Hydrogen Europe

Hydrogen Europe Position Paper on PFAS

The importance of fluoropolymers across the hydrogen value chain, and impacts of the proposed PFAS restriction for the hydrogen sector

January 2023

Executive Summary

In 2020, the new EU Chemicals Strategy for Sustainability set out the plan bring the European Union's framework on chemical regulation in line with the increased targets of the Green Deal. Since then, geopolitical, and climate-related developments propelled this ambition even further, raising the goals of the bloc through the Fitfor55 Package and the REPowerEU Plan. The EU hydrogen industry will need to reach an annual manufacturing capacity of 25 GW of electrolyser by 2025 - a target endorsed by the Electrolyser Partnership to reach 10 million tonnes of hydrogen produced in Europe, which corresponds to 100 GW of electrolysis capacity by 2030. This is with a view to achieve the European ambition of 20 million tonnes of hydrogen consumption by the end of the decade, to meet Green Deal objectives and replace Russian gas as soon as possible.

The PFAS (Per- and polyfluoroalkyl Substances) restriction proposal, to be submitted by five European countries to the ECHA, is an important pillar to the EU's Chemicals Strategy. However, a restriction could have catastrophic consequences for the EU's nascent hydrogen sector, if it takes a PFAS group approach including fluoropolymers while not factoring in their specific profile, and if it does not duly consider essentiality of uses, availability of ready-to-use alternatives, and socioeconomic, industrial, and environmental impacts. Clean technologies are essential for the green transition and energy security, and thus they need a favourable regulatory framework to thrive.

Why are PFAS relevant to the hydrogen sector?

Electrolysers and fuel cell applications, the hydrogen industry's fundamental technologies, use fluoropolymers (considered a PFAS subtype). No alternative is foreseen to be able to substitute today or in the near future these highly specialised materials, central to the functioning of the hydrogen value chain. These are produced and used in a highly controlled industrial environment, where their emissions are negligible and, due to their high initial price, their reusability and recyclability are actively investigated.

A rushed PFAS ban without granting any exemption for applications in the hydrogen sector would have destructive effects on the industry's €30-billion worth of investment in a decade (only including electrolysers and fuel cells). Such a ban would also jeopardise up to 200,000 direct jobs and over 260,000 indirect within 10 years in a market with a potential value of €820 billion employing 5.4 million jobs by the middle of the century.

Recommendations of the hydrogen industry:

Instead of an outright ban of the use of fluoropolymers in electrolysers, fuel cells and key applications in the hydrogen industry, the restriction should focus on substances that present an unacceptable risk in line with REACH regulation, and for which alternatives may be available. For exempted uses, legislators should set up a framework incentivising a) best practices for the manufacturing, use and end-of-life stages of fluoropolymers, implementing circular economy practices across value chains (closed circle with take-back system implementation and recycling/reuse at disposal stage) in the short and medium term, and b) research into finding non-fluoropolymer alternatives that could reach the same KPIs as fluoropolymers offer (considering quality, durability, efficiency, and economic viability) in the medium to long term.

Key messages of the hydrogen industry:

1. **The proper functioning of electrolysers, fuel cells and other technologies across the hydrogen value chain rests on the essential use of fluoropolymers (often classified as a PFAS category).**
2. **No alternative to fluoropolymers today comes close to the same KPIs in the H2 sector – research can play a role, but no fluorine-free breakthrough is foreseen in the near future.**

3. **Environmental and human health risks of fluoropolymers, which are considered by the OECD as 'polymers of low concern,' are extremely limited across the hydrogen value chain (both in terms of environmental and human exposure).**

4. **Adequate regulation, based on best practices, should be set up to both limit emissions and foster recovery of materials at end of life to the largest extent possible (and there is already an inherent incentive due to the economic value of Platinum Group Metals-PGM and fluorine).**

5. **Not exempting the use of fluoropolymers in the hydrogen sector (especially in electrolysers and fuel cells) under the PFAS restriction would threaten the whole European hydrogen industry and its global competitiveness, as well as jeopardise the achievement of the EU's REPowerEU and climate objectives.**

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I. Introduction

Hydrogen has seen an unprecedented development since 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 clean 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 (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."* Fluoropolymers, which are often classified as a PFAS category (as described by the five competent authorities drafting the REACH restriction proposal), are specialty plastics that are used in the hydrogen value chain, not least in electrolysers and fuel cells. As no substitute is available today, an incautious and general PFAS ban would thereby impact both directly and heavily the hydrogen industry and would jeopardise the achievement of the EU's Hydrogen Strategy and REPowerEU 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 definition of the European Chemicals Agency (ECHA), there would be over 4,700 PFAS types. 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, Authorisation, and restriction of Chemicals), national authorities at the ECHA can file their intention to develop a regulatory management option analysis (RMOA) – formerly 'risk management option analysis'. These are voluntary case-by-case analyses 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 with the ambition of restricting the use 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 was completed in July 2021 and was the basis for a Registry of Intention (RoI) under REACH submitted to the ECHA. The RoI triggered 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 by the competent authorities for 12 months (from July 2021 to July 2022), which external stakeholder will then be able to comment on under a 6-month public consultation. After a 6-months extension was granted to the filing authorities, the timeline shifted, with

the submission of dossier expected by 13 January 2023. The 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 (to be finalised by end of 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.
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, as well as under the ongoing revision of REACH, the conclusions of which may influence the PFAS restriction process, although both parallel processes are clearly distinct from each other

Relevance for the hydrogen sector

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**, so far including fluoropolymers under its scope. 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 polymers meeting the criteria defined by the five submitters of the restriction proposal, 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 57% of the projects and 33% 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

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[1] The strategy foresees already the complete ban of PFAS in fire-fighting foams, e.g.
[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 557 operating and planned projects and 131 GW of water electrolysis projects that Hydrogen Europe tracks within EU/EEA/UK by 2030, electrolysis type is available for 12,854 MW and 217 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.

not contain PFAS. Yet, like for the PEM technology, fluoropolymers are used in the product, e.g., as sealing materials and gaskets. ALK electrolysis accounts for 35% of the projects and 59% 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] It is important to note that as the hydrogen industry ramps up, it is crucial that both technologies are taken into account and supported, as no single technology can be used in isolation to achieve electrolyser ramp-up objectives.

In the hydrogen value chain, fluoropolymers are used to manufacture proton exchange membranes in PEM electrolysers and fuel cells, as binder materials in the electrodes, both anode and cathode, and as a component of the gas diffusion layers (GDLs). Moreover, fluoropolymers are used for gaskets and sealings in most electrolyser and fuel cell types, and in parts of the transport and distribution system in valves. Henry et al. (2018) in the Integrated Environmental Assessment and Management (2018)[5] and Korzeniowski et al. (2022)[6] demonstrated that the vast majority of 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 currently include fluoropolymers as part of the scope, thus potentially impacting many key parts of the hydrogen value chain and the whole sector at large.

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, chemically stable proton-conducting fluoropolymer membranes, which comprise fluoropolymers. Not only would a ban dangerously threaten the European hydrogen value chain industry, but it would also jeopardise the achievement of the EU Hydrogen Strategy, REPowerEU 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 several thousands of substances, **fluoropolymers** are used in PEM electrolysers, PEM fuel cells and in alkaline electrolysers. In plain language, fluoropolymers are a speciality plastic that underpins electrolyser and fuel cell systems. Here are the types of fluoropolymers

[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.

[6] Korzeniowski, S.H., et al. (2022), A critical review of the application of polymer of low concern regulatory criteria to fluoropolymers II: Fluoroplastics and fluoroelastomers. Integr Environ Assess Manag.

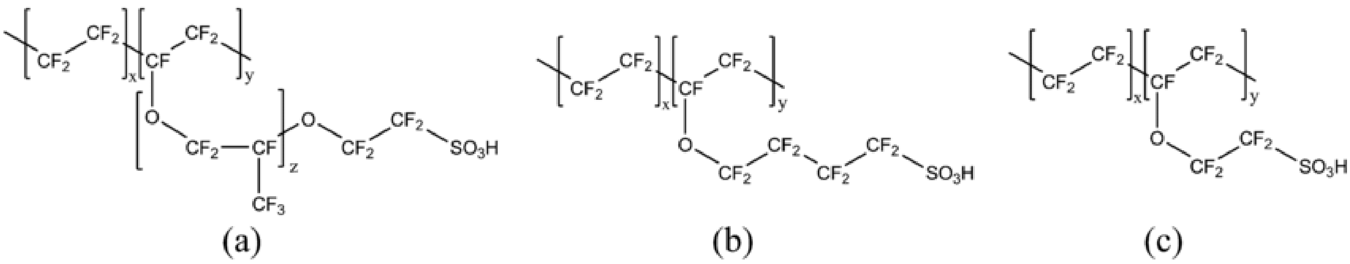
used in the value chain, including in Membrane Electrode Assemblies (MEA) – constituting the core of a PEM electrolyser or fuel cell stack:

A. Membrane Electrode Assemblies (MEA):

a. Membranes:

- The membrane is a critical component in the MEA for both fuel cell and electrolyser application. Its role is threefold: to isolate the electrodes from each other electrically, and so prevent a short circuit; to act as the electrolyte and conduct protons from the anode to the cathode; and to provide a mechanical barrier to the MEA, in particular to prevent mixing of hydrogen and oxygen. To manufacture these membranes, "materials providing the best association of conductivity, chemical stability and mechanical strength are **ionomers** that carry sulfonic acid groups (SO3H); most commonly reinforced by PTFE (therefore fluoropolymers) such as Nafion®, Forblue® S, Aquivion®, 3M Corporation ionomers. The high proton conductivity of these ionomers is correlated with their morphology in which ionic domains are well-percolated and phase-separated from hydrophobic domains that provide mechanical strength,"[7] 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. The mechanics of the ionomers are relatively poor, so almost all current membranes include a polymer reinforcement made from polymer fibres. Most commonly, a reinforcement of porous polytetrafluoroethylene **(PTFE)** is used, both in woven and non-woven form, 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 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 (–SO3H). 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 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 (by Chemours)."[8]

Figure 1: Three example types of ionomers used in membranes



[7] 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.

[8] 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.

- , The Chloralkali electrolysis industry typically uses a membrane process too. Yet, unlike PEM electrolysis, Chloralkali electrolysis process is based on two layers: one made of a perfluoro sulfonic acid ionomer and the other one of perfluoro carboxylic acid (PFCA) ionomers. Nafion, (by Chemours) and Flemion (by Asahi Glass Company – AGC) are examples of product lines containing composite membranes utilising perfluorinated sulfonic and carboxylic polymeric resins for Chloralkali electrolysis applications. The use of fluorinated ionomer technology in the Chloralkali industry has eliminated the need for environmentally harmful mercury cells.

- Nafion is also used in direct-methanol fuel cells (DMFC). Aciplex (by Asahi Kasei Chemicals) and Forblue® S are other examples of a membrane that carries sulfonic acid groups (SO3H) used in PEM electrolysers and fuel cells, as well as in Chloralkali electrolysis.

- In addition, anion exchange membrane (AEM) electrolysis technologies use similar types of fluoropolymers as those used in PEM technologies, both in the membranes and in sealings, coating and bindings.

b. Gas Diffusion Layers (GDL): The role of the GDL is to disperse reagents and collect products from across the face of the catalyst layer. In a fuel cell, they consist of carbon fibre paper or felt. The GDL substrate currently contains **PTFE** (polytetrafluoroethylene), also commonly known as Teflon (a trademark of The Chemours Company). It is used as hydrophobic agent and – depending on the GDL type – also as binder. The hydrophobic impregnation is necessary to help water management, 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. A PEM electrolyser typically uses one of these GDLs on the cathode side, while the highly oxidising conditions on the anode require a non-carbon material (e.g. titanium).

c. 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 levels 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.

d. 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 electrolyser or fuel cell. In addition to key characteristics, such as chain length and catalyst/ionomer ratio, the property of high oxygen permeability to keep the catalyst particles accessible for reactant gases, which is characteristic of perfluoropolymers is an essential feature of ionomer binders at the cathode, necessary for its high performance. Today, many MEAs are assembled using a hot pressing approach, where the catalyst layers are printed onto a backing polymer, which can contain fluorine (such as ETFE (poly(ethene-co-tetrafluoroethene)) or PTFE). To this date, in spite of efforts, the industry has not been able to reproduce this with alternatives that would reach the same KPIs.

B. Sealing materials: 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 fluoropolymers (FKM and **PTFE**) 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. Seals are also made using a ETFE, PTFE, tetrafluoroethylene propylene (FEPM) and perfluoroelastomer (FFKM) materials, giving the seals their necessary properties. PFSA is also being used as binder material, while PTFE are used in valves and diaphragms with characteristics that cannot be replaced with other materials.

C. Coating materials: PTFE is also used as a coating material in several applications within the hydrogen industry to protect surfaces and structures from harsh processing conditions. In particular, fluoropolymers, such as PTFE are used in Alkaline Electrolysis technologies, where warm caustic solutions require extensive surface protection.

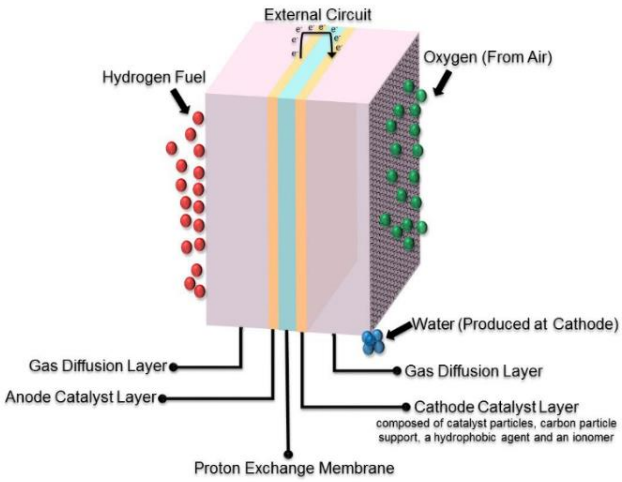
D. Gasification separating membranes: Key fluoropolymers, such as PTFE are also used in gasification (biomass and waste) applications, in biogas and methane reforming. These substances are used for air compression in autothermal gasification; and in syngas purification, CO2 separation units and in hydrogen purification units to act as gas separating membranes.

E. Infrastructure for transport and storage of hydrogen:
   a. In critical infrastructure and storage applications, fluoropolymers are used for their irreplaceable characteristics. In aboveground storage and in salt cavern storage, PTFE, PFA and ETFE are used as lining materials, packing rings and valve internal seals. In solid storage PTFE PEEK and Viton are being used for the same purposes.
   b. In gas grids, fluoropolymers (PFSA ionomers and PTFE) are used as key materials in mechanical compression, electrochemical compression (proton exchange membranes), cryogenic impression and in volumetric compression. Additionally, fluoropolymers are being used as gas separating membranes. PTFE (including Teflon-types), PEEK and Viton are used in gas grids in valves and joints to achieve crucial low friction and wear and good seal and fitting.
   c. In cryogenic liquid hydrogen carrier solutions, PTFE and FKM are utilised for compact heat exchange technologies and PTFE are used in cooling systems for catalysis, and as equipment insulation and cryogenic vessels. The fluoropolymers' advanced characteristics are necessary in such extreme circumstances.
   d. Similarly, fluoropolymers are used for sealing materials in valves and compressors in liquid organic hydrogen carrier (LOHC) technologies.
   e. Even for the transport of gaseous and liquid hydrogen by road and water transport, and for onshore storage of bulk liquid hydrogen, fluoropolymers, such as ETFE and PFA in compounds in addition to PTFE are used. PTFE is used in compressors in such transfer systems to achieve sufficiently low friction and long lifetime.

F. Hydrogen Refuelling Stations (HRS): In HRS applications PTFE (nylon bands) is used in a variety of applications, such as in valves, flow meters and dispensers in addition to being key in hydrogen compressors. PTFE's essential characteristics make them optimal for seal pipe and fittings connections.

G. Potential H2 end-uses: Regarding end-uses of hydrogen, PTFE are used in turbines in flanged connections in order to mitigate leakages. Additionally, fluoropolymers are used in burners and boilers for similar purposes.

Figure 2: Schematic representation of a Membrane Electrode Assembly (MEA)[9]



3. What are the weights of the fluoropolymers 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 for PEM water electrolysis given below are only based on the current state of the technology, and do not account for possible efficiency improvements. This innovation could be substantial and should not be ignored, particularly if membrane development history gives an accurate indication of potential future performance. To illustrate, the PEM fuel cell industry has been developing for over 20 years and in that time has reduced the thickness of membranes dramatically. Starting with Nafion® 117 from Chemours, considered an industry standard at 175 µm thick, this was replaced with Nafion® 115 at 125 µm thick. Developments are still underway to even further reduce membrane thickness. Proton exchange membranes' thickness for fuel cells used in automotive applications is typically under 20 µm, whereas thickness is usually around 100 µm for electrolyser membranes.

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 (typically, ETFE, PTFE, FEPM and FFKM; seal-on-MEA assumed)
- 0.2 kg ionomer carrying sulfonic acid groups (in the ionomer membrane, reinforced with PTFE)
- 0.15 kg PTFE in the GDL

[9] 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.

The weights presented above per component clearly show that finding fluorine-free sealants would enable the large substitution of fluoropolymer 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-moulded 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 need of 44.25 tonnes, and an 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 fuel cell trucks and 1,000,000 fuel cell light vehicles on the roads by 2030, the total of required ionomer 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...).[10] Besides, it is obviously extremely unlikely for the fuel cell capacity to be reached by one unique technology, in that case, PEM.

In May 2022, the European Commission introduced its REPowerEU Plan[11] , which revised upwards the hydrogen targets of the 2020 EU Hydrogen Strategy[12]. According to the new figures, the EU will need to secure 10 million tonnes of imported renewable hydrogen and would have to ensure the production of another 10 million tonnes of renewable hydrogen by 2030. **If the EU were to reach its new REPowerEU objective for the production of 10 million tonnes of renewable hydrogen (i.e., ca. 140 GW of electrolyser capacity in terms of electricity input) only with PEM technology (which requires the ionomers), we would need a maximum of 1750 tonnes of ionomers** , 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, basis weight 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). The advances in reducing membrane thickness, highlighted above, clearly show potential to reduce this estimated tonnage.

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 fluoropolymer use in electrolysers through 2030, and the actual use is likely to be much lower, also because of the gradual improvements in the technology. It is very difficult to make predictions past 2030 because cell construction, mode of operation, and market size are either unknown or difficult to predict. Hydrogen Europe collects operational water electrolysis deployments. Based on data as of August 2022, there are 106 water electrolysers that are operational today, for which Hydrogen Europe knows the electrolyser technology. This corresponds to 142.2 MW of capacity. PEM represents 83.5 MW from 55 deployments and ALK represents 57.7 MW from 42 deployments. The rest are operational solid oxide, anion exchange membrane (AEM), or other technologies.

[10] 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

[11] European Commission, REPowerEU Plan, May 2022: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A230%3AFIN&qid=1653033742483

[12] European Commission, A hydrogen strategy for a climate-neutral Europe, July 2020: https://ec.europa.eu/energy/sites/ener/files/hydrogen_strategy.pdf

Based on the same benchmark of 140 GW electrolysis capacity in terms of electricity input (which would amount to around 100 GW in terms of hydrogen output), other fluoropolymer use for the sealing materials (especially PTFE) would roughly amount to 8,750tonnes at manufacturing, resulting in about 4,375 tonnes in the end-product.

In addition to the volumes in electrolyser and fuel cell applications, fluoropolymers use in the hydrogen industry is substantial due to their unique characteristics. As it has been evaluated above, a variety of fluoropolymers are being used as valves, seals and other membranes in all stations in the value chain, from through production through infrastructure applications to hydrogen-specific end-uses. It would therefore be difficult to estimate the total tonnage of these fluoropolymers in the entire value chain.

4. At which stage(s) (manufacturing, use, disposal) do fluoropolymers used in the H2 value chain pose an emission risk? What is the level of danger?

- 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. The process of making ionomers is complex, requiring safe and responsible manufacturing. In 2021, members of the Fluoropolymer Product Group (the EU industry association of fluoropolymer manufacturers) have committed to responsible manufacturing principles in terms of continuously improving and developing best available techniques in the manufacturing process, management of environmental emissions, R&D for the advancement of technologies (including the industrialisation of those technologies) allowing for the replacement of PFAS-based polymerisation aids, and the increase of recyclability and reuse of its products in line with the objectives of circular economy. 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 ionomer 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 fluoropolymers are sealed inside an engineered product (electrolyser or fuel cell) as a perfluorinated ionomer 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 misplaced or that could end up in the environment as any B2C product. The ionomers used in electrolysers and fuel cells, which are B2B products, are thermally stable during their intended use as they only start to degrade at temperatures above 175°C and have an exceptional degree of proven chemical stability in application. 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, the ionomer does not pose a risk. In case of electrolyser operation, it is mostly covered by water (<100°C) in the contained electrolyser system 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. 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[13], perfluorinated polymers like PTFE, PFA and FEP (Fluoroethylenepropylene) 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 ionomer 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 ionomer , 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, there is strong promise that the ionomers can be recovered and reused at the end of its lifecycle as demonstrated in the UK Research and Innovation (UKRI) project Frankenstack[14]. In addition, several patents exist entailing methods for recovering and recycling CCMs through dissolving the membranes and separating the components.[15] 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. [16] The study carried out by Aleksandrov et al. in 2019[17] 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. It should be noted however, that Dutch Institute for Public Health and Environment (RIVM) drew slightly fewer concrete conclusions, mentioning that, although it can be assumed that the polymer molecules are destroyed with the gasification process, this does not provide enough information on the kind and degree of by-products formed and on the rate of mineralisation.[18]

[13] Ibid

[14] Frankenstack, UK Research and Innovation, https://gtr.ukri.org/projects?ref=133704

[15] E.g.: Grot S. and Grot W., US7255798B2 - Recycling of used perfluorosulfonic acid membranes - Google Patents; Coleman R. Ralph T., and Plechkova N., EP3275036B1 - Process - Google Patents

[16] 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).

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).

[18] Bakker et al., Per- and polyfluorinated substances in waste incinerator flue gases, RIVM rapport 2021-0143, 2021. DOI 10.21945/RIVM-2021-0143

5. What could be the alternatives to the fluoropolymers currently used in the H2 value chain? By when could they become available? What is the potential for research?

Are there alternatives to fluoropolymers 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[19]. 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, which 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 (polybenzimidazole) 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.
- Electrodes
  - Electrodes or catalyst layers using non-fluorinated, hydrocarbon-based ionomers as binder polymer pose another challenge in research and development due to requirements of high gas permeability in the electrode, as mentioned earlier. These drawbacks are also confirmed by recent academic efforts on fluorine-free MEAs.[20]

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[19] See, amongst others: Chi Hoon Park, Chang Hyun Lee, Michael D. Guiver, Young Moo Lee, Progress in Polymer Science, Volume 36, Issue 11, 2011, Pages 1443-1498, ISSN 0079-6700, https://doi.org/10.1016/j.progpolymsci.2011.06.001; Dong Won Shin, Michael D. Guiver, and Young Moo Lee,Chemical Reviews 2017 117 (6), 4759-4805 DOI: 10.1021/acs.chemrev.6b00586; N. Esmaeili, E. M. Gray, C. J. Webb, *ChemPhysChem* **2019**, *20*, 2016.

[20] https://onlinelibrary.wiley.com/doi/full/10.1002/aenm.202103559 "Even with optimized ionomer content, ion exchange capacity, and solvent systems, hydrocarbon MEAs feature inferior performance compared to state-of-the-art PFSA MEAs even at high humidity (>80% RH) and especially in the kinetic region (E > 0.7 V).[1, 17, 59] The inferior performance of hydrocarbon MEAs at high humidity and at high cell potentials might be linked to 1) a lower ECSA, 2) a lower oxygen permeability of hydrocarbon ionomers, and 3) a slightly lower proton conductivity of hydrocarbon ionomers in the catalyst layer."

- Gas Diffusion Layer (GDL)
  - Hydrophobisation of the GDL is today always achieved using 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 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 materials
  - Due to the harsh environment in combination with the sensitivity of the MEA for contamination, very stable sealing materials are needed. 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. In limited amounts graphene and flexible graphite applications were tested to substitute fluoropolymers in sealings, gaskets and wedges. However, such products would sacrifice chemical resistance if a metal sheet were to be used to add strength, while it would also increase the cost substantially, while limiting uses in key sectors. These should be considered as unproven in both economic viability and in technological terms for the sake of providing an alternative for fluoropolymers.

    Therefore, fluorinated sealing materials are today a standard for water electrolysis technologies and for a variety of applications in the hydrogen value chain. Based on failed past efforts in research for alternatives, we predict that those will surely be standard for another 10 years at least. However, for environmental and cost reasons, efforts are made to eliminate the PFAS/fluoropolymers 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.

Concisely, the material properties of perfluorinated polymers are unique and impossible to replace in the near future. Restrictions on fluoropolymers, including PTFE and ionomers with bound PFSA, would make 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. Such lowering of the performance of essential applications in the hydrogen industry would drastically slow down the ramp up of this nascent industry, potentially killing such a crucial industry for decarbonisation.

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. Earlier 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?

Ionomers are significantly stable, mechanically strong and contained inside membrane/electrode assemblies containing expensive catalysts. Therefore, any sort of contamination during use is negligible. So far so that beyond F- (fluorine anions) contamination, which is non-toxic in these concentrations, there are no detected contaminations caused by PEM fuel cells and electrolysers.

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 little chance of the membrane entering the general waste stream, besides of the exceptionally low contamination risk. Fluoropolymers such as ionomers with bound PFSA, 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 fluoropolymers make sense for fuel cells and electrolysers?

Potential alternatives to perfluorinated membranes would have to comply with rigorous KPIs, including on stack degradation, current density and gas impermeability.[21] There are no alternatives to perfluorinated membranes that offer the same durability, gas impermeability, thermomechanical performance, efficiency, and current density, or that can provide minimum acceptable levels thereof for the membranes to fulfil their function. In fact, gas impermeability might even be improved in the case of hydrocarbon membranes, which, in the case of specialised use in electrolysers, makes them unsuitable to use as binders in electrodes, where high permeability is necessary.[22]

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 fluorocarbon membranes. Alternative materials that are currently being studied are hydrocarbon sulfonated polymers that suffer from dimensional stability and require mechanical reinforcements. Important R&D efforts are still needed in order to find viable solutions to replace ionomers. Over fifty years of development place fluorocarbon membranes 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, while it is necessary to stress that both performance and environmental and health related trade-offs need to be considered. Today, there is new low-TRL (technology readiness level) 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,

[21] For further information on key performance indicators for PEM electrolysers, alkaline electrolysers, and fuel cell technologies (amongst others), please consult in particular Annexes I-III of the most recent Strategic Research and Innovation Agenda by the Clean Hydrogen Partnership (2022) https://www.clean-hydrogen.europa.eu/about-us/key-documents/strategic-research-and-innovation-agenda_en

[22] https://onlinelibrary.wiley.com/doi/full/10.1002/aenm.202103559 "There have been drastic improvements made in the electrochemical properties of hydrocarbon membranes in terms of proton conductivity and durability. However, two weak points of this material class remain. First, the improvement of proton conductivity at low RH is a crucial parameter for future applications, which requires further optimization on ionomer level. Second, on experimental cell level, promising mechanical and chemical fuel cell durability (>1000 h open circuit voltage (OCV) and >30 000 RH cycles)[19] was demonstrated, but not proven on full size cell yet or short stack level."

but it can be diversionary and a waste of resources, unless the same KPIs (key performance indicators) 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 (original equipment manufacturer) products, and be introduced into the marketplace, which is not foreseen at the very least within the next 10 years.

Overall, 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 an early stage and many questions are still open. Although the definition of such a concept is taking place under the ongoing revision of REACH and is therefore separate from the PFAS restriction process, it is still relevant for sectors consuming PFAS-based materials like the hydrogen industry to engage on this issue being discussed in parallel to the PFAS restriction process. One of the most controversial questions 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 shows that the criteria for essential uses are planned to be defined in the period 2021-22, although as of today the process is ongoing and has not been finalised.

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. Firstly, the REPowerEU fixes the ambitious objective of around 140GW of electrolyser capacity (in terms of electricity input) and 10 million tonnes of renewable/low-carbon 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 fluoropolymers 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 fluoropolymers 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[23] and environmental perspective[24]. 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 barrier now. Finally, just as in the spirit of the Carbon Border Adjustment Mechanism (CBAM) 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 electrolyser and fuel cell manufacturers in non-EU 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, i.e., that would not exempt fluoropolymers use across the hydrogen value chain, would have devastating consequences for the hydrogen industry, from the jobs and revenues it provides and will provide, to the key role hydrogen is to play to reach decarbonisation, system integration objectives and independence from fossil fuels.

The use of fluoropolymers is at the core of numerous hydrogen applications, not least many electrolyser and fuel cell types. Whereas the future market shares of respective electrolyser and fuel cell technologies cannot yet be estimated exactly, PEM electrolysers and fuel cells are expected to reap significant market shares and could possibly prove more suited to certain 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 ionomers. Additionally, alkaline water electrolysis, along with all electrolysers and fuel cell types, and a variety of key hydrogen infrastructure and end-use applications would be severely affected since fluoropolymers, such as PTFE are used as sealants, valves, fittings and in addition to membranes in those products.

What could be the socio-economic impacts of a ban?

In the short term the ban would slow down deployment of the clean hydrogen ecosystem and would effectively eliminate PEM electrolysers and PEM fuel cells from the market. Taking the EU Hydrogen Strategy and the REPowerEU as basis for future investment, a general PFAS ban would jeopardise around €1.8 bln by 2024 in electrolysers only.[25] Since PEM electrolysers are indispensable for large scale RES integration with the power grid, and are key in sector coupling, a ban would not only restrict the hydrogen market, but would potentially also negatively affect the deployment of needed RES capacities on the EU market.

In a ten-year view, the ban would jeopardise investment worth €18.75 bln in electrolysers only (based on the same 2030 REPowerEU strategy). In the mid-term, the general PFAS ban would most severely impact applications in the mobility market (both maritime and road). With expected fleet numbers, the fuel cells systems alone on all those vehicles are estimated to be around €18.7 bln, with an additional €2 bln for

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[23] 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)

[24] 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)

[25] Assumed 25% of all EL projects to rely on PEM based on own analysis of existing project pipeline, w/ assumed CAPEX=€750/kW (average betw. current costs of €1000/kW + CHE PPP SRIA KPI 2030 target=€500/kW)

refuelling stations.[26] In total, in a ten-year timeframe the proposed general PFAS ban would put at risk a total investment value in the clean hydrogen sector of €26-36 bln. Additionally, it would put 147-203 thousand jobs, and an extra 263-282 thousand indirect jobs at risk.[27]

Therefore, an incautious ban on the use of PFAS would set back the PEM fuel cell and PEM electrolysis 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.
To sum up: no PFAS, no PEM fuel cells & electrolysers, no successful EU Hydrogen strategy roll-out.

8. What best practices can the industry propose to legislators, to ensure the risks posed by fluoropolymers 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 use stage, adsorption techniques (e.g., ion exchange resin) could be used to remove trace amounts of PFAS from effluent streams.

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"[28] 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[29]. There is or should be an economical

[26] FC vehicles deployed by 2030 assumed based on IA of 2021 RED revision and FuelEUMaritime. Total value of investments at risk calculated assuming €400/kW of FC module for ships & HDV & €200/kW for LDV w/ added value of H2 tanks=€300/kg (30kg storage/HDV and 5kg storage/LDV). Nb of HRS estimated at 1,000 (based on AFIR targets). CAPEX assumed at €2M/HRS w/ a 1t/day capacity (CHE PPP SRIA KPI 2030 target)

[27] Jobs at risk calculated based on FCHJU Study (https://www.fch.europa.eu/sites/default/files/Evidence%20Report%20v4.pdf; https://www.fch.europa.eu/sites/default/files/Findings Report v4.pdf): 5.6 FTE direct jobs (DJ) & 1.84 FTE/€1M worth of PEMEL deployment; 2.3 FTE DJ & 14.1 indirect jobs(IJ)/€1M worth of HD FCEV depl. (incl. ships); 2.8 FTE DJ & 12.9 FTE IJ/€1M worth of LD FCEV depl.

[28] 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.

[29] Examples here: https://info.ballard.com/technical-note-recycling-fuel-cells; https://www.umicore.com/en/newsroom/news/umicore-fuel-cell-catalysts--0/

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, which 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 physically bound to the membrane, thus cannot be separated from each other), there are two ways to recycle. Today, the most common technique is to ash the catalyst-coated 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 is likely to be achieved by using conventional solvents. The ionomer is transferred into the liquid phase and can be separated from electrocatalyst and reinforcement. The aim of this process is to try and recycle the ionomer. Such an ionomer is also a highly expensive and valuable material, so the development of recycling processes can be commercially attractive. Whether this process can be successfully done on an industrial scale is still an open question, however early projects show potential. Recycling of the ionomer is investigated by academia and industry, e.g., in the Germany-funded project BReCycleEU[30], or the EU-funded project BEST4Hy[31], with the aim to recover 70% of the ionomer, demonstrating a TRL of 5 by the end of 2023.

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 set up 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 summary, the main fluoropolymers used in the hydrogen industry are ionomers and PTFE. Fluorine can be recovered from all of them, as part of 100% recyclable MEAs for PEM water electrolysers and PEM fuel cells. Multiple recycling techniques exist and are being experimented by the industry. Yet, both the hydrogen and fuel cell industry and those recycling techniques are at a nascent stage, explaining why most perfluorinated materials are still being incinerated today. Recycling and recovery processes should be developed further, ramped up, and receive proper 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.

[30] https://www.iwks.fraunhofer.de/de/presse-und-medien/pressemeldungen-2020/neues-forschungsprojekt-brecycle.html
[31] https://best4hy-project.eu/

V. Conclusion

Due to the concerns raised by the negative impacts of 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 products (fuel cells and electrolysers are sealed B2B products and cannot be regulated in the same way as consumer textiles 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-fluoropolymer alternatives at a same level-playing field in terms of KPIs offered by fluoropolymers (i.e., considering quality, lifetime, efficiency and cost aspects), which alternatives should also present lower health, environmental and sustainability concerns than current fluoropolymer applications, 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. Membranes manufacturers have invested heavily because they see rising sales to fuel cells and electrolyser manufacturers in the context of the growing acknowledgment of hydrogen technologies. Therefore, the timing of this potential ban on PFAS would be extremely unfortunate 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 REPowerEU, 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 fluoropolymers in fuel cells and electrolysers needs to be classified as an essential use for society, because there is no alternative, because fluoropolymers 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 and their suppliers should be exempted from any proposed fluoropolymer ban if the EU wants to deliver on its REPowerEU and climate objectives.

Annex I - Glossary

AEM	Anion exchange membrane
ALK	Alkaline Water Electrolysis
B2B	Business to business
B2C	Business to consumer
BAT	Best available techniques
CBAM	Carbon Border Adjustment Mechanism
CCM	Catalyst-coated membrane
DMFC	Direct-methanol fuel cells
ECHA	European Chemicals Agency
ETFE	Poly(ethene-co-tetrafluoroethene)
EU	European Union
FEP	Fluoroethylenepropylene
FEPM	Tetrafluoroethylene propylene
FFKM	Perfluoroelastomer
FKM	Fluoroelastomers
GDL	Gas diffusion layer
HFP	Hexafluoropropylene
HRS	Hydrogen refuelling station
KPI	Key performance indicator
LOHC	Liquid organic hydrogen carrier
MEA	Membrane electrode assembly
MPL	Microporous layer
OECD	Organisation for Economic Cooperation and Development
OEM	Original equipment manufacturer
PBI	Polybenzimidazole
PEEK	Polyetheretherketone
PEM	Proton Exchange Membrane
PFA	Perfluoroalkoxy alkanes
PFAS	Per- and Polyfluoroalkyl substances
PFCA	Perfluoroalkyl carboxylic acids
PFSA	Perfluorosulfonic acid
PGM	Platinum Group metals
PLC	Polymers of low concern
PMVE	Perfluoromethylvinylether
PTFE	Polytetrafluoroethylene
RAC	Risk Assessment Committee
REACH	Restriction, Evaluation, Authorisation and Restriction
RES	Renewable energy sources
RMOA	Regulatory management option analysis
RoI	Registry of Intention
SEAC	Socio-Economic Assessment Committee
TFE	Tetrafluoroethylene
TRL	Technology readiness level
VDF	Vinylidene fluoride

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