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| **Short Title** | Submission to ECHA on the use of PFAS in Fuel Cell Systems |
| **Full Title** | Submission to ECHA on the use of PFAS in Fuel Cell Systems |
| **Abstract** | A response to the European Chemicals Agency's proposal to restrict the use of per- and poly-fluoroalkynated substances under the EU's REACH regulations. |

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# 1.0 Executive Summary

In ECHA's restriction proposal, the various exemptions (e.g., for biocidal and medicinal active ingredients) and 12 year derogations acknowledge that trade-offs are required where substitutions for PFAS are not feasible.

For several applications in fuel cells there are no viable alternatives to using PFAS. This is particularly critical regarding membrane electrode assemblies (MEAs), where there is no currently visible pathway to an alternative material or technology for critical components. A complete restriction of PFAS, even with a 6.5 year derogation for fluoropolymers used in PEM fuel cells, would be a major setback to the hydrogen fuel cell industry, including Ballard Power Systems. Consequently, it would incur challenges for the EU to meet its decarbonization targets.

We recognize that fluoropolymers in other applications may pose a higher risk for emissions. We believe that a PFAS restriction should allow for fluoropolymers generally, and restrictions should be targeted at specific markets or applications based on a risk assessment of those respective applications. As non-PFAS fuel cell technology matures, the risks in the fuel cell industry can be re-examined.

Alternative measures to manage PFAS emissions from the fuel cell industry, such as producer recovery, and development of recycling technologies should be investigated. Ballard intends to continue analyses to better understand our emissions and tools to mitigate them. By taking a risk based, measured approach we believe the EU can meet the objectives of reducing PFAS emissions while maintaining a strong hydrogen fuel cell industry that supports the Union's clean energy goals.

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## 3.0 Definitions and Acronyms

- BoP – Balance of Plant
- CCM – Catalyst Coated Membrane
- DRE - Destruction and Removal Efficiency
- ECHA – European Chemicals Agency
- EPA – Environmental Protection Agency (US)
- EPTFE – Expanded PolyTetraFluoroEthylene
- ESG – Environmental, Social and Governance

- FKM – the American standard short form name for fluoroelastomers or fluoro rubber materials
- GDL – Gas Diffusion Layer
- MEA – Membrane Electrode Assembly
- OCV – Open Circuit Voltage
- PEM – Proton Exchange Membrane
- PFAS - Per- and Poly-Fluoroalkyl Substances
- PTFE – Polytetrafluoroethylene

## 4.0 Background and Objectives

Ballard was founded in 1979 under the name Ballard Research Inc. to conduct research and development on high-energy lithium batteries. In the course of investigating environmentally clean energy systems with commercial potential, Ballard began development work on fuel cell technology. Following initial development work done for the Canadian Government, Ballard decided in 1989 to focus our main research and development efforts on proton exchange membrane (PEM) fuel cells and fuel cell systems. To that end, we sold our battery subsidiary in 1995. Since committing ourselves to the development of PEM fuel cell technology, we have delivered PEM fuel cells and PEM fuel cell systems worldwide to a number of leading product manufacturers.

From 1992 to 1994, a number of subscale and full-scale projects were developed to demonstrate the Ballard technology. In 1993 the company succeeded in fulfilling a contract from the B.C. government to build a fuel-powered demonstration bus. Many in the company thought it was too soon, fearing the huge risk of public failure if it didn't work. But the bus did work, and demonstrated to the world that Ballard was way out in front in developing fuel cells.

Major developments have occurred in the company since 2000. Focused on building their capabilities as a low-cost, high-quality, high-volume manufacturer, Ballard made the transition from hand-built prototypes to automated, volume-oriented processes. Ballard Power Systems' first fuel cell manufacturing facility, a 10,220-square-metre plant in Burnaby, B.C. that opened in 2000, is the world's first volume manufacturing facility for PEM fuel cells and provides an additional competitive advantage for Ballard in bringing its fuel cell products to market. The move enabled Ballard to work on fundamental improvements in design, materials and processing, further driving the company's product innovation and expanding its manufacturing strength.

Today, Ballard Power Systems, Inc.is a global leader in PEM (proton exchange membrane) fuel cell technology. We provide clean energy fuel cell products enabling optimized power systems for a range of applications. Ballard offers smarter solutions for a clean energy future.

Ballard is actively putting fuel cells to work in high-value commercial uses every day. Currently this work uses PFAS for a variety of applications in fuel cells and fuel cell systems. This report intends to summarize the key uses of PFAS in Ballard's fuel cells and fuel cell systems, the state of alternatives available, and Ballard's recommendations for minimized potential PFAS emissions while providing a clear pathway for zero emissions technologies including fuel cells.

## 5.0 PFAS, Fluoropolymers and Risks

The European Chemicals Agency (ECHA) has proposed to restrict effectively all PFAS under a single restriction. However (from Ballard Power Systems Inc. Response to Draft State of PFAS Report, 3),

*This class is of materials is comprised of more than 4700+ individual substances, which are highly varied in physical and chemical properties, health and environmental profiles, uses, and benefits. Included in this PFAS designation is a subgroup of polymeric materials, fluoropolymers, that is critical for hydrogen fuel cell development and use and is essential in many other industries related to the hydrogen economy. These materials are specifically chosen and used for their distinctive combination of properties which include durability, mechanical strength, inertness, and resistance to degradation in harsh chemical conditions. In the fuel cell industry where they are used as key components in the technology, there are other unique properties which they deliver including hydrophobicity, ionic conductivity, hydrogen-imperviousness, and chemical resistance. At the current time, there are no viable alternatives to the fluoropolymers that would deliver the same performance, durability and longevity required by the industry.*

*Ballard is actively engaged with suppliers of key PFAS components used in fuel cells to understand their activities and response to the environmental and health concerns coming to our attention. Most suppliers have committed to immediate targets around eliminating the shorter chain processing aids from their fluoropolymer manufacturing and many have longer term goals to investigate non-fluorinated options to completely replace fluoropolymers. However, this work is in its infancy requiring many years and much investment to materialize.*

*While there are many substances within the 4700+ grouping of PFAS that certainly require strict control and regulation such as perfluorooctanoic acid (PFOA) and perfluoro octane sulfonate (PFOS), the properties of these specific compounds, such as toxicity, cannot reasonably be extended to all compounds within the larger grouping. It is our concern that should the entire grouping of PFAS compounds be treated as a single class, the resulting and subsequent regulations regarding PFAS would be applied wholistically and therefore restrict use of fluoropolymers without the specific data to support such a restriction.*

*Instead, Ballard would urge that ECHA's approach to PFAS should be not a blanket approach, but rather in the spirit of aligning with actions in other jurisdictions, follow the examples of various countries which provide approaches and regulations suited to each reasonable subclass of material. Further research and risk assessments should be performed against these subclasses to ensure regulations and restrictions are based on sound evaluations and data. Examples of countries taking this, or a similar approach, include the following:*

> *USA - To accelerate EPA's ability to address PFAS and deliver public health protections sooner, EPA is working to break the large, diverse class of PFAS into smaller categories based on similarities across defined parameters (such as chemical structure, physical and chemical properties, and toxicological*

*properties). EPA plans to initially categorize PFAS using two approaches. In the first approach, EPA plans to use toxicity and toxicokinetic data to develop PFAS categories for further hazard assessment and to inform hazard- or risk-based decisions. In the second approach, EPA plans to develop PFAS categories based on removal technologies using existing understanding of treatment, remediation, destruction, disposal, control, and mitigation principles.[a]*

*Australia - The National Industrial Chemicals Notification and Assessment Scheme (NICNAS) assessed the risks of more than 200 PFAS chemicals available for use in Australia, focusing on PFOS and PFOA and their direct and indirect precursors (other chemicals that break down in the environment to form PFOS and PFOA). NICNAS also assessed the risks of related chemicals including shorter chain PFAS that may be used as replacements for PFOS and PFOA.[b]*

*China – governed by the Ministry of Ecology and Environment (MEE), uses implementation of the Stockholm Convention to address PFAS, through the Action Plan on Controlling New Pollutants.[c],[d],[e]*

*UK - A generic PFAS definition may not be particularly useful from a regulatory perspective, and it may be more appropriate to consider regulatory approaches on the basis of particular PFAS groups and/or uses. As such, this is the approach adopted by this RMOA (Regulatory Management Options Analysis). The UK also defines PFAS as "Fluorinated substances that contain at least one fully fluorinated methyl carbon atom (without any hydrogen, chlorine, bromine or iodine atom attached to it), or two or more contiguous perfluorinated methylene groups (–CF2–)."[f]*

*[a]* https://www.epa.gov/system/files/documents/2021-10/pfas-roadmap_final-508.pdf

*[b]* https://www.industrialchemicals.gov.au/consumers-and-community/and-poly-fluorinated-substances-pfas

*[c]* https://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/countryinformation/china.htm

*[d]* http://english.www.gov.cn/policies/latestreleases/202205/24/content_WS628cd024c6d02e533532b3e1.html

*[e]* https://www.gov.cn/zhengce/content/2022-05/24/content_5692059.htm

*[f]* https://www.hse.gov.uk/reach/assets/docs/pfas-rmoa.pdf

In these other countries' approaches, the primary risk to be managed is toxicity, not persistency. This report will show that it is that same persistency that makes fluoropolymers ideally suited for fuel cell applications.

As covered in the response to Environment and Climate Change Canada above, Ballard believes that the grouping of fluoropolymers in the same category as demonstrated toxic substances such as PFOS is not supported by the current research.

1. The risks posed by fluoropolymers are small compared to other PFAS.
2. PFAS emissions from the fuel cell industry are small relative to the main sources of PFAS emissions.
3. The majority of PFAS emissions from the fuel cell industry can be managed through appropriate measures.

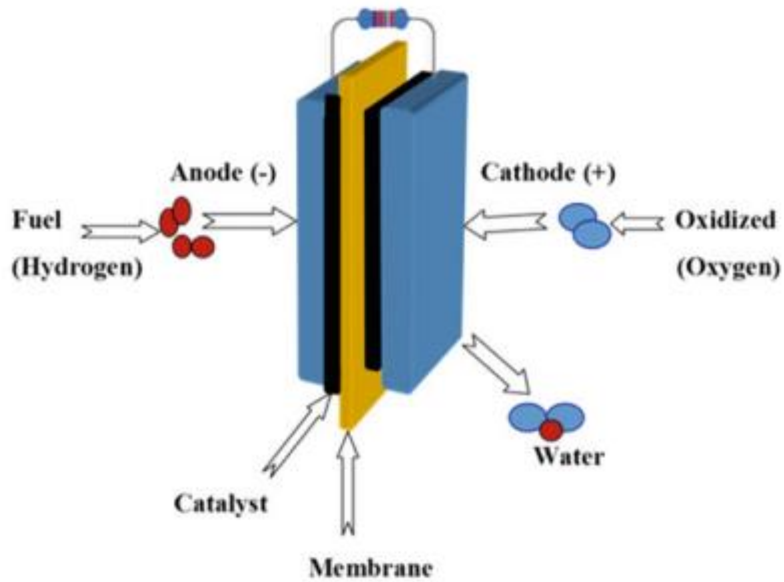
In ECHA's restriction proposal, the various exemptions (e.g., for biocidal and medicinal active ingredients) and 12 year derogations acknowledge that trade-offs are required where substitutions for PFAS are not feasible. This report hopes to demonstrate that fuel cell systems are an application where the alternatives are not feasible to substitute out PFAS within the proposed 6.5 year derogation.

## 6.0 Uses of PFAS in Fuel Cell Systems and their Alternatives

A fuel cell is an electrochemical device that converts chemical energy into electrical energy. Due to the electrochemical reactions occurring on both electrodes of the FC, the fuel at the anode side is oxidized to release electrons, which are then transferred to the cathode side via an external circuit, reducing the oxidant species (usually oxygen). The flow of electrons during these electrochemical processes gives rise to current in the electrical circuit, while potential differences exist over the two electrodes based upon the nature of the redox reactions (Albarbar and Alrweq, 4).

A fuel cell consists of several components. The membrane is the heart of the fuel cell – it allows hydrogen protons to pass through the membrane, while electrically isolating both sides. A catalyst, often platinum, is mixed with an ionomer and coated on both sides of the membrane to accelerate the hydrogen reduction on the anode side, and oxidation on the cathode. A gaseous diffusion layer helps distribute and smooth the flow of the reactant gases.

**Figure 1: Functionality of the proton exchange membrane fuel cell**



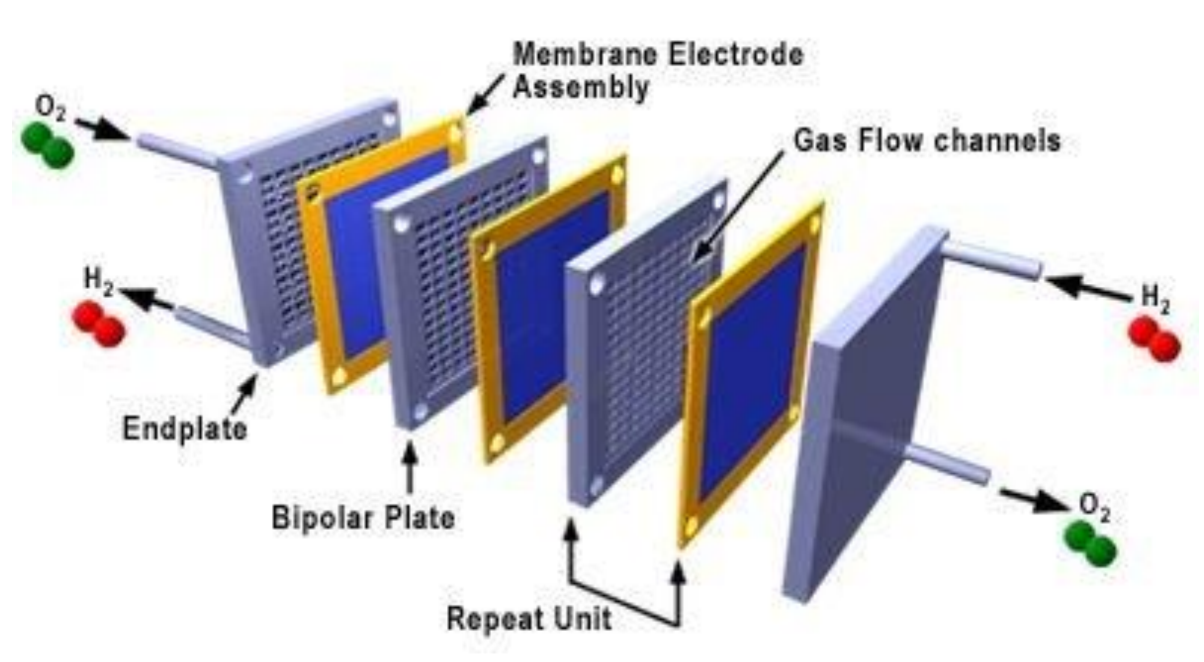

*An overview of a single PEM fuel cell. PFAS materials are used for a variety of purposes throughout the membrane. (Albarbar and Alrweq, 4)*

Fuel Cell Stack

A single fuel cell can only produce a voltage on the order of 1 volt. To produce a useful voltage, multiple fuel cells are assembled in series to create a fuel cell 'stack.' To do this requires a bipolar plate to be added between the MEAs. This plate provides channels for the reactant fluids and coolant (typically water/glycol or air) and isolates each cell while remaining electrically conductive. Bipolar plates (plates) are commonly made from graphite reinforced resin or metal.

Seals are required between the plates and MEAs to prevent reactant fluids from leaking. Additional hardware is added at either end of the stack – this including bus bars and electrical connectors to complete the electrical circuit, compression hardware to ensure appropriate contact between all the components of the stack, fluid connections to plumb in reactants and coolant, and mounting hardware to provide for attaching the stack.

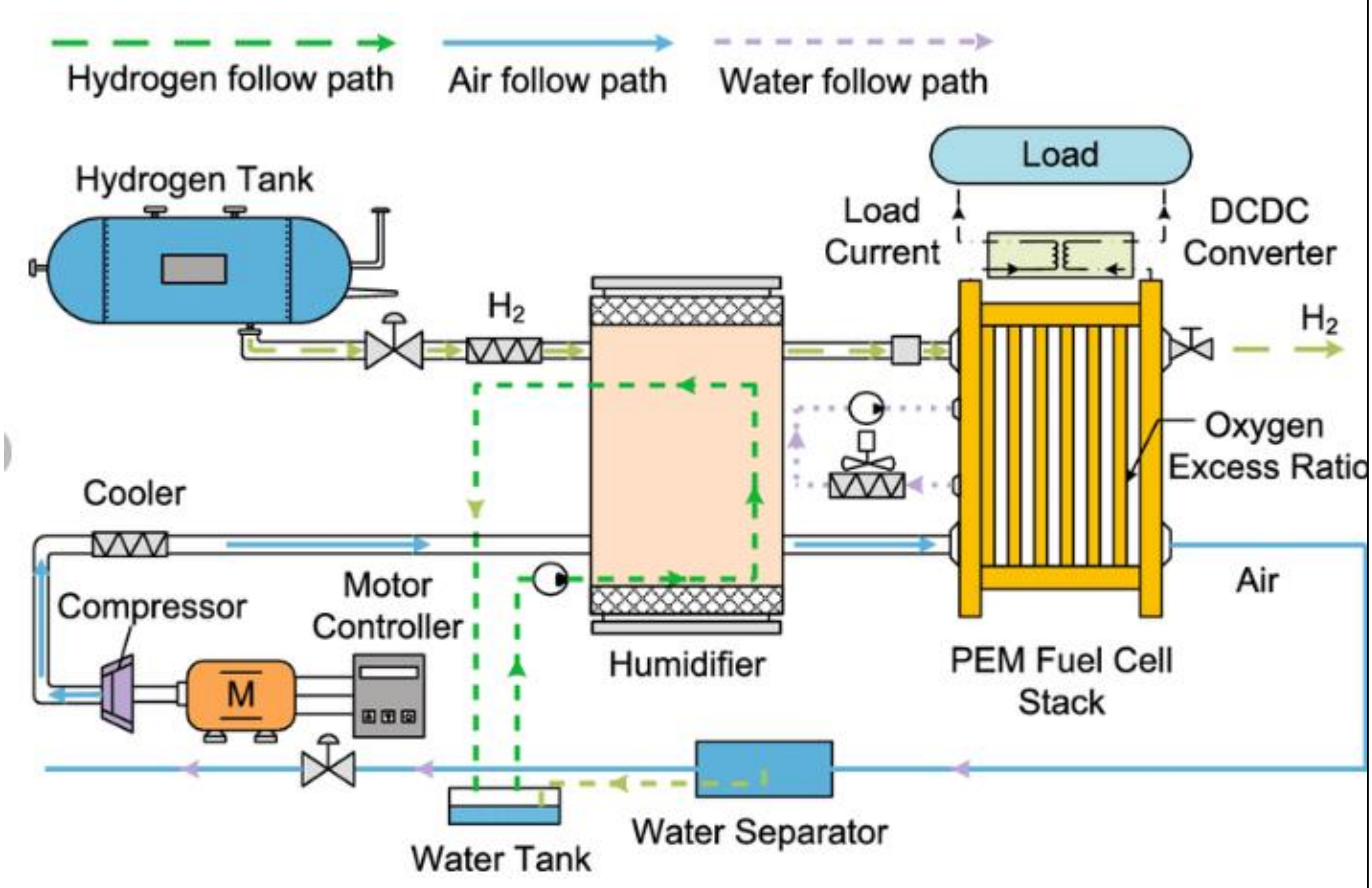
**Figure 2: Fuel Cell Stack**




*Exploded assembly of a generic fuel cell stack. Outside of the membrane electrode assembly (MEA) there is minimal use of PFAS bearing materials in the stack. Image source: "Mathematical modeling of polymer exchange membrane fuel cells" Colleen Spiegel.*

Fuel Cell System

**Figure 3: Fuel cell system**




*Block diagram of a simple fuel cell system. In addition to the fuel cell stack itself, materials containing PFAS are used throughout the entire system. Some of these uses are based on the deliberate choice of PFAS for its unique properties (e.g. hoses, some humidifiers), while for other components the use of PFAS is more incidental (e.g. gaskets, O-rings, sealants, lubricants, electrical and electronic components). Image source "Robust composite adaptive neural network control for air management system of PEM fuel cell based on high-gain observer", Wang et al.*

The fuel cell stack requires supporting equipment to function properly and create a fuel cell system. This additional equipment is commonly called the "Balance of Plant (BoP)." The specific equipment in the BoP can vary depending on the application, but common components include:

- Piping and valving for reactant fluids and coolant
- Air compressors and intercoolers
- Coolant pumps, fans and radiators
- Humidifiers
- Hydrogen recirculation pumps
- Motors and controllers for rotating equipment
- DC/DC converters
- Sensors and controllers

Fluoropolymers can be found in many BoP components. PTFE is commonly used in seals and gaskets. Electrical and electronic components may contain various PFAS. A challenge with the BoP is that Ballard does not have full visibility into the detailed material selection of all of these parts. Ballard is actively working with our supply chain to better understand where PFAS may be used in our system components, however this work is at an early stage.

Fluoropolymers are used extensively within the fuel cell itself, as well as the stack assembly and fuel cell system, as their key properties of chemical stability, hydrophobicity and electrical resistance are necessary to make the fuel cell and system meet the expected level of performance. Key uses of fluoropolymers are detailed below.

### *6.1 Membrane – Ionomer*

Proton Exchange Membrane (PEM) fuel cells

The ionomer is the heart of a fuel cell – it is what allows the hydrogen ions to cross the membrane while electrically isolating the electrons, creating an electric circuit. An ionomer needs several properties to be effective:

1. Chemical resistance. The membrane is in the heart of the fuel cell and subjected to harsh oxidative and reductive chemical conditions that will include exposure to reactants such as hydrogen and unintended reaction byproducts, all of which can react chemically with the membrane. Therefore, material choice for the membrane composition is critical to localized and subsequently, overall, durability.
2. Thermal resistance. Ballard's PEM fuel cells typically operate at temperature between 60°C and 90°C. The ionomer material needs to be stable in this region, while also withstanding non-operating temperature as low as -40°C.
3. Electrical resistance. Along with proton conductivity, electrical resistance is a necessary property in order to create an electric circuit. Lower electrical resistance leads to higher electrical losses, lower efficiency and greater difficulty in maintaining thermal balance.
4. Non-flammability. Given the proximity of hydrogen, oxygen and electrical potential, non-flammability is an important safety property. While there are some limited exemptions for membrane material, most fuel cell system standards (such as IEC 62282-2-100) require materials in the fuel cell system to be non-flammable, typically at least V-0 rated per IEC 60695 or UL-94.

5. Mechanical strength. During operation the membrane is subjected to changing conditions, including humidity level. As the humidity changes, the membrane will shrink or expand. As this occurs consistently and frequently over the life of the cell, the mechanical strength of the membrane is critical to ensure its ability to withstand the mechanically induced stress.
6. Proton conductivity. The ionomer must allow hydrogen protons to cross the membrane. It is this movement of protons combined with the electrical resistance that creates the voltage differential across the cell.

While individually these properties may be obtained with other materials, it is this unique combination of properties that makes fluoropolymers ideally suited for fuel cell ionomers.

Ballard is constantly evaluating alternative materials and has over 20 years of research on other ionomers. The challenges of alternative ionomer materials are listed below.

Due to confidentiality agreements with non-PFAS membrane suppliers, unfortunately we cannot provide detailed test data. What we can share is:

1. Hydrocarbon membranes show promising electrical performance under certain conditions.
2. Hydrocarbon membranes reinforced with ePTFE do not show any advantages with regards to humidity and temperature sensitivity.
3. Hydrocarbon membranes tend to show lower gas crossover.
4. Hydrocarbon membranes show significantly lower mechanical durability than PFAS based membranes, particularly under wet/dry cycling conditions.

Ballard acknowledges certain literature shows promising potential for hydrocarbon membranes. While we know that progress is continuing with these materials, we believe that the tests done in these settings are not representative of the environment membranes need to operate in for commercial products. Where there are indications that progress is being made with new materials and testing shows promising results against individual stressors (e.g., chemical degradation by open circuit voltage (OCV) or mechanical degradation by humidity cycling), true durability testing where all stressors are combined has not yet been proven out. [Long et al, 8]. Additionally, when the membrane material is not PFAS-based, trade-offs are inevitable. For example, aromatic and hydrocarbon ionomers still face mechanical stability issues due to high water uptake and swelling, so therefore require mechanical reinforcement from an expanded PTFE support layer to meet mechanical degradation targets [Noh et al, 10]. Industry is actively working towards replacing PFAS materials in fuel cells for additional reasons such as enabling higher temperature operation. However, subject matter experts recognize that there are gaps remaining in the current technologies which will take a great deal of research to close [Nguyen et al, 11].

Existing design texts even specifically call out fluorinated compositions as being particularly suited for fuel cells, for example, “Because of their good features and properties, fluorinated compositions are relatively stable in terms of chemical and thermal sense. For ion exchange, DuPont’s Nafion and Gore’s Primea membrane series are utilised. The lifetime of such membranes may be extended to thousands of hours.” (Albarbar and Alrweq, 4).

### *6.2 Membrane – Mechanical Reinforcement*

In order to last the required lifetime of a fuel cell stack, ionomers need to be mechanically reinforced. Fluoropolymers are currently the only materials capable of providing this reinforcement and meeting the other requirements of the fuel cell. These materials are called out explicitly in fuel cell design textbooks.

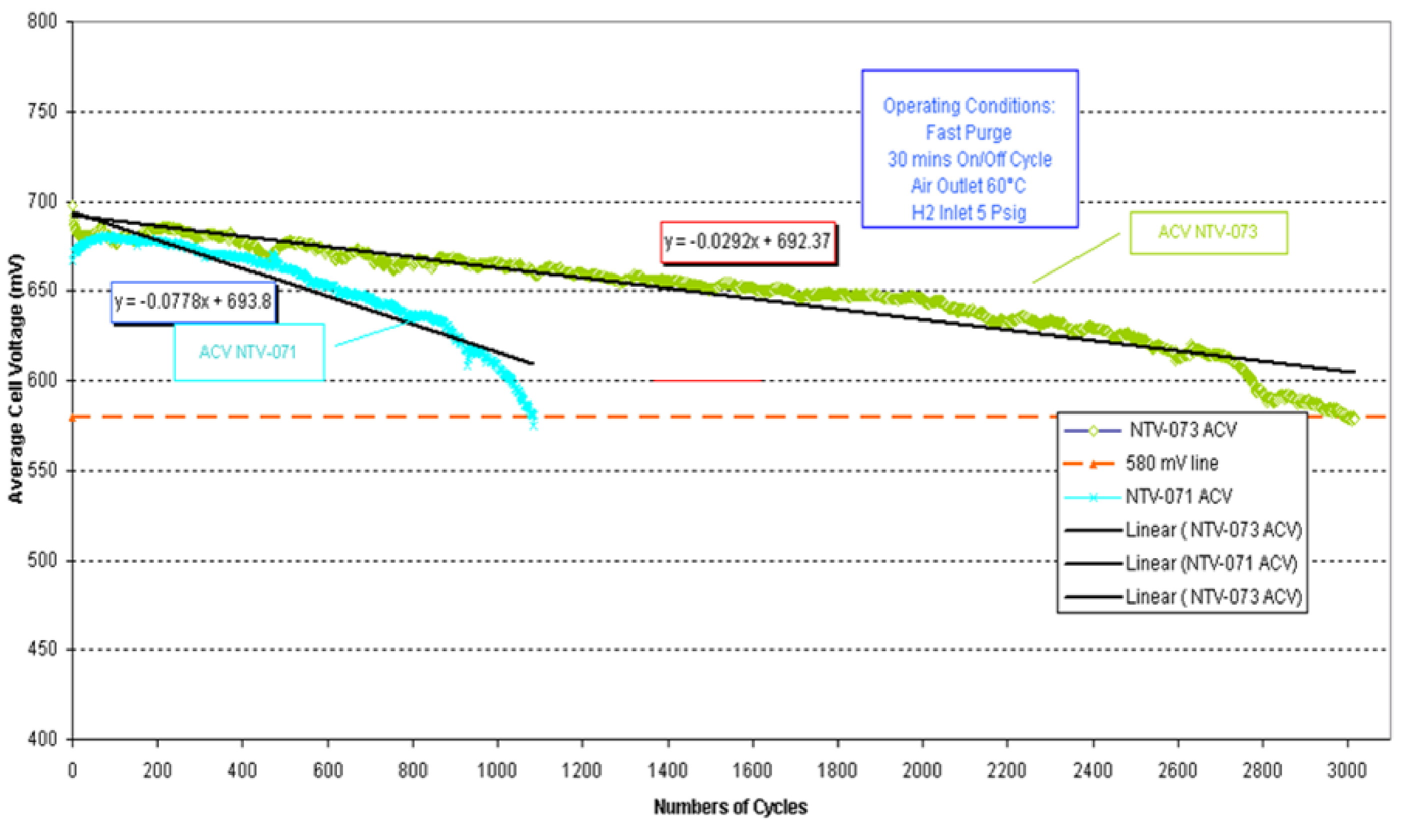
"To avoid or mitigate the mechanical failure of the proton exchange membrane (PEM), the membrane electrode assembly (MEA) and flow field structure of the cell should be carefully designed. In addition, preventing the hydration levels of the membrane to lower the allowable limit is essential, specifically at the reactant inlet area. Gore FC Technologies developed a PEM reinforced with e-PTFE, which demonstrated a lifetime, much longer than a non-reinforced PEM of relative thickness. Koh et al. [27] reported similar results for PEM with enhanced mechanical strength through use of 'Nafion®–Teflon®–phosphotungstic acid' composite membranes and reinforced Aciplex® membranes, respectively." (Albarbar and Alrweq, 4)

While non-PFAS alternatives to ionomers have been identified, it is important to note that even these non-PFAS ionomers use fluoropolymer materials for mechanical reinforcement. Ergo, a fuel cell using a non-PFAS ionomer would still not be compliant with the proposed restriction once the derogation period for PEM fuel cells ends.

To date there have been no substances identified that can provide mechanical reinforcement for the ionomer while also meeting the other key properties identified in section 6.1 above.

As mentioned above, we cannot share any non-PFAS ionomer data, but for comparison the charts below show the data emphasizing the difference in lifetimes between non-reinforced and e-PTFE reinforced membranes using a PFAS based ionomer.

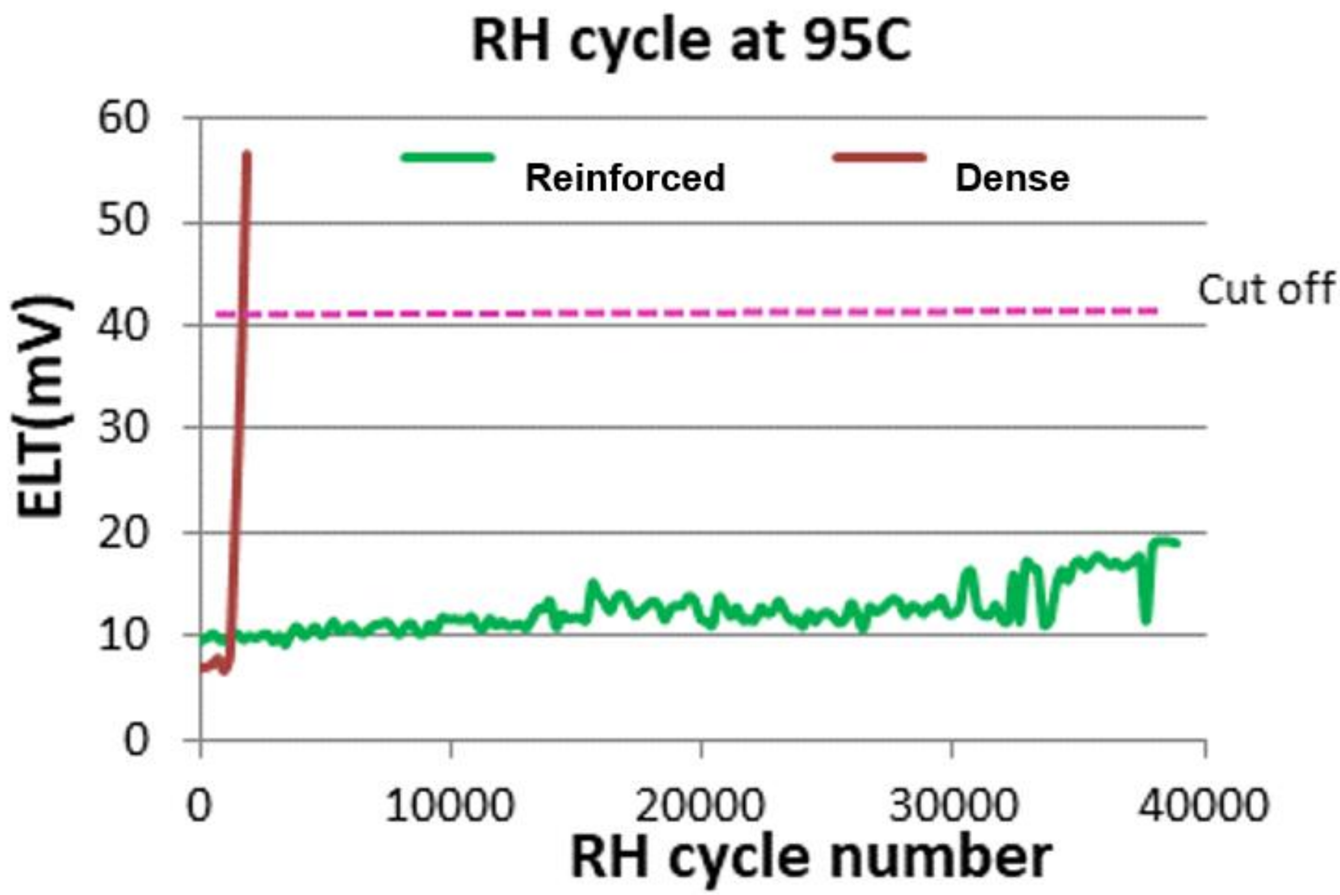
**Figure 4: Time to failure in a chemical stress test with varying levels of membrane reinforcement**




*There is a difference in lifetime between 2 MEA designs with differing levels of e-PTFE reinforcement when subjected to an accelerated chemical stress test. Test article ACV NTV-073 had an e-PTFE layer that was 33% thicker than test article ACV NTV-071. In this accelerated stress test the influence of the mechanical reinforcement is clear, with ~3x increase in time-to-failure for the test article with the thicker layer. Source: Ballard internal report.*

*580 mV = defined failure point*

**Figure 5: Time to failure in a mechanical stress test for an MEA with and without reinforcement**




*There is a very large difference in time to failure between MEA designs with and without e-PTFE reinforcement when subjected to an accelerated mechanical stress test. Test article "Reinforced" had an e-PTFE layer whereas test article "Dense" did not. The results of this test show the criticality of a mechanically reinforcing layer in the design of the cell. Source: Ballard internal report.*

*ELT = Electrochemical Leak Test, RH = Relative Humidity, Cut off = defined failure point*

### *6.3 Unit cell – Electrode binder*

The electrodes, cathode and anode, are mainly comprised of catalyst and ionomer. They serve a critical purpose in the cell – the platform for the targeted reactions to occur. They require several properties to function efficiently, which include providing ionic connection between the membrane and active catalyst sites, the ability to conduct protons, the ability to hold water in the layer and providing high oxygen permeability for reactant accessibility. Additionally, the ionomer must act as an adhesive to create a good membrane-catalyst layer interface. Within Ballard and in literature, the development of electrode layers with anything other than PFAS ionomer has been limited and shown minimal success. Currently, to utilize alternate materials may require trade-offs such as higher catalyst usage or use of more hazardous organic solvents. [Hyun et al, 9]

### *6.4 Unit cell – Additives*

Within the construction of the unit cell there are additional fluoropolymers present to provide structural or functional benefits. These will not be disclosed due to intellectual property considerations, but in these cases as well, the fluoropolymers are chosen for their collection of unique properties that are not present in non-fluorinated options.

### *6.5 Unit cell – Gas Diffusion Layer (GDL) and microporous layer*

Composition of the gas diffusion layer is based on a carbon fibre paper and is treated with a polytetrafluoroethylene (PTFE) additive to change the hydrophobicity of the material for water and reactant management purposes. In addition, the GDL will have a microporous layer added to it as an additional interface with the electrodes, providing a smoother surface with better electrical and thermal contact to the catalyst layers. This layer will also contain PTFE to provide a binding matrix for the components and to further control hydrophobicity.

### *6.6 Systems – Hoses*

Fluid handling is critical part of fuel cell system design. Material compatibility is a major factor in selecting fluid handling components. While a variety of materials have been developed for handling air and coolant, two particular issues arise when selecting materials for a fuel cell system:

1. Material compatibility with hydrogen
2. Avoiding contamination of the fuel cell

Additionally, the fluid handling system must meet typical engineering requirements such as

3. Mechanical requirements
4. Packaging
5. Manufacturability, Maintainability, Serviceability
6. Codes and standards
7. Cost and availability

Ballard has done extensive evaluation of hose and pipe materials to understand their impact on the fuel cell. The results of this work have led to a current approach of using silicone hoses lined with FKM (fluoroelasomers or fluoro rubber material) for hydrogen lines. Coolant, which does not directly contact the MEA, is carried in unlined silicone hoses to save cost.

#### 6.1.1 Metallic piping

Metallic pipes or tubes are a commonly used fluid connector for fuel cell systems. The challenges with piping are

1. Cost
2. Iron contamination
3. Serviceability
4. Packaging

Despite those challenges, stationary systems in particular will partially use metallic piping. However, the trade-offs are not as favorable in smaller systems requiring higher power densities, so flexible hoses are usually the choice for those.

#### 6.1.2 Silicone hoses (unlined)

Ballard has used unlined silicone hoses in fuel cell systems. The primary drawback of unlined silicone hoses is that silicone will leach from the hoses and embed into the MEAs, causing degradation and potentially damage to the MEAs. This results in a shorter lifetime of the fuel cell stack.

Our analyses have shown that by lining the hoses with FKM to prevent silicone from leaching out of the hoses, reduces the rate of siloxane extraction on the order of 50 times.

**Figure 6: Lined vs. Unlined silicone hoses**

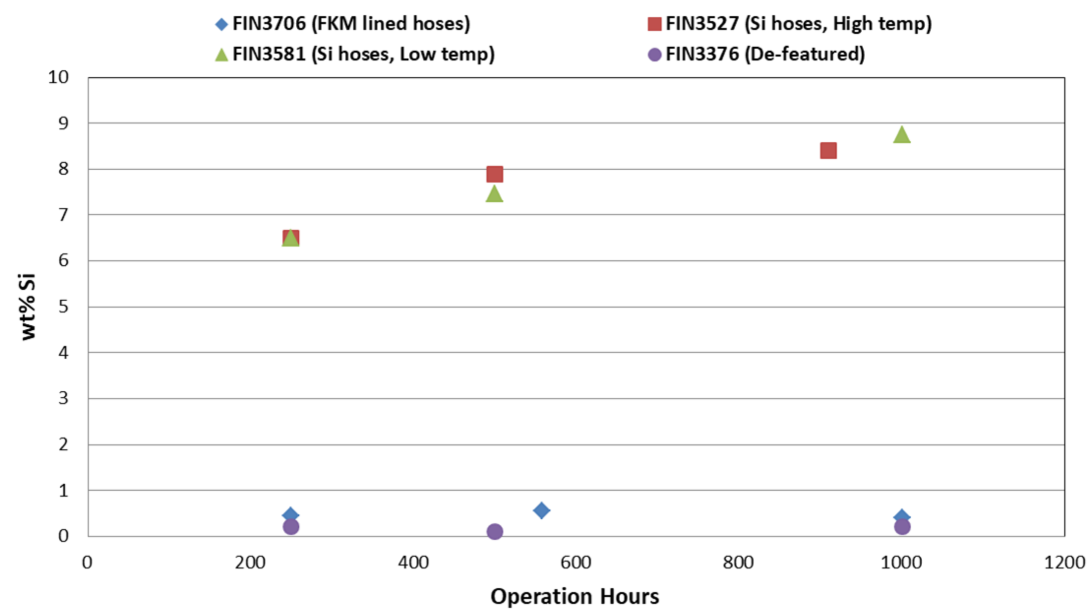
| Hose Type | Pt-cured Silflex hose | | | Viton lined Silicone hose | | |
|---|---|---|---|---|---|---|
| |  | | |  | | |
| Hose ID | 3.81 cm (1.5") | | | 3.81 cm (1.5") | | |
| Hose length tested | 19.2 cm | | | 5.5 cm | | |
| Inner layer thickness | unknown | | | 1.13 mm | | |
| Siloxanes extracted (and measured) (ug/cm2) | 0-24 hrs | 24-48 hrs | 48-72 hrs | 0-24 hrs | 24-48 hrs | 48-72 hrs |
| | 1.12 | 1.15 | 1.82 | 0.00 | 0.03 | 0.07 |
| Rate of extraction (ug/cm2/hr) | 0.047 | 0.048 | 0.076 | 0.000 | 0.001 | 0.003 |

*The difference in siloxane extraction results from an unlined silicone hose and an FKM lined silicone hose. Source: Ballard internal report.*

*ID = Internal Diameter*

This lower rate of siloxane extraction leads directly to lower impact in the MEA. From the same report:

**Figure 7: Silicone accumulation by hose type**




*Short stack silicone accumulation is approximately 2x to 5x less using an FKM lined hose or a non-Si based hose. Source: Ballard internal report.*

In summary, while alternative technologies do exist to replace FKM lined hoses, these alternatives come with penalties in hose lifetime, cost, complexity, serviceability and packaging, or shorter lifetime of the MEA itself.

### *6.7 Systems – other components*

Fluoropolymers are ubiquitous throughout common mechanical and electrical components. Surveying our systems we found fluoropolymers contained within

- Gaskets
- O-rings
- Lubricants
- Thread sealants
- Electrical insulation
- Printed circuit board assemblies
- Plating and coatings

Unlike the uses discussed earlier in this section, the PFAS in these components were not selected specifically, but were present in existing components that offered the best balance of technical and economic feasibility. As the industries supplying these components are dealing are far more reaching than fuel cells, we expect to adapt as supply chains phase out the use of PFAS by implementing new or existing alternatives. While there may be costs associated with these components, they will be minor compared to the issues above.

# 7.0 Fuel Cell emissions of PFAS

PFAS emissions may occur throughout the lifecycle of a fuel cell system. The Hydrogen Europe Position Paper on PFAS shows that even assuming generous growth of the fuel cell industry, emissions from fuel cell systems represent small portion of emissions. Below we describe the primary sources of emissions, along with current and potential measures to mitigate these emissions further.

As a complete detailed assessment of PFAS life cycle emissions of Ballard's fuel cell systems was not feasible within the comment period of the proposal, these results are preliminary. The scope is limited to representative examples of fuel cells and systems. Data is provided where available, and where estimates are used assumptions are stated.

It is expected this analysis will continue and we would appreciate the opportunity to continue to work and inform regulators on the use of PFAS, alternatives and trade-offs in fuel cell systems as our understanding evolves.

## *7.1 Manufacturing*

PFAS may be emitted during the manufacturing process in three ways:

1. Waste material of the MEA, hoses and other PFAS bearing components
2. Waste material of processing aids containing PFAS
3. Contamination of effluent due to PFAS contained in test equipment and articles

The first losses are inherent in any production process with less than a 100% yield. As MEAs are manufactured, there is some material loss as raw stocks cannot be fully utilized. Materials may be scrapped due to failing to meet quality or other requirements. These PFAS bearing materials will end up in dedicated waste streams.

In addition to embedded PFAS within the fuel cell and fuel cell system, fluoropolymers are used as processing aids at various stages of fuel cell production. A loss of these materials due to a prohibition on their use would cause challenges for the manufacturing of fuel cells. As an example, often PTFE is used as a carrier material in electrode production. Chosen for its limited interaction and processability, a replacement material for PTFE would degrade the quality of the electrode layers, create deviation from design intent and initiate premature degradation of the fuel cells, resulting in a shorter overall lifetime. At a minimum this will cause costs and delays in manufacturing while replacement parts and materials are qualified

Any manufacturing process results in waste. Waste containing PFAS is handled in accordance with local regulations regarding waste streaming. Currently at our main manufacturing facility in Burnaby, Canada, waste is streamed into recycling, landfill and hazardous materials. In 2022, 93% of Ballard Canada's waste was recycled.

**Figure 8: Recycled and Recovered by Material – Ballard Canada**

| Waste | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|
| Total waste (tonnes) | 933.0 | 1,315.4 | 1,685.0 | 2,395.4 |
| % of waste that is recycled | 83% | 88% | 91% | 93% |
| % of waste that is hazardous | 4% | 7% | 4% | 2% |
| Total non-recyclable waste (tonnes) per employee | 0.22 | 0.20 | 0.15 | 0.12 |
| Total waste (tonnes) per employee | 1.33 | 1.68 | 1.64 | 1.85 |

*Waste and recovery rates at Ballard Canada. Source: 2022 Ballard Environmental, Social and Governance (ESG) Report.*

Under current regulations, PFAS does not require separate streaming, so articles containing PFAS are recycled, treated as hazardous, or otherwise streamed depending on the other materials and properties of the waste. As regulations evolve in the handling of PFAS bearing waste, our waste streaming processes will be updated to reflect those changes.

Ballard's wastewater effluent meets regulatory requirements for their relevant jurisdiction. Further work needs to be done to characterize PFAS emissions in the wastewater and identify its sources.

### *7.2 Operation*

During operation, a fuel cell generates water as part of the electrochemical reaction. While some of this water may be recirculated to humidify incoming gas streams, depending on the operating characteristics of the system a portion of this generated water may be discharged out of the system. Due to the temperatures involved this will typically be a mixture of liquid water and water vapor.

On a road vehicle system, this water will typically be exhausted as part of the cathode exhaust out of the vehicle's tailpipe. On a stationary system, water vapor will typically be exhausted out of the system's exhaust stack, while liquid water is collected via a separate port and be discharged as wastewater, directed in accordance with local regulations.

As the fluids work through the system, there is potential for PFAS in wetted components to leach into the fluid streams, and thus end up in an exhaust stream. Work still needs to be done to understand if PFAS are present in the vapor exhaust, and to characterize any substances there. Additionally, these compounds need to be traced back to their source. This information will be used to meet the objective of minimizing the environmental impact of our products. In the interim, given their expected low concentrations, and as stated within the Hydrogen Europe position paper, "adsorption techniques (e.g., ion exchange resin) could be used to remove trace amounts of PFAS from effluent streams" if necessary.

Work to examine effluent has been initiated and to date there is limited data. Our understanding is preliminary and will therefore remain confidential at this time. There are 2 recent data sets presented in the Confidential Annex for reference. Additional testing is planned for greater confidence and understanding in the results.

### *7.3 End of life*

End of life involves recovery, recycling, incineration or landfilling of materials from the fuel cell. Ballard already has in place a system to recover fuel cell stacks.

Stacks that reach their end of life for any reason can be returned to Ballard for recycling and precious metal recovery. Specific materials used in different stacks may differ and the specific processes to recover those materials will vary to reflect those materials, but generally

1. Hardware –
    a. inspected and reused to manufacture reconditioned fuel cell stacks.
    b. Metal components recycled
2. Bipolar plates – incinerated
3. MEA Assemblies - sent to incineration facilities for precious metal recovery

Incineration facilities used by Ballard are in the United States and comply with all relevant emissions regulations. Individual facilities may vary, but key suppliers use high temperature thermal treatment, a process suitable for recovering PFAS emissions from the incinerated waste.

**Figure 9: Example incineration process**

**Gannon & Scott (white paper):**
This system has all the elements mentioned in the Fume Eliminator and Combustion references above. It should be sufficient/suitable for PFAS emission control

(The combination of a thermal oxidizer with a quencher and scrubber can result in more than 99.9 percent removal of all VOCs, HAPs and HF entering the system.)

Thermal reduction @1400°F --> Quench @300°F --> Wet Scrub = Cyclonic separator (removal of water droplets) + Packed Tower (neutralize Halide acid gases) --> reheat gas --> Dust collector

*Example incineration process used for MEAs. https://www.4cleanair.org/wp-content/uploads/Tom_Gentile-NACAA11-12-2020.pdf*

*VOC = Volatile Organic Compounds, HAP = Hazardous Air Pollutants, HF = Hydrofluoric Acid*

Considering these processes, the research on how effectively this will eliminate PFAS from the emissions is mixed. Per the Gannon and Scott paper, the process in Figure 4 removed more than 99.9% of all VOCs, HAPs and HF entering the system. Two other studies suggested > 1000°C temperatures may be required for sufficient destruction in the gaseous phase of PFAS. However, the incineration process does include additional processes that may reduce the emissions (Ross et al, 15; Watanabe et al, 16).

Other research (Krug et al, 17) at a pilot scale assessment showed destruction and removal efficiency (DRE) may be 60-95% for some PFAS compounds ($CF_4$ was used as a surrogate) even at 1000°C.

Ballard is continuing to work with our suppliers to better understand their current capabilities and plans to mitigate PFAS emissions going forward.

Other components of fuel cell systems are disposed of in accordance with local waste regulations. High value components may be returned for repair or refurbishment.

### *7.4 Professional users*

Fuel cell systems are used almost exclusively in commercial and industrial environments, where they are handled by trained professionals. Potential exposure to PFAS is limited as the substances are embedded within the fuel cell system, which is then integrated into a vehicle or operating environment where only trained professionals have access. The small amount of material that is emitted due to operations is addressed in section 7.2.

Being contained in industrial and commercial environments makes fuel cell systems ideally suited for producer recovery and is likely to ensure better streaming of waste. As discussed in section 7.3, this already takes place in many instances for the fuel cell stack itself. Ballard is open to having a mandatory fuel cell stack recovery program, where Ballard accepts their stacks back at end of life for recycling and recovery. Ballard is open to considering similar recovery programs for key system components that also use PFAS, such as humidifiers.

If an exemption is granted for fluoropolymers generally, we would expect other generic components containing PFAS (e.g., gaskets, electrical components, plastic hardware) to be managed through general waste streaming processes.

### *7.5 Recycling*

Ballard works closely with membrane suppliers. Current suppliers of PFAS based membranes have indicated they are researching techniques for recycling their PFAS membranes. Development of this technology, along with producer recovery, could mitigate a portion of the PFAS waste. However, work on this technology is too early to estimate expected costs and benefits.

## 8.0 Socio-economic issues

### *8.1 EU Green Deal*

Adopted in June 2021, the EU climate law (2021/1119) made legally binding a target of reducing emissions 55% by 2030 and climate neutrality by 2050. It was followed by the “Fit-for-55" package, a set of 14 laws translating these objectives into concrete policy measures.

Among them, the revised EU Emission Trading Scheme, FuelEU Maritime initiative, FuelEU aviation, revised Renewable Energy directive, Alternative Fuels Infrastructure Regulation, and the revised energy taxation directive, all incentivize adoption of low and zero-emission technologies in industry, energy and transport applications.

As a result, industries are expected to massively invest in clean tech value chain, swiftly ramping up production and deployment capacities. The European Commission estimates that deployment of renewable energy sources must reach 60 GW/year (50% more than in 2021) to hit the EU’s 2030 decarbonization targets.

Unfortunately, most – if not all – the technologies propped up by the EU Green Deal and related laws, today rely on the extensive use of fluoropolymers: batteries, solar panels, wind turbines, power grid technologies, etc. Hydrogen fuel cells are no exception and also contain fluoropolymers in core components.

### *8.2 Decarbonization goals*

Extensive PFAS restrictions will lead clean technology providers to revise their plans and prioritize R&D for PFAS alternatives. Even if alternatives exist – which has yet to be demonstrated for most products – a likely consequence of the ban will be the EU failing to meet its 2030 decarbonization objectives.

Even if no alternatives can be found, the quantities of PFAS used in hydrogen technologies is small in the overall picture of PFAS emissions. From the Hydrogen Europe Position Paper on PFAS, “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”

From the PFAS Restriction Proposal Media Briefing (February 7, 2023), PFAS emissions in the EU in 2030 are projected to be ~30,000 tonnes per year. Given that MEAs are typically incinerated for recovery of precious metals at the end of life, even assuming the lower estimate of 60% elimination via incineration, this would represent approximately 0.7% of the total emissions in 2030.

### *8.3 Environmental risks of alternatives*

One key application for fuel cells is transport. Today the road transport sector represents one fifth of the EU's greenhouse gas (GHG) emissions and is the main cause of NOx air pollution [17], due to the use of vehicles with internal combustion engines powered with diesel or petrol. With the regulation on emission standards for light-duty vehicles (2023/851) and the one on emission standards for heavy-duty vehicles currently under negotiations, the European Union is paving the one for a phase-out of combustion engines in most road vehicles in the 2030s.

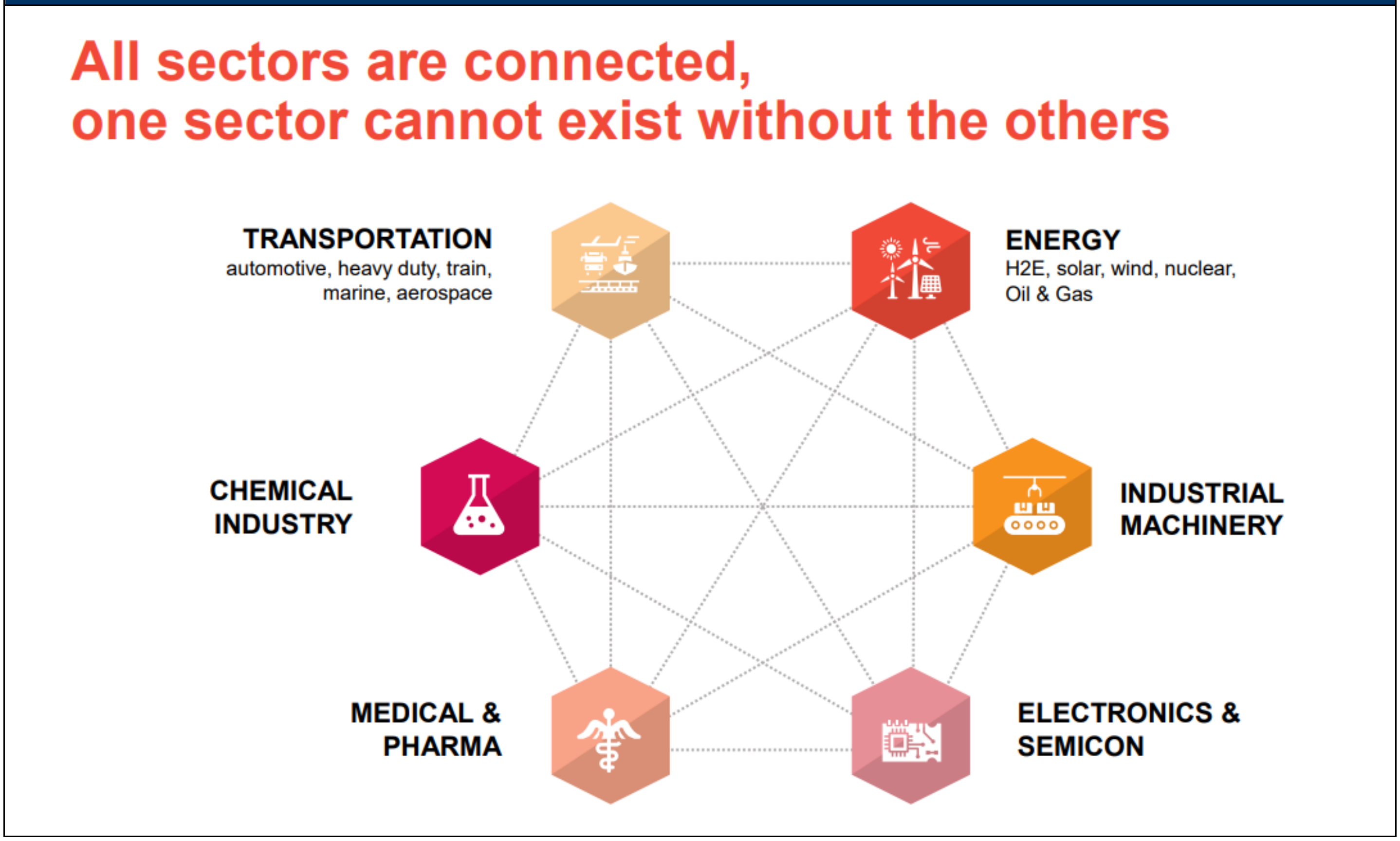
The replacement of traditional vehicles with new ones equipped with batteries and hydrogen fuel cells is expected to drastically improve air quality, in cities especially. Delaying the introduction of vehicles with zero tailpipe emissions will slow down air quality improvements in urban areas and directly impact the health of European citizens.

### *8.4 Fluoropolymer value chain*

While fluoropolymers are critical for fuel cell use, fuel cell uses make up only a small portion of the fluoropolymer industry.  While industry wide numbers are difficult to estimate, for example the Chemours company is one of the major suppliers of fuel cell membrane material.  Their Advanced Performance Materials Division, which manufactures fuel cell membranes generated $1.618 billion, or only 23% of Chemours' $6.874 billion in net sales [18]. Fuel cell membranes are only a portion of those sales: "Our Advanced Performance Materials segment has a diversified offering of products that includes various specialty product solutions, membranes, industrial resins, and coatings. These product offerings position the business to serve a breadth of markets, segments, and applications, including electronics, communications, transportation, wire and cable, energy, oil and gas, and medical, among others, and our product offerings are fundamental to the future of clean energy and advanced electronics." [18].

Given the fuel cell market makes up a small portion of the fluoropolymer industry, the concern with a fuel cell only derogation is the fluoropolymer industry will lack the scale needed to provide fluoropolymers for the fuel cell industry at a viable cost and quality. And this ignores the challenges of interconnections between different markets and applications.

**Figure 10: Industry interconnectedness**




*The fluoropolymer industry impacts many different industries, making it challenging to predict the downstream impacts of restrictions on these materials. Source: Chemours*

We recognize that fluoropolymers in other applications may pose a higher risk for emissions. We believe that a PFAS restriction should allow for fluoropolymers generally, and restrictions should be targeted at specific markets or applications based on a risk assessment those respective applications.

## 9.0 Summary and Recommendations

In summary, a complete restriction of PFAS, even with a 6.5 year derogation for fluoropolymers used in PEM fuel cells, would be a major setback to the hydrogen fuel cell industry, including Ballard Power Systems. Consequently, it would incur challenges for the EU to meet its decarbonization targets.

For several applications in fuel cells there are no viable alternatives to using PFAS. This is particularly critical regarding MEAs, where some uses such as mechanical reinforcement and electrode binders there is no currently visible pathway to an alternative material or technology.

The rest of the fuel cell system has a clearer path. Investigation has started on non-PFAS lining materials for silicone hoses, and in some applications other technologies can be used although with trade-offs in cost and other aspects. Other system components can be managed as the larger supply chains adapt to regulations on PFAS.

Given the relative risk of emissions and hazardous substances, we believe fluoropolymers should not be generally restricted under this proposal. Instead, where risk assessment shows it is warranted, specific applications could be targeted with restrictions on the use of fluoropolymers. As non-PFAS fuel cell technology matures, the risks in the fuel cell industry can be re-examined.

Alternative measures to manage PFAS emissions from the fuel cell industry, such as producer recovery, and development of recycling technologies should be investigated. Ballard intends to continue analyses to better understand our emissions and tools to mitigate them. By taking a risk based, measured approach we believe the EU can meet the objectives of reducing PFAS emissions while maintaining a strong hydrogen fuel cell industry that supports the Union's clean energy goals.

## 10.0 Appendix

*See separate attachment, "Appendix 1 to Ballard Submission to ECHA on the use of PFAS in Fuel Cell Systems: Confidential Data"*