1. Missing uses ; Analysis of alternatives and socio-economic analysis

Due to the lack of well investigated alternatives, the continuous use of Polymeric PFAS as sealing components is currently the only available option to commit to the EU green deal in the hydrogen refueling sector. The European Parliament adopted the EU Climate Law on 24 June 2021, which makes a target of reducing emissions by 55% by 2030 and climate neutrality by 2050 legally binding. To reach its climate neutrality goal by 2050, the EU is taking action to reduce emissions from cars as road transport accounts for approximately one fifth of the EU's CO_2 emissions. The EU aims to cut emissions from cars 55% and from vans 50% by 2030, compared with 2021, in order to reach the goal of zero emissions from new cars and vans by 2035. From 2035, all new cars that come on the market cannot emit any CO_2. This is to ensure that by 2050, the transport sector can become carbon-neutral.

As part of the "Fit for 55 in 2030 package", which the EU Parliament adopted in July 2023 and will enter into force once endorsed by the Council, EU countries have to ensure that hydrogen refueling stations along core Trans-European Transport Network (TEN-T network) will be deployed at least every 200 km by 2031.

Linde Hydrogen Fueltech (LHF) manufactures hydrogen refueling stations (HRS). HRS can be distinguished on the basis of the type of fuel: gaseous or liquid hydrogen. Linde Hydrogen Fueltech was founded from combination of two former companies in 2019:

- The first company is "Anwendungstechnische Zentren" (ATZ), which was founded in 2000 and developed the ionic compressor in 2006. Production of hydrogen refueling stations (HRS) based on the ionic compressor started in 2012.
- The second company is Linde Hydrogen Solutions, which built its first liquid hydrogen refueling station in 1978. The improved cryo-compressed LH2 pump was developed in 2009 and production started in 2019.

Until the end of 2022, 254 hydrogen refueling stations were in operation in the EU [1], a significant number of these are manufactured by LHF. Due to potential dismantling and closing of HRS by the fuel station operators, the real number of HRS can deviate. Due to the dynamic market situation, the number of companies in the hydrogen refueling station sector is assumed to be less than 15 with employees in the lower four-digit spectrum. Based on market research [2], the global hydrogen refueling station market was valued at USD 315.9 Million in 2022 and is projected to reach a value of USD 903.6 Million by 2030 at a CAGR (Compound Annual Growth Rate) of 16.2 % between 2023 and 2030.

In order to fulfill the requirement of deployed hydrogen refueling stations at least every 200 km by 2031, the expansion of HRS has to be accelerated. Banning the use of these Polymeric PFAS components would have a considerable negative influence on the service, functionality, and safety of HRS as well as on the envisaged expansion based on the "Fit for 55 in 2030 package" in the near future. The ramping up of clean technology manufacturing required to align with such ambitions represents a tremendous challenge. Advanced materials (such as Polymeric PFAS) are a pre-requisite for providing the required investment certainty. They have been researched, tested, and developed across decades and are now essential and integral parts of our highly specialized technology.

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Hydrogen refueling stations operate within many exceptional environments. Components made from Polymeric PFAS are often the only available substance to allow safe operation. Hydrogen refueling stations require components that can withstand some or all of the following harsh and extreme process conditions:

- Wide range of temperatures – process can operate between approximately -250 degree C to +150 degree C, consistent material properties and characteristics are required across the wide temperature range.
- High pressures up to 900 bar – In order to fill fuel-cell vehicles with pressures of 700 bar, the HRS has to compress and store hydrogen at distinctly higher pressures up to 900 bar. Strict requirements on permanent technical gas tightness are present for the hydrogen system (pipework/machines/storage) based on explosion classification [3-5]. Pressures higher than 900 bar are conceivable in the future.
- Hydrogen atmosphere – material compatibility with hydrogen has to be ensured due to potential embrittlement.
- Ionic liquids – Some HRS uses ionic liquids (IL), which reduces friction, increases thermal conductivity, and reduces dead spaces in the compressor, whereby the efficiency of the hydrogen compressor is enhanced, reducing power usage. However, material compatibility with potentially corrosive ionic liquids has to be ensured. Polymeric PFAS seals provide thereby an extraordinary corrosion resistance against IL.

By using resistant PFAS polymers, operational safety and reliability are achieved, which are indispensable for this rather new technology. Safety and reliability are critically important elements for HRS systems, to establish trust and credibility for this new form of fuel stations in society. Additionally, operational safety is absolutely necessary for hydrogen refueling stations, to avoid harm to people who operate these systems and the communities in which these are being used.

Key functionalities: Across the range of harsh and extreme process conditions listed above, the components chosen for HRS systems need to consistently maintain the following functionalities:

- Flexibility: Many of the PFAS substances are used in sealing such as PTFE tape, gaskets and valve seats in order to maintain a gas tight seal. Many sealing materials become rigid and inflexible at low temperatures as well as hydrogen atmosphere which would lead to unacceptable leaks and failures.
- Permeation resistance: The small size of the hydrogen molecule makes its sealing very challenging when it comes to leakage behavior. A study by Jung et al. [6] shows that fluoroelastomers such as FKM show superior permeation properties compared to ethylene propylene diene monomers (EPDM) and nitrile butadiene rubber (NBR). The permeability was obtained with the magnitude in the order $P_{EPDM}>P_{NBR}>P_{FKM}$.
- Low friction coefficient and low wear resistance: PFAS polymers as sealings improve the performance characteristics of the ionic compressor and cryogenic pump due to the low frictional coefficient. Moving parts need to be able to operate for multiple cycles without degradation. A total low wear leads additionally to improved maintenance intervals.

- Material-compatibility: Hydrogen refueling station may contain potentially corrosive substances such as ionic liquids. The Polymeric PFAS components are able to be in direct contact with these substances and not change weight, surface conditions and shape. This leads to longer lifetimes compared to other gasket materials.
- Low thermal expansion (across the operating range): Many seals are sited within a machined groove to maintain a gas tight seal. If there is large thermal expansion across the operating temperature range (-250 °C to +150 °C) the seal may be compromised, and leaks will occur.
- H2 Compatibility: Embrittlement of materials is faster in H2 service which can lead to early leakage.

Materials and components made from Polymeric PFAS are at higher cost than alternatives but are chosen due to their enhanced and reliable safety performance. At this point in time, no alternatives are available for many of the uses identified and LHF therefore requests a derogation for use of Polymeric PFAS in LHF's hydrogen refueling stations for harsh and extreme process conditions until an alternative is available and proven to meet all requirements.

A study by Lovrec et al. [7] on material compatibility tests of seal materials with IL shows that the test results obtained by standardized tests may not be directly applicable to real operating systems under real operating conditions. Typical sealing material such as NBR or EPDM exhibited minor changes in dimensions, mass and volume of the O-ring, whereas PTFE exhibited no changes in this study. Significant testing effort is required, as every established sealing material has to be long-term tested with the respective IL under real operating conditions in order to receive reliable long-term performance data.
Hydrogen refueling stations require components that can withstand some or all of the aforementioned harsh and extreme process conditions.

Specific uses where no alternative materials are currently available have been identified as:

Components in pumps, compressors and dispenser with fueling hoses

PTFE, PTFE/metal mixes, PTFE containing graphite, FKM and steel bushings with PTFE liner/coating (summarized as Polymeric PFAS) are used within pumps, compressors and fueling hoses as static seals, dynamic seals and sliding or rolling components such as piston rings.
Pumps, compressors and dispenser with fueling hoses are essential in the hydrogen refueling stations in order to generate the required pressure of up to 900 bar, to transfer cryogenic or high-pressure gases to storage bottles and to refuel customer's fuel cell vehicles.

The Polymeric PFAS are selected to ensure consistent properties across a wide temperature range (-250 degree C to +150 degree C), to withstand high pressure up to 900 bar, to provide superior corrosion resistance in the presence of ionic liquids and excellent material compatibility with hydrogen. Most importantly, the Polymeric PFAS components provide operational safety and reliability for public hydrogen refueling stations now and in near future.

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Unfortunately, the restriction proposal fails to recognize the fact that fluoropolymers meet OECD requirements as polymers of low concern. Research by Henry et al. [8] and Korzeniowski et al. [9] have shown that Polymeric PFAS are safe and do not pose a significant risk to human health or the environment when used for their intended purposes. Polymeric PFAS do not present significant toxicity concerns, and are not bioaccumulative or water soluble, which is highly favorable. PTFE is described in literature at operation temperatures below 200 degree C as stable [10,11]. At 250-260 degree C, there is an on-set for degradation of PTFE, which, however, stays at negligeable values (expressed in terms of weight loss in a TGA test) till temperatures becomes higher than 340 degree C and full decomposition arises at temperatures higher than 400 degree C leading to toxic and hazardous substances such as HF and C_2F_4 among others. As the use of these Polymeric PFAS compounds in hydrogen refueling stations is below 150 degree C, no thermal decomposition is expected and was also not observed with our service experience and manufacturer's data.

The only degradation of PFAS components observed is based on mechanical abrasion within the compressor or the pump systems. However, it is assumed that most of the PFAS abrasion product is collected in the filter system, which is installed upstream the fueling hoses. This filter prevents any solid matter with a particle size larger than 5 µm entering the tank system of the fuel cell vehicle and thus the distribution of PFAS abrasion products in the environment is prevented. Unfortunately, no measured data on the abrasion particle size of PFAS or accumulation in the filter element is yet available due to difficulties in measuring PFAS at very low concentration. However, the emissions during use are assumed as minimal as components are chosen for their high durability in use. Concluding, PFAS components are within high value technical machines, industry approved maintenance and safe disposal of any hazardous waste components can be assured to prevent unintentional release into the environment at end of life.

At this stage no alternatives exist, that meet all the required characteristics. For example, PEEK or POM could be an alternative to Polymeric PFAS for piston rings or sealing material. However, no data on its corrosion resistance against ionic liquid could be verified in the literature. Moreover, by looking at the range of operating temperature, maintenance of a tough and ductile behavior is extremely important, which is not met by polymers like PEEK or POM throughout the full range of temperature (-250 degree C to +150 degree C). Therefore, every potential sealing material has to be tested for longer duration under the expected real operating conditions to understand reliable long-term performance data and to meet with Linde's high safety requirements and zero incident strategy.

<u>Time and cost to analyze alternatives</u>

As described above, current alternatives to Polymeric PFAS are not available that meet all the required characteristics to safely operate LHF's hydrogen refueling stations. Should suppliers identify any possible alternatives, an extended testing period is required to ensure safety and durability of the proposed materials. Therefore, a derogation of at least 12 years is requested assuming that an alternative can be proven to safely work in that timescale.

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