# THE EU'S CHEMICALS STRATEGY, PROPOSED BAN OF PFAS, AND IMPACT FOR THE HYDROGEN AND FUEL CELL SECTOR.

## Key messages

1. **PFAS are essential to the proper functioning of fuel cell and electrolysers.**
2. **No alternative to PFAS today comes close to the same KPIs – research can play a role but no foreseen fluorine-free breakthrough in the near future.**
3. **Emission risks are extremely limited (both in terms of environmental and human exposure) and fluoropolymers are 'polymers of low concern'.**
4. **Best practices for the industry and incentivisation can and should be set up to limit emissions at a maximum and to foster recovery of materials at end of life (for which there is already an inherent incentive because of the PGM + fluorine economic value).**
5. **Not exempting electrolysers and fuel cells from the PFAS ban would threaten the whole European fuel cell and electrolyser industry and its global competitiveness, as well as jeopardise the achievement of the EU's Hydrogen Strategy targets and climate objectives.**

## I. Introduction

Hydrogen has seen an unprecedented development in the year 2020. From an innovative niche technology, it is fast becoming a systemic element in the European Union's (EU) efforts to transition to a climate neutral society in 2050. It will become a crucial energy vector and the other leg of the energy transition – alongside renewable electricity – by replacing coal, oil, and gas across different segments of the economy. The rapid development of hydrogen is not only important for meeting the EU's climate objectives but also for preserving and enhancing the EU's industrial and economic competitiveness.

The EU Chemicals Strategy for sustainability released on October 14th, 2020, plans for the ban and phasing out of all per- and polyfluorinated alkyl substances (PFAS), *"allowing their use only where they are essential for society."* PFAS are chemicals that are used in the hydrogen value chain, not least of electrolysers and fuel cells. As no substitute is available today, an incautious ban would thereby impact both directly and heavily the hydrogen industry, and would jeopardise the achievement of the EU's Hydrogen Strategy targets and decarbonisation objectives.

The term PFAS represents a broad family of chemistries containing fluorine and carbon, which encompasses a wide range of chemicals. Following the OECD definition used by the five countries driving this ban proposal, there are more than 4,700 PFAS. These chemicals all have varying physical and chemical properties, health, and environmental profiles, uses, and benefits.

## II. PFAS in the EU’s regulatory framework and policy plans

### 1. What are the institutional plans to restrict PFAS, not least those used across the hydrogen value chain? How is the hydrogen industry concerned by these plans?

*Institutional plans and ongoing process to restrict PFAS*

Under current EU chemicals legislation REACH (Registration, Evaluation, Authorization and restriction of Chemicals), national authorities at the European Chemicals Agency (ECHA) can file their intention to develop a regulatory management option analysis (RMOA) – formerly ‘risk management option analysis’. These are voluntary case-by-case analysis carried out by countries or the ECHA, *“to help authorities clarify whether regulatory action is necessary for a given substance and to identify the most appropriate measures to address a concern.”*

In May 2020, the Netherlands (submitter), as well as Germany, Norway, Sweden, and Denmark (co-submitters), via their respective chemicals/environmental national authorities, filed a dossier to carry out a RMOA. In this framework, these national authorities had published a Call for Evidence and information on the use of PFAS in May 2020 (NB: deadline to answer was 31 July 2020) in the ambition of going towards a ban of PFAS. Those Member States had sent a letter to the Commission to ask for an EU action plan to address the concern posed by PFAS. The RMOA they initiated is still ‘under development’ as of today and should be completed some time by mid 2021. It will be the basis for a Registry of Intention (RoI) under REACH before the ECHA. An RoI triggers a REACH Restriction process according to Article 68 (1) and defines the scope of the restriction. It consists in the preparation of Annex XV dossier (lasts up to 12 months), which external stakeholder can then comment on under a 6-month public consultation. ECHA’s Socio-Economic Analysis Committee (SEAC) will also draft an opinion on the dossier, which can also be commented on during a 2-month public consultation. Eventually, the work of the ECHA (planned for 2023) will feed into a **draft proposal from the European Commission to restrict PFAS in the EU under REACH** (planned for 2024) and could enter into force around 2025.

In parallel, the EU Chemicals Strategy, published by the European Commission in October 2020, reaffirmed this objective of ***“phasing out the use of per- and polyfluoroalkyl substances (PFAS) in the EU, unless their use is essential.”***

The policy measures put forth in the strategy plan for a change in the policy and regulatory approach of PFAS. The Strategy draws the following observations and conclusions:

1. ***Regulating all PFAS together as a chemical class***: The Commission wants to phase out from the current approach based on regulation of individual or of groups of closely related PFAS as it has led to substitution with other PFAS, which are becoming an increasing concern. The very high number of PFAS would make it impossible to do a substance-by-substance assessment. Therefore, PFAS should be addressed with a group approach, under relevant legislation on water, sustainable products, food, industrial emissions, and waste.
2. ***Restrict all uses of PFAS except those that are essential*** for society and which currently *do not have alternatives* that provide the same level of performance should be allowed[1]. For such uses, society could accept the related costs, until suitable alternatives are available.

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[1] The strategy foresees already the complete ban of PFAS in fire-fighting foams, e.g.

3. ***Developing a definition of essential use***: at present, there is no agreed definition of what an 'essential use' is or of what criteria could be used to define those uses. The European Commission could contribute to the debate by developing a policy document on the concept of essential use.
4. ***Support R&I for remediating* PFAS** contamination in the environment and in products.
5. ***Support R&I to develop alternatives.***

Discussions on the definition of 'essential uses' are therefore currently being held amongst Member States competent authorities, the conclusions of which are expected to feed into the ongoing REACH Restriction process.

## *Relevance for electrolysers and fuel cells*

Electrolysers and fuel cells are principally concerned by the action of the Chemicals strategy which focuses on a proposed ban of a large category of chemicals called **PFAS**. The core of both proton exchange membrane (PEM)[2] water electrolysers and PEM fuel cells is an electro-chemical reaction through a membrane in which certain types of PFAS are used. A very large proportion of planned projects involving electrolysers and fuel cells (and in some applications 100%) are based on this PEM technology. Amongst tracked water electrolysis projects to be completed by 2030 in EU/EEA/UK for which information is available, PEM electrolysis accounts for 53% of the projects and 13% of the capacity[3]. In the case of alkaline water electrolysis (ALK), a diaphragm (e.g., Zirfon) is used instead of a membrane and does not contain PFAS. Yet, like for the PEM technology, PFAS types (i.e., TFE) are used in the product, e.g., as sealing materials and gaskets. ALK electrolysis accounts for 38% of the projects and 77% of the capacity. The remaining shares belong to solid oxide technology projects and projects combining multiple technologies for which the capacity cannot be split.[4]

In the hydrogen value chain, a subset of PFAS called fluoropolymers is used to manufacture proton exchange membranes. Henry et al. (2018) in the Integrated Environmental Assessment and Management (2018)[5] prove that fluoropolymers meet the OECD criteria to be defined as 'polymers of low concern' (PLC). They verifiably do not pose a risk to human health or the environment as they do not dissolve or contaminate water, are not found in drinking water, and cannot enter or accumulate in a person's bloodstream.

The procedure kickstarted in May 2020 by some Member States aims at restricting all PFAS as one homogenous group in the EU and at phasing out the production, import, sale and use of all non-essential PFAS, including in products marketed in the EU. The Member States are in the process of defining the scope of the restriction before filing the RMOA report with the ECHA in the summer of 2021. This scope currently includes fluoropolymers, thus potentially impacting the manufacture of proton exchange membranes.

With no substitute available today, the impact of an ill-considered ban on all PFAS would be to severely inhibit the manufacture and use of PEM fuel cells and electrolysers, because these technologies depend on gas-impermeable proton-conducting fluoropolymer membranes, which comprise fluoropolymers. Not only

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[2] The PEM acronym also sometimes stands for "polymer electrolyte membrane," which essentially refer to the same membrane type.

[3] Hydrogen Europe data. Out of 250 operating and planned projects and 104 GW of water electrolysis projects that Hydrogen Europe tracks within EU/EEA/UK by 2030, electrolysis type is available for 9,085 MW and 112 unique projects. It is therefore just an "excerpt" based on available information and is not meant in any way to represent future market shares of these technologies.

[4] Ibid

[5] Henry et al. (2018), A critical review of the application of polymer of low concern and regulatory criteria to fluoropolymers, Integrated Environmental Assessment and Management published by Wiley Periodicals, Inc. on behalf of Society of Environmental Toxicology & Chemistry (SETAC), Volume 14, Number 3, pp. 316-334. Retrieved on: https://setac.onlinelibrary.wiley.com/doi/10.1002/ieam.4035.

would a ban dangerously threaten the European hydrogen value chain industry, but it would also jeopardise the achievement of the EU Hydrogen Strategy and of the Green Deal objectives.

## III. PFAS in the hydrogen sector

### 2. What are the exact types of PFAS used along the H2 value chain, where (in which products) are they used, and why?

Within the very large family of PFAS, which includes around 4,700 substances, it is useful to distinguish some sub-categories. Amongst the various PFAS types, fluoropolymers are used in PEM electrolysers and fuel cells and in alkaline electrolysers. In plain language, fluoropolymers are simply a speciality plastic that underpins electrolyser and fuel cell systems. Here are the types of fluoropolymers used in Membrane Electrode Assemblies (MEA) – constituting the core of an electrolyser or fuel cell stack:

- In MEA:
    - Membranes:
      The membrane is the core component that, with the catalyst, separates protons and electrons and provides the proton conductivity (thereby producing electric current) while separating the reactants: hydrogen and air (oxygen), in the case of a fuel cell. In the case of an electrolyser, the electric current and the catalyst coated membrane split water into hydrogen and oxygen, hence hydrogen production and oxygen as a by product. To manufacture these membranes, "materials providing the best association of conductivity, chemical stability and mechanical strength are **Perfluorosulfonic acid (PFSA) ionomers** such as Nafion®, Aquivion®, 3M Corporation ionomers. The high proton conductivity of PFSA-membranes is correlated with their morphology in which ionic domains are well-percolated and phase-separated from hydrophobic domains that provide mechanical strength,"[6] a claim very widely shared across the industry.
      **The ionomer membrane consists of perfluorinated copolymers that carry sulfonic acid groups** so they can act as ion exchanger and are therefore called ionomers. Mechanics of the ionomers is relatively poor, so almost all current membranes include a polymer reinforcement made from polymer fibers. Most commonly, a reinforcement of porous **PTFE** is used, comparable to the Gore-Tex-Material, which is filled with the ionomer and to which layers of pure ionomer are attached, meaning the reinforcement thickness is only at a fraction of the total membrane thickness. "The chemical structures of these PFSA ionomers are shown [on Figure 1 below: (a) Nafion; (b) 3M ionomer and (c) Solvay Aquivion ionomer]. Each ionomer consists of a highly hydrophobic **PTFE** backbone and hydrophilic side chains each terminated with a sulfonic acid group (–$SO_3H$). The hydrophobic PTFE backbone provides effective mechanical stability, whereas the pendant sulfonic acid groups form interconnected domains with the absorbed water and are responsible for the conduits for proton transport. The

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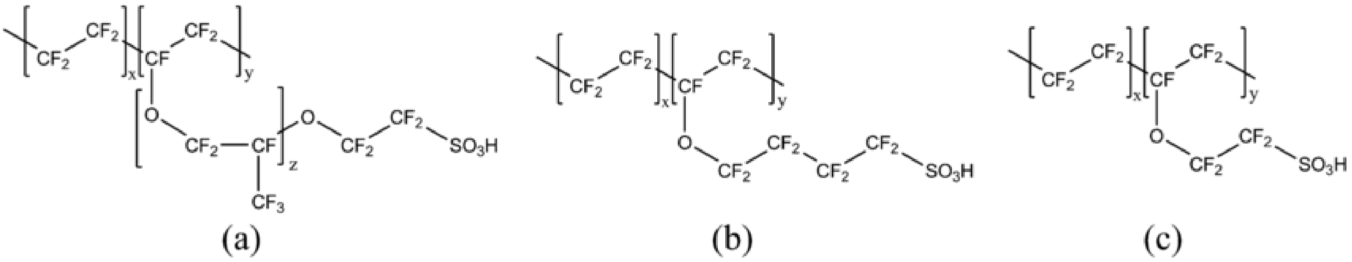
[6] Rakhi Sood, Sara Cavaliere, Deborah Jones, Jacques Rozière. Electrospun Nanofibre Composite Polymer Electrolyte Fuel Cell and Electrolysis Membranes. Nano Energy, Elsevier, 2016, 10.1016/j.nanoen.2016.06.027. hal-01342720.

difference between these ionomers is the length of their hydrophilic side chain and their equivalent weight (i.e., reciprocal of the ion exchange capacity). The side chain is the shortest for the Aquivion ionomer (made by Solvay) and longest for Nafion."[7]

*Figure 1: Three example types of ionomers used in membranes*



In contrast to a few years ago, the Chloralkali electrolysis industry now usually uses a membrane process. Yet, unlike PEM electrolysis, Chloralkali electrolysis process is based on two layers: one made of a PFSA membrane and the other one of a PFCA membrane. Flemion (by Asahi Glass Company – AGC) is an example of **PFCA (Perfluoroalkyl carboxylic acids)** membrane used in Chloralkali electrolysis and therefore based on a fluorinated carboxylic polymer.

Nafion, in addition to PEM electrolysers and fuel cells, is used in Chloralkali electrolysis to act as a PFSA membrane. It is also used in direct-methanol fuel cells (DMFC). Aciplex (by Asahi Kasei Chemicals) is another example of PFSA membrane used in PEM electrolysers and fuel cells, as well as in Chloralkali electrolysis.

- Gas Diffusion Layers (GDL): These consist of carbon fibre paper or felt/nonwoven. The GDL substrate currently contains **PTFE** (polytetrafluoroethylene), also commonly known as Teflon (a brand name from Chemours). It is used as hydrophobic agent and – depending on the GDL type – also as binder. The hydrophobic impregnation is necessary to avoid flooding of the cell, thus making the operation of the fuel cell possible. The amount of PTFE in the GDL is usually between 8 and 20 % relating to the total GDL weight.
- Microporous layers (MPL): GDL are often equipped with an additional layer at the interface to the electrode, called microporous layer or MPL. The smooth MPL layer equalizes the GDL surface and, therefore, prevents damage of the membrane by fibres from the GDL substrate and improves electrical and thermal contact between GDL and the electrode. A mix of **PTFE** is also used for MPL because of its hydrophobic properties.
- Finally, the electrodes (anode and cathode), which are attached to the membrane, contain a certain amount of the ionomer too – whose type depend on the used membrane. It enables an ionic connection between membrane and active catalyst sites, which is necessary for the overall function of the fuel cell.

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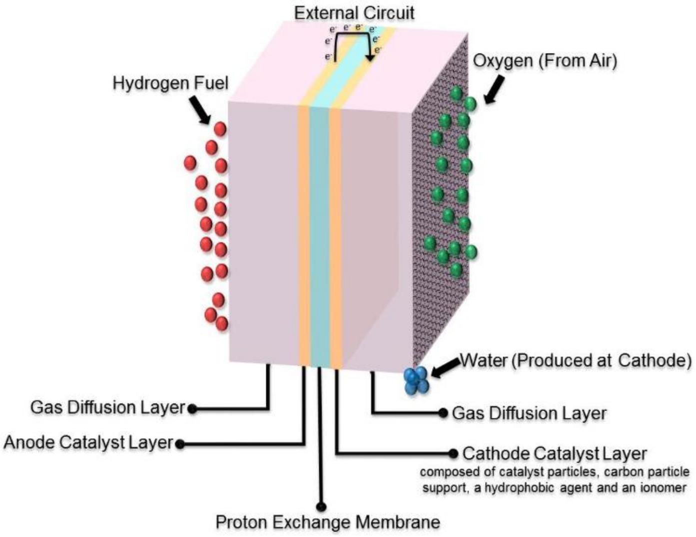
[7] Wang, Chen & Krishnan, Veena & Wu, Dongsheng & Bledsoe, Rylan & Paddison, Stephen & Duscher, Gerd. (2013). Evaluation of the microstructure of dry and hydrated perfluorosulfonic acid ionomers: Microscopy and simulations. Journal of Materials Chemistry A. 1. 938-944. 10.1039/C2TA01034H.

- Some typical sealing materials, such as gaskets, in electrolysers and fuel cells, as well as in equipment in the distribution network (regulator membranes, meters, etc.) are also made of **TFE** or fluorine rubber made of fluorinated elastomers (also called '**fluoroelastomers'**). A product example is Viton, a trademark of the Chemours company. Fluoroelastomers are composed of i) copolymers of hexafluoropropylene (HFP) and vinylidene fluoride (VDF or VF2), ii) terpolymers of **tetrafluoroethylene (TFE)**, vinylidene fluoride (VDF) and hexafluoropropylene (HFP), or iii) perfluoromethylvinylether (PMVE) containing specialties.

*Figure 2: Schematic representation of a Membrane Electrode Assembly (MEA)*[8]



## 3. What are the weights of the PFAS types respectively used in the H2 value chain? What can we estimate those weights to be in 2030?

Before all, it should be mentioned that the estimations given below are only based on the current state of the technology, and do not account for possible efficiency improvements.
Proton exchange membranes' thickness for fuel cells used in automotive applications is typically under 20 µm, whereas thickness is usually over 100 µm for membranes for electrolysers.

In total, a 60-kW **PEM fuel cell** stack with a total weight of 28.5 kg contains the following amounts of fluorinated components:

- 2.5 kg sealing material (fluoroelastomer including TFE; seal-on-MEA assumed)

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[8] Rakhi Sood, Sara Cavaliere, Deborah Jones, Jacques Rozière. Electrospun Nanofibre Composite Polymer Electrolyte Fuel Cell and Electrolysis Membranes. Nano Energy, Elsevier, 2016, 10.1016/j.nanoen.2016.06.027. hal-01342720.

- 0.2 kg ionomer membrane (PFSA ionomer reinforced with some PTFE)
- 0.15 kg PTFE in the GDL

The weights presented above per component clearly show that finding fluorine-free sealants would enable the large substitution of PFAS demand, whereas the amounts in catalyst-coated membrane (CCM) and GDL are much lower. Switching to a different sealing concept, i.e., using a metal-bead seal with an elastomer layer will reduce the amount of elastomer significantly compared to an injection-molded volume seal.

Using the same data, without consideration for possible ameliorations and assuming the CCM and GDL will still contain fluorinated compounds by then, this distribution would imply a **PTFE/TFE need of 44.25 tonnes, and a PFSA ionomer (e.g., Nafion) need of 3.25 tonnes to reach an indicative 1 GW of fuel cell capacity**. Based on a prospective demand of 100,000 trucks and 1,000,000 light vehicles on the roads by 2030, the total of required PFSA would amount to around 500 tonnes. Yet, there is no clear estimate today on the future fuel cell capacity needs for 2030, aggregating the various applications (all transport modes, stationary applications...).[9] Besides, it is obviously extremely unlikely for the fuel cell capacity to be reached by one unique technology, in that case, PEM.

If the EU was to reach its Hydrogen Strategy objective of 40 GW of **electrolysis** capacity by **2030 only with PEM technology** (which requires the PFSA membranes), we would need a maximum of **500 tonnes** of PFSA, using the following assumptions: Operating voltage of 2 V, current density of 2 A/cm², 50% of membrane is within the active area, 127 µm membrane is used, density is 0.25 kg / m². In the case of Nafion, nearly all material makes it into the end-product (<10% would be lost in manufacturing).

Just like for fuel cells, it is extremely unlikely for the electrolysis capacity to be reached by one unique technology, in that case, PEM (cf. page 3). The estimation therefore represents an upper bound for the accumulative PFAS use in electrolysers through 2030, and the actual use is likely to be much lower, also because of the gradual improvements for the technology. It is very difficult to make predictions past 2030 because cell construction, mode of operation, and market size are all unknown. Besides, Hydrogen Europe is in the process of collecting operational water electrolysis projects. While the collection process is not complete yet, we can say that there are more than 58 operational water electrolysis projects that Hydrogen Europe knows of, constituting 97 MW. Out of those, 21 projects representing 38 MW use ALK. 27 projects representing 48 MW use PEM. The rest is unknown or solid oxide technology.

Based on the same 40 GW capacity benchmark, other PFAS use for the sealing materials would roughly amount to 2,500 tonnes at manufacturing, resulting in about 1,250 tonnes in the end-product.

## 4. At which stage(s) (manufacturing, use, disposal) do PFAS used in the H2 value chain pose a risk? What is their level of danger?

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[9] The IEA tables over 15 million fuel cell vehicles on the road by 2030, in: IEA, Net Zero by 2050 A Roadmap for the Global Energy Sector, 2021.
As a complement, Table 1 on page 9 of the report 'Value Added of the Hydrogen and Fuel Cell Sector in Europe' (FCH 2 JU, 2019) provides some estimates for 2024 and 2030, but in amounts of units and not in MW/GW capacities.
Looking at today's data, based on tables page 41 of the same study and assuming a 78% share of PEMFC in Europe, we can deduct an adopted capacity of 116 MW of PEMFC in Europe (forecast for 2020). URL: https://www.fch.europa.eu/sites/default/files/Value%20Chain%20study%20SummaryReport_v2.02.pdf

- Manufacturing: If any, production of the polymers is probably the stage with the main risk of environmental exposure, because the building blocks and solvents are fluids. After the polymer is synthesised, purified, and treated, it poses minimal risk. The ionomer dispersion is a liquid but is mixed with precious metals and has a low likelihood of making it into a waste stream. The solid polymer membrane has an even lower risk for environmental release. When membranes are processed or cut during manufacture, the PFSA belongs to a fluoropolymer and remains stable, or waste are collected and either recycled by professional recycling companies or sent to chemical waste.

- Use: The PFAS are sealed inside an engineered product (electrolyser or fuel cell) as a PFSA proton exchange membrane (only for PEM fuel cells and electrolysers), and as a PTFE-based GDL or sealing materials, among others. It should be stressed that an electrolyser or fuel cell stack is not a consumer product that can be lost or leaked into the environment. The PFSA ionomers used in electrolysers and fuel cells, which are B2B products, are chemically stable at their intended use as they only start to degrade at temperatures above 250°C. There is no normal operation condition where that temperature level will be reached as it also would have a negative impact on the performance. Therefore, during normal operation and manufacturing, PFSA does not pose a risk. In case of electrolyser operation, it is mostly covered by water (<100°C) and in fuel cells cooled to stay below 120°C. Industries are running assessments to ensure that emission risk at use stage is indeed negligible. Although fluoropolymers are persistent, they are not bioaccumulative or toxic. They therefore do not meet the PBT (Persistent, Bioaccumulative and Toxic) criteria, and thus cannot be classed under substances of very high concern (SVHCs) category under REACH[10]. Moreover, fluoropolymers constitute a distinct PFAS category as they are solid, inert, stable, safe, and do not degrade into other PFAS. According to Integrated Environmental Assessment and Management[11], perfluorinated polymers like PTFE, PFA and FEP do not pose any significant threat to human life or to the environment and meet the OECD "polymers of low concern" criteria. Said fluoropolymers should be classed as such.

- Disposal: At end of life, the PFSA material can be fully recovered for electrolysers and fuel cells. Moreover, there is an overwhelming economic imperative to recover PEM stacks at the end of the life cycle in order to reclaim and recycle the expensive PGM (Platinum Group Metals) catalysts contained within the membrane/electrode assemblies, as well as the fluorine. Recycling processes enable the recovery of the fluorine contained in the PFSA material, for instance in the form of calcium fluoride, made of fluorspar, or fluorite (which is on the EU's 2020 critical raw materials list). Calcium fluoride can then be used as a raw material input for further production of fluorine-containing material. Therefore, it is unlikely that associated fluoropolymer components will enter the general waste stream. Furthermore, it should be noted that the PFSA membrane can be recovered totally intact at the end of its lifecycle as demonstrated in the UKRI project Frankenstack[12]. Recent peer-reviewed studies on the disposal of end-of-life PTFE have shown incineration to be an appropriate way to dispose of the fluoropolymer too, with no environmental concern. The study carried out by

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[10] Henry et al., *A critical review of the application of polymer of low concern and regulatory criteria to fluoropolymers*, Integrated Environmental Assessment and Management published by Wiley Periodicals, Inc. on behalf of Society of Environmental Toxicology & Chemistry (SETAC), Volume 14, Number 3, pp. 316-334, 2018. Retrieved on: https://setac.onlinelibrary.wiley.com/doi/10.1002/ieam.4035.

[11] Ibid

[12] https://gtr.ukri.org/projects?ref=133704

Aleksandrov et al. in 2019[13] found that the combustion of PTFE under typical waste incineration conditions and using Best Available Techniques (BAT) did not generate PFAS. It also showed that "PTFE can be almost fully transformed to fluorine as hydrofluoric acid (HF)." They concluded that the municipal incineration of PTFE should therefore be considered an acceptable form of waste treatment. They tested for the presence of 31 different PFAS and 11 of these were detected but deemed to be due to contamination from the environment.

## 5. What are the alternatives to the PFAS currently used in the H2 value chain, if any? By when could they become available? What is the potential for research?

*Are there alternatives to PFAS in fuel cells and electrolysers?*

- Membrane
    - Fluorine-free ionomers and membrane materials have been around in science for decades. Research work has been ongoing for hydrocarbon membrane and sulphonated polyetheretherketone (PEEK) membrane development, for instance. Usually, properties and performance of these materials can be reasonably good whereas the durability is often poor, as oxidation by oxygen radicals, which are inevitably generated at the cathode electrode, occurs. The non-fluorinated membrane concepts, that are currently available from suppliers, are not produced in high enough volumes and above all still highly immature, lasting only dozens of hours against lifetime requirements of >25,000 hours. Of course, those ionomers are still rather new, potentially promising, and the situation may change in the future. Activities to replace the conventional perfluorinated ionomers by fluorine-free materials have existed for the last 25 years but so far, no commercial product has indeed been released due to poor oxidation stability. Fuel cell manufacturers are in close contact with the manufacturers of the components to test the materials at relatively early stage and thus identify and qualify promising materials, promote their industrialisation and replace the current perfluorinated compounds, as early as possible. However, building from past experience, it is impossible to know for sure when a validated alternative material may be available in volume, meaning that to reach our 2030 climate goals and beyond, the existing perfluorinated materials are required to be able to scale up electrolysis and fuel cell technologies and enable the fulfilment of their decarbonisation potential.
    - As for the reinforcement material, promising approaches are currently made to replace the PTFE by fluorine-free compounds like electrospun PBI-type materials. The commercial use of these reinforcements is expected to begin not before five to ten years, also motivated by superior mechanical properties compared to those of PTFE.

- Gas Diffusion Layer (GDL)
    - Hydrophobisation of the GDL is today always achieved by the use of PTFE. Currently, the PTFE impregnation of the GDL cannot easily be replaced and some effort will have to be made to find alternative hydrophobising agents that are as durable as PTFE. It would surely be desirable to set up funding for projects with the aim to find replacement for the PTFE in the GDL, a topic that has

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[13] Aleksandrov et al., *Waste incineration of Polytetrafluoroethylene (PTFE) to evaluate potential formation of per- and Poly-Fluorinated Alkyl Substances (PFAS) in flue gas*, Chemosphere, Volume 226, 2019, Pages 898-906, ISSN 0045-6535, https://doi.org/10.1016/j.chemosphere.2019.03.191, (https://www.sciencedirect.com/science/article/pii/S0045653519306435).

  - not been addressed widely in the past. It will perhaps be possible to replace the PTFE in the GDL – probably not before 10 years – if the right incentives are triggered (i.e., relevant funding and research in this area).

- Sealing material
  - Due to the harsh environment in combination with the sensitivity of the MEA for contamination, very stable sealing materials are required. Fluorine-free-elastomers are under evaluation but contamination of the MEA – limiting its lifetime – as well as oxidative deterioration of the material itself are issues. They indeed suffer from dimensional stability and require mechanical reinforcement. Therefore, fluorinated sealing materials are today a standard for water electrolysis technologies and will surely be standard for another 10 years at least. However, for environmental and cost reasons, efforts are made to eliminate the PFAS from the sealing materials as soon as possible. Some elastomers without fluorine exist and could potentially be used in the future for this function. Those could be cheaper but are, today, not as chemically stable, hence the need for further R&D here. As for gas-permeability and cost, the fluorine-free materials are superior to fluorinated elastomers thus also from technical and economical point of view, replacement of these materials is desirable when possible.

In a nutshell, the material properties of perfluorinated polymers are unique and impossible to replace in the near future. Restrictions on fluoropolymers, including PTFE and PFSA ionomers, would render several critical applications from water electrolysis, fuel cells, to hydrogen transport technologies unfeasible or would dramatically reduce their service life, efficiency and increase the probability of malfunction.

All polymeric alternatives' performance, such as that of hydrocarbon membranes, is still very low because they suffer from reduced thermal and chemical stability, reduced efficiency (e.g., higher ionic resistance) and/or inapplicable mechanical properties and have high deterioration rates and short life expectancies. Previous R&D has shown that there is no business case for building electrolysers based on hydrocarbon membranes.

Therefore, we can say that there are no alternative substances available.

*Could R&I on remediating PFAS contamination make sense for fuel cells and electrolysers?*

PFSA ionomers are significantly stable, mechanically very strong and trapped inside membrane/electrode assemblies containing expensive catalysts. Therefore, they cannot leak or contaminate anything during use. If there is contamination caused by PEM fuel cells and electrolysers, it is so small that for current systems it has not been detected. Current analysis for fuel cell shows only F- (fluorine anions) as contaminants, which are non-toxic in these concentrations.

Moreover, their recovery at end of life is driven by the desire to recover and reuse the catalysts (to keep fuel cells and electrolyser costs down). Therefore, there is very little chance of the membrane entering the general waste stream, besides of the very low contamination risk. Fluoropolymers such as PFSA ionomers and PTFE should be seen by the European Commission and the European Chemicals Agency as a discrete class – especially in the case of sealed B2B products like in the hydrogen and fuel cell industry – and separate from other PFAS types, many of which are deemed dangerous for the environment and human health.

*Could R&I to develop alternatives to PFAS make sense for fuel cells and electrolysers?*

There are no alternatives to PFSA membranes that offer same durability, gas impermeability, thermomechanical performance, efficiency, and current density, or that provide minimum acceptable levels thereof for the membranes to fulfil their function.

R&D efforts to achieve competitive alternatives have been undertaken with hydrocarbon membranes for years, but nothing has come close to fluorocarbon membranes. In the last 5-6 years, the major membrane manufacturers have invested heavily in response to the promise offered by hydrogen technologies and recent improvements have enabled further cost and performance improvements in Nafion membranes. Alternative materials that are currently being studied are hydrocarbonated sulfonated polymers that suffer from dimensional stability and require mechanical reinforcements. Important R&D efforts are still required in order to find viable solutions to replace PFSAs. Over fifty years of development place Nafion (and equivalents thereof) in an outstanding position for building electrolysers and fuel cells. Any compromise in durability or efficiency due to another type of membrane will reposition the techno-economics to an unacceptable position.

In the longer term, we cannot exclude that fluorine-free membranes could be developed. In fact, we should continue looking in this direction. Today, there is some new low-TRL research in laboratories ongoing on the subject. These efforts should be further supported, and Hydrogen Europe takes notes of the EU's plans to bolster research further. Indeed, there is always potential for research, but it can be diversionary and a waste of resources, unless the same KPIs that apply to PEM technology today are those targeted. Hydrocarbon membranes are therefore a possibility, but they will need to reach the same KPIs of today's technologies and then become commercialised and integrated into OEM products, and be introduced into the marketplace, which is not foreseen at the very least before 10 years.

All in all, it remains clear that research will not yield results in time to allow the industry to abstain from the use of fully developed, industrially available products, necessary for the establishment of a hydrogen economy in Europe and for the achievement of the Hydrogen Strategy and the European Green Deal.

# IV. Impact assessment and Recommendations to policymakers

## 6. How will 'essential uses' of PFAS be defined in the context of the plan to phase out PFAS?

*Is the use of PFAS in fuel cells and electrolysers an essential use?*

The concept of essential uses dates back from the Montreal Protocol on Substances that Deplete the Ozone Layer (1987), which defines a use as essential if it is "necessary for health, safety or is critical for functioning of society" and if "there are no available technically and economically feasible alternatives".

Under the Chemicals Strategy for Sustainability, the European Commission has started a debate with all REACH Competent Authorities to define the term 'essential uses'. The debate is at very early stage and many questions remain open. One of the most controversial question is if the term 'essential' refers to the broad application or product that the PFAS is used in or the specific use (functionality) of the PFAS within the product. The Strategy's action plan indicates that the criteria for essential uses will be defined in the period 2021-22.

Fluoropolymer stability translates to unique, durable, lasting performance in critical uses and applications. In the hydrogen industry, as outlined above, fluoropolymers should be deemed essential, until alternatives with comparable KPIs become available.

The Chemicals Strategy for Sustainability states that *"the criteria for essential uses of these chemicals will have to be properly defined to ensure coherent application across EU legislation, and* ***will in particular take into consideration the needs for achieving the green and digital transition****."*

Let us remember what is at stake. First, the European Hydrogen Strategy fixes the ambitious objective of 40 GW of electrolyser capacity and 10 million tonnes of renewable hydrogen production by 2030, which requires a rapid scaling up. Second, Europe is the industrial leader in hydrogen technologies (both fuel cells and electrolysis) and the European Commission identified hydrogen as a strategic value chain. The use of PFAS in the hydrogen and fuel cell industry can therefore be considered as an essential use for society, whether from an energy and climate perspective or from an industrial and geostrategic perspective. Allowing PFAS use in this industry meets both criteria of Montreal Protocol definition of essential use and allowing it will indeed leave society better off from a socio-economic[14] and environmental perspective[15]. Overall, the EU must ensure consistency across its different policies and plans and avoid undue barriers to the uptake of electrolysers and fuel cells. It is therefore not timely to add another one on top now. Finally, just as in the spirit of the Carbon Border Adjustment Mechanism (CBAM) upcoming proposal in the case of CO2 emission reduction, the EU needs to secure a level playing field with its trading partners and competitors. Without it, the EU will lose its industrial lead in this blossoming sector, in the favour of non-EU electrolyser and fuel cell manufacturers in regions where PFAS could be less regulated.

## 7. What would an incautious PFAS ban mean for the hydrogen industry and for Europe?

An incautious ban of all PFAS would be a killer for the hydrogen industry, from the jobs and revenues it provides and will provide, to the key role it is to play to reach decarbonisation and system integration objectives.

PFAS use is at the core of numerous hydrogen applications, not least many electrolyser and fuel cell types. Whereas it cannot be estimated today which will be the exact importance of respective electrolyser and fuel cell technologies in the future, PEM electrolysers and fuel cells are notably expected to reap significant market shares and could possibly prove more suited to some kinds of environments, such as offshore (not least due to higher surface energy yield and better reactivity to load factor). PEM technology would be particularly affected since it requires the use of a PFSA membrane. Besides, alkaline water electrolysis, along

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[14] The sector could create 5.4 million jobs (hydrogen, equipment, supplier industries) and generate €820bn in annual revenue by 2050 (hydrogen and equipment) (FCH 2 JU, Hydrogen Roadmap Europe, 2019; URL: https://www.fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf)

[15] Hydrogen use could abate an annual 560 Mt of CO2 and reduce by 15% local emissions (Nox) relative to road transport by 2050 (FCH 2 JU, Hydrogen Roadmap Europe, 2019; URL: https://www.fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf)

with all electrolysers and fuel cell types, would also be badly impacted since PFAS, particularly PTFE and TFE, are used as sealants, i.a., in those products.

Therefore, an incautious ban on the use of PFAS would set back the PEM fuel cell industry from a point where it is approaching commercialisation, to a research and development phase in the EU. This would be a tragic outcome as the hydrogen industry is finally experiencing a breakthrough. For the EU, the ban would result in holding back a technology that is needed to reach the Unions ambitious climate targets especially when it comes to the decarbonisation of industry and heavy-duty transport as outlined in the EU's hydrogen strategy. It would dramatically harm the competitiveness of the EU's hydrogen and fuel cell industry.
In a nutshell: no PFAS, no PEM fuel cells & electrolysers, no EU H2 strategy successful roll-out.

## 8. What best practices can the industry propose to legislators, to ensure the risks posed by PFAS used in the H2 value chain are limited and controlled at all stages (manufacturing, use, disposal)?

At manufacturing stage, legislation should frame and incentivise best practices fostering minimum risk and waste and limiting emissions from processing aids and all PFAS kinds. This should be a path to follow for the industry.

At disposal stage, recycling of MEAs at end of life, while maximising the recovery rate and minimising incineration should be a best practice. Building on recommendations set forth in Integrated Environmental Assessment and Management (2018), "responsible incineration of fluoropolymers, adhering to regulatory guidelines, at the end of their life cycle," as well as "recycling, reuse, and closed loop systems"[16] should pave the way forward to regulate PFAS at end of life. Those recycling practices of fuel cells and electrolysers will enable to "control" the PFAS risk at end-of-life stage and recover the contained fluorine (which is a critical raw material identified by the EU). The precious metal content of PEM fuel cells and electrolysers and the inherent economic value are an incentive as such to put forward recycling habits[17]. There is or should be an economical imperative to do this, preventing that none of the fluorinated material in the stack be released into the environment by use or disposal of the stack.

Upon recycling of the stack, the GDLs (including PTFE) and sealings (including PTFE) are likely burnt in special facilities which capture fluorine containing compounds from the off-gas by reaction with calcium hydroxide resulting in calcium fluoride, that is used again as a raw material for production of fluorine-containing material. Here the closed loop seems given.

As for the membrane and electrodes (which are laminated, thus cannot be physically separated from each other), there are two ways to recycle. Today, the most common technique is to ash the catalyst-coated

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[16] Henry et al., A critical review of the application of polymer of low concern and regulatory criteria to fluoropolymers, Integrated Environmental Assessment and Management published by Wiley Periodicals, Inc. on behalf of Society of Environmental Toxicology & Chemistry (SETAC), Volume 14, Number 3, pp. 316-334, 2018. Retrieved on: https://setac.onlinelibrary.wiley.com/doi/10.1002/ieam.4035.
[17] Examples here: https://info.ballard.com/technical-note-recycling-fuel-cells; https://www.umicore.com/en/newsroom/news/umicore-fuel-cell-catalysts--0/

membrane (or even the entire MEA including GDLs and possibly sealing), dissolve the residue in acid and use this as a base for recycling of the noble metals. Upon this process the same happens as described above, the fluorine-containing polymers burn and release hydrofluoric acid (HF), which is captured.

An alternative process that is currently under evaluation is to dissolve the ionomer from the unit, which can be achieved by using conventional solvents – usually an alcohol-water-mixture - at high temperature and pressure. The ionomer is transferred into the liquid phase and can be separated from electrocatalyst and reinforcement. Aim of this process is to try and recycle the ionomer, which is also a very expensive material, so recycling is commercially attractive, too. If this process can be successfully done is still an open question.

Besides, setting a legal obligation for manufacturers to take the units back and carry out recycling to recover the various PGMs while isolating the fluorine would be an easy way to start the process. Since the hydrogen market is still a nascent one, the more the volumes of electrolysers and fuel cells coming to end of life will grow, the more efficient processes will be put in place to make use of the larger fluorine quantities to capture and recover. In addition, the development and optimisation of relevant recycling processes should be established and supported by relevant funding, so that a maximum of the materials in the stack can be recycled or disposed of with minimum environmental impact.

In the perspective of further used recycling methods and their improvements going forward, combustion of PTFE under typical waste incineration conditions and using Best Available Techniques (BAT) should be applied as it is considered an acceptable form of waste treatment that does not generate other PFAS (please see paragraphs on disposal, page 8).

In a nutshell, the main PFAS used are PFSA ionomers, PTFE, and TFE. Fluorine can be recovered from all of them, as part of 100% recyclable MEAs for PEM water electrolysers and PEM fuel cells. Several recycling techniques exist and are being experimented by the industry. Yet, both the hydrogen and fuel industry and those recycling techniques are at a nascent stage, explaining why most PFSA/PTFE materials are still being incinerated today. Recycling and recovery processes should be developed further, ramped up, and receive appropriate public funding for this. In the meantime, PTFE incineration has been recognised as an acceptable form of waste treatment that does not generate other PFAS.

## V. Conclusion

Due to the concerns raised by the negative impacts of many PFAS on human health and on the environment, Hydrogen Europe understands the need for an institutional approach restricting these substances further at manufacturing, use and disposal stages.

Yet, public authorities should be made aware that, even though a group approach is foreseen for a phasing out, PFAS remain an extremely large group of various substances (over 4,700) and that regulatory differentiations should be made both considering their types (e.g., fluoropolymers are substances of low concern) and the sectors/products at hand, not least based on:

- The environmental and human exposure to PFAS in those products (fuel cells and electrolysers are sealed B2B products and cannot be regulated in the same way as textile or food packaging).

- The essentiality of sectors/products to reach fundamental objectives, such as that of the EU Green Deal, and on the essentiality of those PFAS for enabling the good functioning of those products.

The way forward should therefore focus on the regulatory incentivisation to:

1) implement circular economy practices across the value chains (closed circle and recycling/reusage at disposal stage) in the short and medium term; and to
2) pursue research efforts to find non-PFAS alternatives at a same level-playing field in terms of KPIs offered by PFSA membranes, PTFE, and TFE for fluoroelastomers (i.e., considering quality, lifetime, efficiency and cost aspects) and to provide for the appropriate resources for that purpose.

The variety and quality of PEM membranes available today is excellent compared to only a few years ago. Manufacturers have invested heavily recently because they see rising sales to fuel cells and electrolyser manufacturers in the context of the growing acknowledgment of hydrogen technologies, not least under the Green Deal. Therefore, the timing of this potential ban on PFAS would be extremely ironic given the effort, R&D experience and investment risks that the stakeholders have made in this niche area to date.

What is at stake here are significant jobs growth potential in European industry, strategic autonomy of key value chains such as that of electrolysers and fuel cells, as well as the objectives of the EU Hydrogen Strategy, of the Energy System Integration Strategy, and of Member States, not least electrolyser and fuel cell capacity targets. Manufacturers are about to install new and much larger electrolysers and fuel cells facilities and hydrogen production plants. If a ban of proton exchange membrane were to be imposed, the first thing that would happen is the relocation of manufacturers outside of Europe before starting to build more and larger factories there.

For all these reasons, the use of PFAS in fuel cells and electrolysers needs to be classified as an essential use for society, because there is no alternative, because PFAS are essential for the functioning of this industry's products, and because hydrogen fuel cells and electrolysers will be a cornerstone in achieving our energy and climate objectives. Besides, environmental and health risks are extremely limited and incomparably differ from B2C products where exposure to PFAS is higher.

Given the above and while the industry commits to keep looking out for alternative materials, fuel cells and electrolyser manufacturers should be exempted from any proposed PFAS ban if we want to deliver on the EU Hydrogen Strategy and our climate objectives.