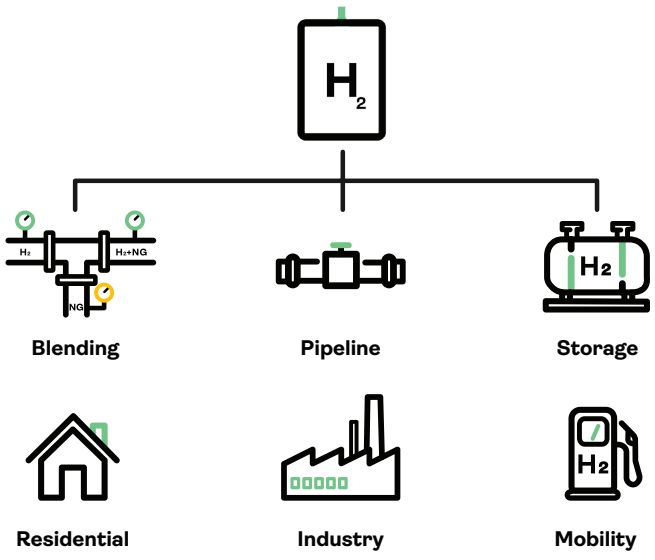

Figure 1 *– Application range of green hydrogen*

HEVO Technology: Fundamental Concept of HEVO Electrolyzer

Fusion Fuel went back to first principles, breaking with convention and taking a fundamentally different approach than the rest of the industry. Rather than focusing on ever larger electrolyzers, Fusion Fuel instead developed the concept of a miniaturized and decentralized design, which required completely rethinking the production methodology, materials, and form factor of the PEM electrolyzer. The name chosen for this miniaturized PEM water electrolyzer is HEVO and the technology has been in evolution since 2018 (Figure 2).

All the generations of HEVO are based on the following disruptive pillars:

- Designed to be made with inexpensive structural materials: injected-mold plastic and titanium stamping.
- Miniaturized and simplified engineering: targeting simpler and automated assembly and unlocking further cost reductions.
- Membrane Electrode Assembly innovative design requires less current for the same amount of power, optimizing electrical systems and enabling significant reductions.
- Proprietary electrochemical cell design: individual cells improve long-term performance by protecting against system wide degeneration.
- Modular approach: reduces O&M cost and downtime, as individual HEVOs can be easily serviced or replaced in-situ.
- Miniaturized design with higher performing individual electrochemical cells by decreasing mismatch losses.

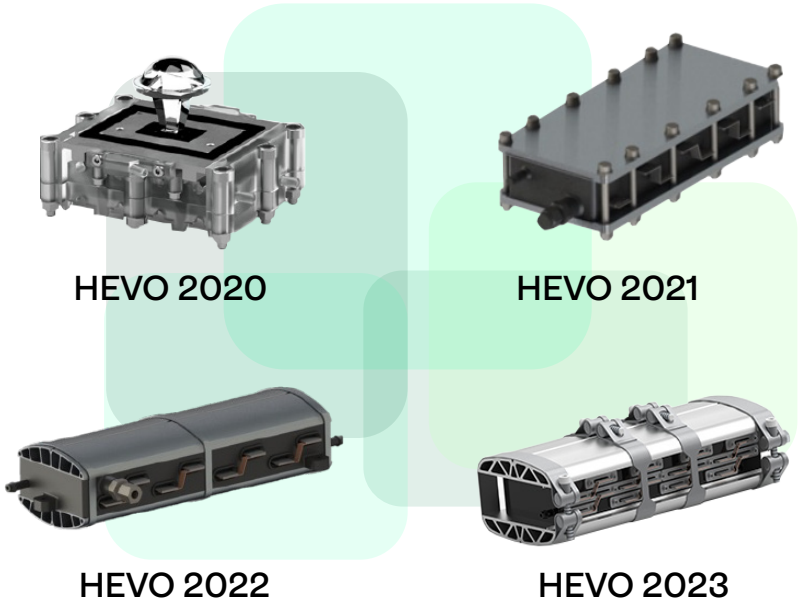

Figure 2 – *Evolution of Fusion Fuel HEVO technology*

Fusion Fuel: Redesign the Electrochemical Core

At the heart of our technology sits the electrolysis cell, which at Fusion Fuel, we designate as the Electrochemical Core (Figure 3). The sole purpose of the Electrochemical Core is to make accessible the production of green hydrogen at the best competitive cost and for the longest amount of time, without compromising efficiency.
The Electrochemical Core is a multi-material and multi-interfacial system, from which the key components are the i. the Membrane Electrode Assemblies (MEAs), ii. the Porous Transport Layers (PTLs), iii. the Flow-Fields and iv. The Current Collectors. All these components contribute to the production of green hydrogen in distinct ways:

- **MEA:** which is responsible for the water electrolysis process, evolving oxygen gas at the anode and hydrogen gas at the cathode. This occurs due to the presence of nano-scale particles of catalyst at both electrodes, combined with the proton conducting capability of the ionomer which impregnates the electrodes and the solid electrolyte membrane.

- **PTLs:** which maximize the water distribution on the electrode surface and gas evacuation, whilst maintaining electrical conductivity. Carbon or titanium-based solutions, with distinct morphologies and intricate networks, can be explored for both cathode and anode, respectively.

- **Flow-Fields:** which solely contribute to the water distribution and play an important role on the gas evacuation. Our innovative design allows these components to be made by injection molding, decreasing the weight of our electrolyzer and cost-competitiveness of our unique technology.

- **Current Collectors:** which conduct the electricity for the electrolysis process and in conjunction with the Flow-Fields, contribute to the water distribution and gas evacuation. Titanium based plates with low-cost unique design features and functional coatings accomplish these functions.

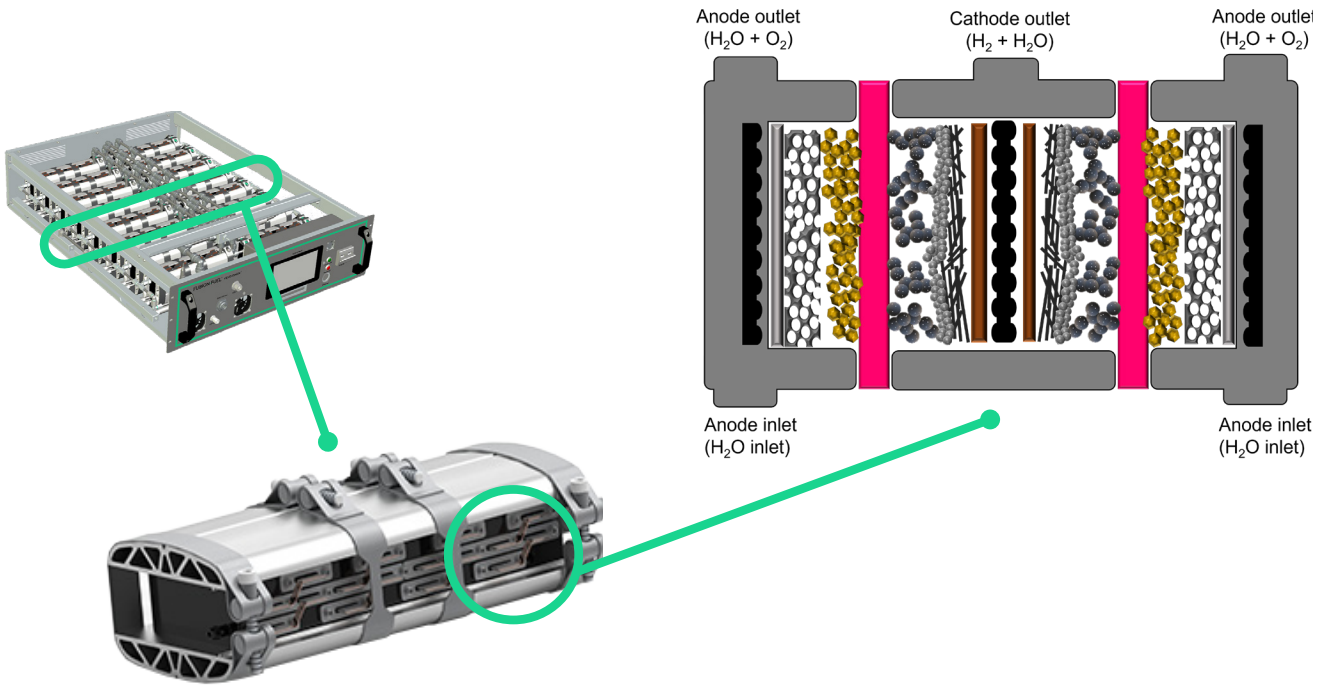

Figure 3 – *The Electrochemical Core of Fusion-Fuel technology*

Table 1 – *Key Performance Indicators (KPIs) or Technical Targets for PEM electrolysis stack*

		HEVO-Chain HU	Clean Hydrogen JU SRIA			DoE Technical Targets PEMEL		
Parameter	**Units**	**2023**	**2020**	**2024**	**2030**	**2022**	**2026**	**Ultimate Target**
Total PGM Content	mg/W	**0.51**	2.5	1.25	0.25	0.8	0.1	0.03
Degradation Rate	%/1000h	**0.24**	0.19	0.15	0.12	0.25	0.13	0.13
Lifetime	Hours	**80.000**	80.000	80.000	80.000	40.000	80.000	80.000

Fusion Fuel is a technology company developing our own HEVO electrolyzer, which may be incorporated in different solutions (Figure 4). We are constantly looking to innovate the standard concepts of hydrogen production through electrolysis, but also, motivated by the demanding technical targets or key performance indicators for PEM electrolysis (Table 1), which are published by institutional organizations as the Hydrogen and Fuel Cell Technologies Office of the Department of Energy (DoE) in the United States of America (USA) or the Clean Hydrogen Partnership in Europe.

These organizations support research and innovation activities in their own geographical regions, motivating the hydrogen industrials to push further to overcome the current technological challenges [3,4].

The innovations which Fusion Fuel integrates in the Electrochemical Core of our HEVO technology are already aligned with these demanding targets. We will address the three topics in which we have placed most of our effort, to distinguish Fusion Fuel from the current standards of technology: i. Total platinum group metals (PGM) content, ii. Degradation rate and iii. Lifetime.

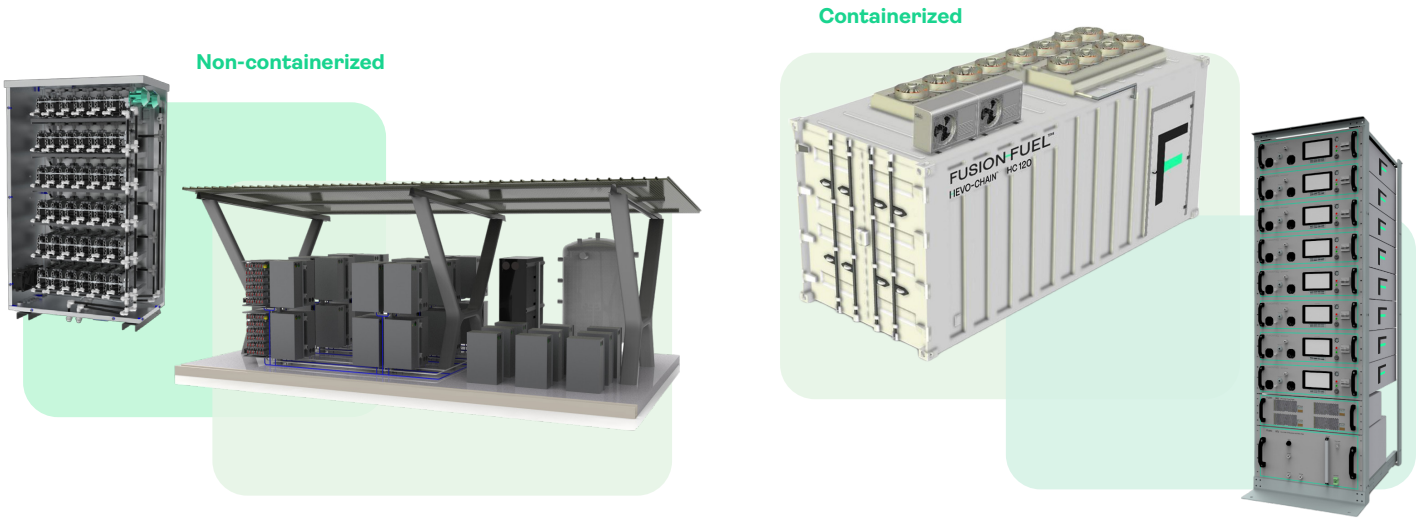

Figure 4 - *Fusion Fuel electrolyzer solutions with HEVO technology*

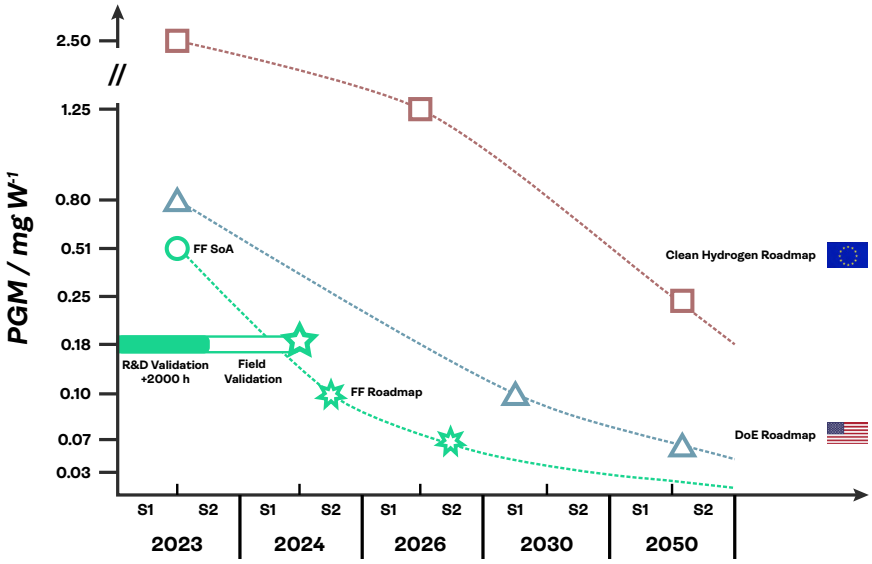

Figure 5 *- PGM decrease roadmap for Fusion Fuel HEVO technology, DOE and Clean Hydrogen*

Total PGM content for MEAs

PEM technologies, both electrolyzers and fuel cells, use precious metals as platinum (Pt), iridium (Ir) and ruthenium (Ru) for the catalyst layers of the MEAs and other valuable materials for functional coatings of current collectors. Given the scarcity and the market cost of these materials, there is an urge to:

i. Decrease the amount of these materials in PEM electrolysis technology.
ii. Improve the recyclability processes of these materials.

Where we have a responsibility to our clients, investors, and our planet, is to use the best we can the minimum amount of PGM in our Electrochemical Core. Presently, the HEVO technology is already well below the PGM targets defined internationally. To push further this challenge, the Electrochemical team has presented a bold roadmap to address the PGM content (Figure 5):

- With a technological partner, validate a disruptive anode design which would bring down the value to 0.18 mg/W without compromising performance and lifetime. This solution has already more than 2000 hours of operation in laboratory validation and field-validation starts in Q3 2023.
- Explore the potential to decrease even further by combining new cathode solutions: we are confident to reach values of 0.1 mg/W already in 2024.
- Challenge for 2026-2030: additional decrease of the PGM content without compromising performance vs. lifetime. We believe that a combined effort between Fusion Fuel and our suppliers will be up to the challenge, similar to the one fuel cells had in the past with platinum catalysts.

For the latter topic, the value-chain and recyclability of components with PGM materials, Fusion Fuel will support our suppliers and the recycling industry to overcome the challenges and provide solutions for the PEM electrolysis industries. These topics are well discussed and illustrated in recent communications [5-9], by institutions supporting hydrogen technologies and recognized suppliers of PGM catalysts for hydrogen technologies.

Lifetime & Degradation rate

To provide the most competitive green hydrogen solution, it is essential to have a full understanding of how our electrolyzer operates and how its inherent degradation processes will impact the expected lifetime and total operating costs over the period of 25 years.

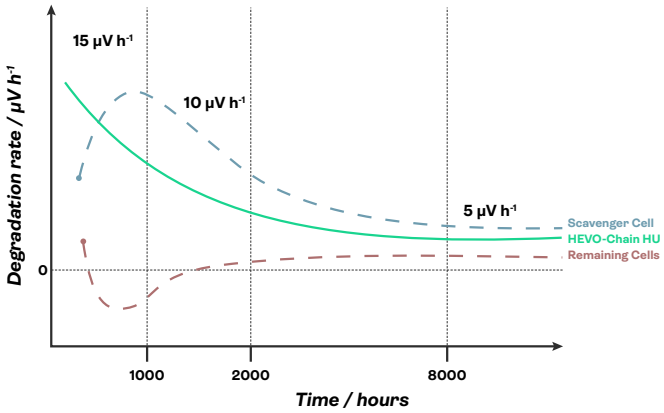

Figure 6 – *Degradation rate profile over time*

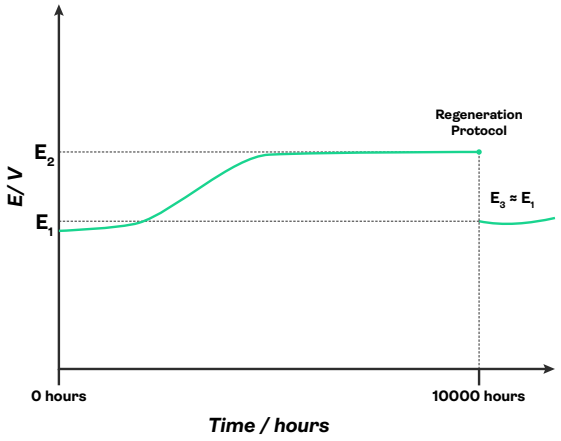

Figure 7 – *Voltage reset with regeneration procedure*

A unique feature of our HEVO electrolyzer, is the proprietary electrochemical cell design: individual cells in the same PEM allow for a flexibility of operation which is not possible for standard designs, resulting in a "stack-less" approach. This is unique in the green hydrogen market. At the same time, it also provides an exclusive interplay on the electrochemical processes during long-term operation, and hence, to a very particular set of properties as:

- Utilization of one electrochemical cell as a scavenger, being more solicitated than the other electrochemical cells during hydrogen production.

- The scavenger electrochemical cell drives the lifetime performance (Figure 6):

i. Prevents the remaining cells from ageing at a higher pace.

ii. Maintains a controlled degradation rate on the remaining electrochemical cells, for extended periods of time.

- Possibility to use the scavenger cell as a "sacrificial cell" and integrate a regeneration procedure which resets the performance of the electrolyzer to beginning of life values (Figure 7) with a simple procedure of applying voltage patterns: initial concept validated in R&D.

These are all exciting properties of our technology, which Fusion Fuel will exploit the most to extend the lifetime or our electrolyzer and provide a long-term solution for our customers.

Forthcoming Challenges for Fusion Fuel

The journey of Fusion Fuel is only at the beginning and even though the progress made so far as been intense and remarkable, there are still major challenges to overcome. To truly contribute in a significant way to the energy transition, and consider green hydrogen as a critical resource for our future generations, we will focus on:

Expand capabilities and test capacity

At Fusion Fuel we are continuously growing and one of our major objectives for 2023 is to expand the capabilities of innovation/prototyping of new electrolysis concepts, alongside a considerable increase in our electrolyzer test capacity.
This includes i. dimensioning and instrumenting test benches adapted to our HEVO technology, ii. guarantee a proper water supply in closed loop, to minimize waste of such valuable natural resource and iii. implement automated routines for test profiles and data acquisition/visualization. At the end of 2023, we expect that all these challenges will become reality.

Re-define the metrics for PEM electrolysis

The Electrochemical Core is a multi-material and multi-interfacial system, where all of them play a major role in the production of green hydrogen. Though, in electrochemistry and materials science, the interfaces hide the most unexpected details and those are the ones Fusion Fuel wants to unveil.

Through an open channel discussion with our suppliers and with detailed instrumentation of our HEVO, Fusion Fuel wants to create the basis of what may re-define methods, metrics and procedures to i. evaluate accurately new design and material solutions, ii. communicate the ideal requirements for HEVO components to our suppliers and iii. feed into new concepts for the HEVO electrolyzer.

Explore additional innovative designs for HEVO technology

PEM water electrolysis is a well-known technology which has been establish in the 1960s. Though, as in all technologies, a never-ending pursuit to find the answer of “what if...?” has led to significant progresses in distinct technological areas as computers, smartphones, virtual reality, and artificial intelligence to name a few.
Hydrogen technologies are no different. With our distinct HEVO electrolyzer, the “what if...?” is what will make us explore new solutions and integrate exotic solutions into our technology. For 2023 we want to take even more and exciting concepts out of the paper and through national and international partnerships, explore the potential of new and custom-made solutions to make our HEVO technology even more colorful, always prioritizing one of the colors: green hydrogen for all.

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Site

https://www.fusion-fuel.eu/

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