Considerations for the Use of Fluoropolymers in HVACR: Request for the Creation of a New HVACR Use Sector and a Derogation for Fluoropolymers Within It

Section IV, Non-Confidential Attachment

August 2023

Notes on the Scope and Terminology of This Document

1. Any reference to company names or brands is not intended to be an endorsement by Copeland, nor an endorsement of Copeland's position on this topic by those companies.

2. Copeland is not a producer of fluoropolymers. As such, this document does not comment on the appropriateness of providing a derogation for the fluorinated processing aids used to make fluoropolymers.

3. This document does not seek a derogation for side-chain fluorinated polymers (SCFPs), which comprise a different class of materials from fluoropolymers.

4. Throughout this document, the term HVACR shall be considered synonymous with the EU-centric term RACHP (refrigeration, air conditioning, and heat pump). Although specific terminology may vary, they represent the identical industry sector.

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List of Abbreviations

AC	Air conditioning
AHRI	Air Conditioning, Heating, and Refrigeration Institute
AREA	Air Conditioning and Refrigeration European Association
ASERCOM	Association of European Component Manufacturers
CARACAL	Competent Authorities for REACH and CLP
COF	Coefficient of friction
EEV	Electronic expansion valve
EHPA	European Heat Pump Association
EN	European Standards
EPA	Environmental Protection Agency
EPEE	European Partnership for Energy and the Environment
ETFE	Ethylene tetrafluoroethylene
EU	European Union
Eurovent	European Industry Association for Indoor Climate, Process Cooling, and Food Cold Chain Technologies
FEP	Fluorinated ethylene propylene
FEPM	Tetrafluoroethylene propylene
FFKM	Perfluoroelastomer
FKM	Fluoroelastomer
GHG	Greenhouse gas
GWP	Global warming potential
HDPE	High-density polyethylene
HFC	Hydrofluorocarbon
HP	Heat pump
HVACR	Heating, ventilation, air conditioning and refrigeration
IEA	International Energy Agency
IEC	International Electrochemical Commission
ISO	International Organization for Standardization
LCD	Liquid crystal display
OECD	Organisation for Economic Cooperation and Development
OEM	Original equipment manufacturer
PCB	Printed circuit board
PCTFE	Polychlorotrifluoroethylene

List of Abbreviations continued

PEEK	Polyether ether ketone
PFA	Perfluoroalkoxy polymer
PFAS	Per- and polyfluoroalkyl substances
PI	Polyimide
PMT	Persistent, mobile and toxic
PTFE	Polytetrafluoroethylene
PVDF	Polyvinylidene fluoride
R&D	Research and development
RACHP	Refrigeration, air conditioning and heat pump industry
REACH	Registration, Evaluation, Authorization and Restriction of Chemicals
RoHS	Restriction of Hazardous Substances in Electrical and Electronic Equipment
RPM	Revolutions per minute
SCFP	Side chain fluorinated polymers
SNAP	Significant New Alternative Policy (U.S. EPA)
UNEP	United Nations Environment Programme
U.S.	United States of America
WEEE	Waste from Electrical and Electronic Equipment

1. Request Overview

Copeland LP, including Copeland Europe GmbH and other affiliated entities, ("Copeland") has closely reviewed the REACH Annex XV Per-and Polyfluoroalkyl Substances (PFAS) restriction proposal and identified missing uses of PFAS that are critical to the EU. This public consultation submittal provides justification for adding Heating, Ventilation, Air Conditioning and Refrigeration (HVACR) as a new use sector to fill a critical gap in the restriction proposal. Although the dossier does acknowledge the HVACR sector in terms of "refrigerant use" under the sector called "Applications of Fluorinated Gases (Annex E.2.8.)", it does not acknowledge the equipment used within HVACR [1], nor the materials of construction used therein.

Due to the omission of an HVACR use sector, Copeland is unable to request a derogation for fluoropolymers used in HVACR equipment within one of the use sectors currently listed in the restriction proposal. Fluoropolymers are present in nearly all HVACR equipment, independent of the sub-use, application, or refrigerant type. Therefore, Copeland is requesting the addition of an HVACR use sector to the restriction proposal and a minimum of a 20-year derogation for the use of fluoropolymers within it, including those utilized in aftermarket and spare parts for existing equipment.

The rationale for this request is based on the points summarized in Tables 1 and 2, namely:

- Fluoropolymers having properties that present limited to no risk to human health or the environment.
- Fluoropolymer-containing components being essential to the safe operation of HVACR equipment that enables critical-to-society functions.
- Fluoropolymer-containing components being essential to the operation of heat pumps, which are anticipated to contribute significantly to the EU's decarbonization initiatives.
- Fluoropolymers having a low substitution potential in HVACR applications, as there are no known alternatives that can directly replace them and provide equivalent performance.

Table 1. Properties of fluoropolymers

Material scope	Persistent	Bioaccumulative	Toxic	Degradation potential under normal use conditions
Fluoropolymers (including the subgroup of materials commonly called fluoroelastomers)	**Yes** Per a recent UNEP report "... a majority of a panel of experts agreed that 'all PFAS should not be grouped together, persistence alone is not sufficient for grouping PFAS for the purposes of assessing human health risk, and that the definition of appropriate subgroups can only be defined on a case-by-case manner.'"[2]	**No**	**No**	**Negligible** Fluoropolymers are not expected to degrade under environmental conditions or normal use and processing conditions. This differentiates them from side-chain fluorinated polymers (SCFPs). The side-chains of SCFPs can break off and form non-polymeric PFAS with the potential to be water soluble [3]. This document does not seek a derogation for SCFPs.

Table 2. Fluoropolymers used in the HVACR sector, their impacts, and substitution potential

Fluoropolymers of known interest to the HVACR sector*	Socioeconomic benefits	Safety benefits	Emissions	Substitution potential†
• PTFE • ETFE • PCTFE • PFA • FEP • FEPM • FKM • FFKM • PVDF *All are polymers of low concern per the OECD criteria, as discussed in [3] and [4].	**High** The use of fluoropolymers in HVACR equipment enables the following critical-to-society functions: • Food and beverage preservation, including transport which improves quality, helps prevent the growth of dangerous food-borne pathogens, and reduces waste within the food chain • Comfort cooling, air quality/humidity control and heating of essential buildings to promote human comfort and protect health-compromised individuals from the dangers of extreme heat or cold • Pharmaceutical and medical specimen temperature control The use of fluoropolymers in HVACR equipment is critical to a more sustainable society because: • They are used in heat pumps, which are expected to contribute significantly to decarbonization initiatives [5]. • They enable longer equipment lifetime, which keeps materials out of the waste stream.	**High** Fluoropolymers prevent flammable refrigerant leakage into occupied building spaces and higher direct global warming emissions. Fluoropolymers help prevent sealing failures in high-pressure parts of the HVACR systems, including CO_2 that could lead to major safety concerns.	**Low** Many fluoropolymers are contained in the hermetically sealed portion of HVACR systems. Therefore: • There is limited to no contact of these materials with humans during use. • There are near zero emissions during use. HVACR equipment tends to have a very long life (12–26 years on average). Fluoropolymers are used in discrete solid components that can be separated from the equipment at end of life.	**Low** Two unique challenges in HVACR applications make substitution very difficult: • Lubrication dilution effects from refrigerants • Polymers in HVACR systems are subject to potential degradation from exposure to oil and refrigerant across wide temperature and pressure ranges. Currently, no alternatives are available that can replace fluoropolymers with equal performance. No drop-in alternatives are anticipated to become available that will not be persistent. † Several case studies comparing fluoropolymers to non-fluoropolymers are included here and in the Section V Confidential Attachment to demonstrate the current lack of alternatives in HVACR applications.

Copeland has been in communication with EPEE (European Partnership for Energy and the Environment) and ASERCOM (Association of European Component Manufacturers) on the topic of fluoropolymers in HVACR equipment. Our position closely aligns with theirs on this subject matter.

2. HVACR Sector Overview

The HVACR industry has manufacturing sites and R&D facilities throughout the EU. **According to EPEE, equipment manufacturers within the industry realize a turnover of over 30 billion euros and employ more than 200,000 people in Europe alone**[6]. These employment numbers do not count the vast network of small- and medium-sized enterprises such as contractors who install, service, and maintain refrigeration, air conditioning, and heat pump equipment. It is estimated that those small- and medium- sized enterprises would bring the total count of HVACR-related companies in the EU to 15,000+.

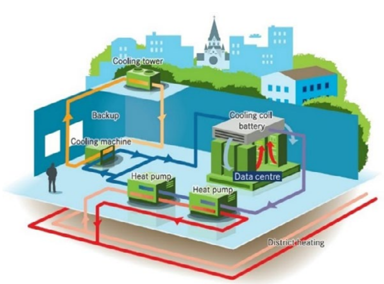
As one of the world's largest compressor manufacturers, Copeland plays key roles within many HVACR markets. A compressor is the heart of an HVACR system, as it pumps refrigerants through all system components to create either heating or cooling. Copeland (formerly an Emerson Electric Co. business unit) has 18 locations and 1,500+ personnel in the EU and employs 18,000+ persons worldwide.

HVACR equipment supplies critical services to society by providing climate control, ventilation, and air quality in the applications shown in Table 3.

Table 3. HVACR equipment and end uses primarily adapted from U.S. EPA SNAP listings [7]

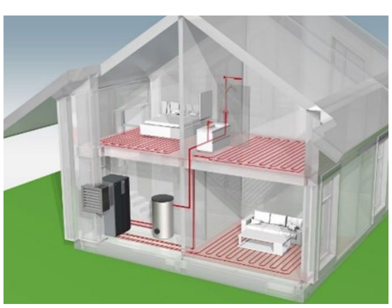
1. District Heating and Cooling

District heating is expected to play a key role in the energy grid and supply, particularly when heat pumps are connected to the system. District heating is a system for distributing heat to buildings through a system of insulated pipes. Heat pumps can utilize waste heat sources of low temperatures (below 45°C) in the district heating grid, minimizing heat losses. By running when the production of renewable power is high, they can also facilitate the integration of renewable power in electricity networks. District heating could cover up to 50% of the heating demand in Europe, and heat pumps could deliver around 25% of the energy transported by the district heating grid[8].



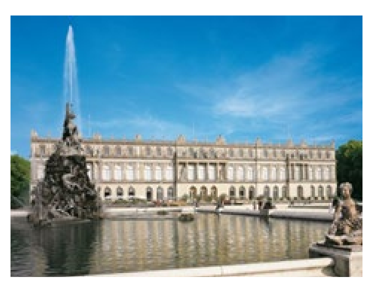
2. Residential and Light Commercial Air Conditioning and Heat Pumps

This end use includes equipment that cools or heats enclosed spaces in households and commercial industries for human comfort (i.e., AC and heating in homes, hospitals, schools, elder care facilities; computer room cooling; and commercial buildings) but excludes chillers. Products include: room AC such as window units, packaged terminal air conditioners and heat pumps, and portable air conditioners; central air conditioners (i.e., ducted); non-ducted systems (both mini and multi splits); packaged rooftop units; water-source and ground-source heat pumps; and other products. Residential and light commercial AC and heat pumps are often distinguished from chillers by the fact that they condition air directly, rather than cool (or heat) water that is then used to condition air. In colder regions in Europe, hydronic systems with radiators or underfloor heating are more common. Indoor farming is also included in this product grouping.



Hydronic underfloor heating system

Residential heat pump and air conditioning



Example of an existing building retrofitted with heat pump technology, Herrenchiemsee Palace, Germany

Table 3. HVACR equipment and end uses primarily adapted from U.S. EPA SNAP listings [7]

3. Cold Storage Warehouses

Cold storage warehouses store meat, produce, dairy products and other perishable goods. Most cold storage warehouses in the United States use ammonia as the refrigerant in a vapor compression cycle. Some of these systems may rely on other refrigerants. In Europe, smaller cold storage warehouses mostly use synthetic refrigerants, as ammonia would require a closed machine room with restricted access — typically only applicable in very large warehouses.

4. Chillers

Chillers typically cool water, which is then circulated to provide comfort cooling throughout a building or other location. Chillers can be classified by compressor type, including centrifugal and positive displacement. Chillers used to cool industrial processes are discussed under Industrial Process Refrigeration.

5. Refrigerated Transport

Refrigerated transport maintains necessary cold chain temperatures while moving products (e.g., perishable goods) from one place to another via various modes of transportation, including refrigerated ship holds, truck trailers, vans, railway freight cars, ships, and other shipping containers.

Table 3. HVACR equipment and end uses primarily adapted from U.S. EPA SNAP listings [7]

6. Retail Food Refrigeration

Retail food refrigeration (aka commercial refrigeration) includes equipment designed to store, display, process, or dispense chilled or frozen food for commercial sale. This end use includes the following categories of equipment: stand-alone units, remote condensing units, supermarket systems, and refrigerated food processing and dispensing equipment. The cold chains for both food and medical supplies (e.g., blood, vaccines, etc.) depend on commercial refrigeration and transportation refrigeration equipment manufactured specifically for this industry sector. HVACR equipment was considered critical and essential during the COVID-19 pandemic.

7. Industrial Process Refrigeration

Industrial process refrigeration systems cool process streams in industrial applications. This includes dairies, breweries, waste heat recovery, indoor farming, industrial sanitation heating, chemical processing plants, large-scale food processing, ice skating rinks, etc.

8. Industrial Process Air Conditioning

Industrial process AC units, which are distinct from commercial and residential AC, provide comfort cooling for operators and protect process equipment. This end use can experience temperatures approaching 93 °C (e.g., in crane cabs in steel plants).

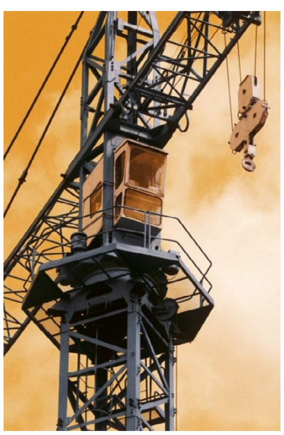


Image source: FrigorTec GmBH

Table 3. HVACR equipment and end uses primarily adapted from U.S. EPA SNAP listings [7]

9. Very Low-Temperature Refrigeration

Very low-temperature refrigeration systems require maintaining temperatures at approximately -62 °C or lower. Examples include medical freezers (e.g., vaccines, etc.) and freeze-dryers, which generally require extremely reliable refrigeration cycles to maintain low temperatures and must meet stringent technical standards that do not apply to other refrigeration systems.

10. Motor Vehicle Air Conditioning

Motor vehicle AC systems provide comfort cooling for passengers in light-duty cars and trucks, buses, trains, and other forms of transportation. Trains have an expected lifespan of several decades, and the development process for new models can span years. Road vehicles must undergo approval for any new model, without reducing safety standards and requirements compared to previous ones.

11. Vending Machines

Vending machines are self-contained units that dispense goods which must be kept cold or frozen.

12. Water Coolers, Ice Machines

Water coolers are self-contained units providing chilled — and potentially heated — water for drinking. They may or may not feature detachable containers of water.

3. Public Consultation Specific Information Request 6:

Missing Uses – Analysis of Alternatives and Socio-economic Analysis

The following topics relate to the section of the public consultation questionnaire called "Specific Information Request 6".

You will find a continuation of topic 6e in the Section V Confidential Attachment of this submission.

3.1 Topic 6a: The annual tonnage and emissions (at sub-sector level) and type of PFAS associated with the relevant use.

The tonnages shown in Table 4 are approximate. This is in part due to the amount of fluoropolymers used in electronic components in HVACR equipment being difficult to assess, and therefore those values in particular are still essentially unknown. The values in the table represent the summing of the production volumes of all the HVACR market applications described in this document. The source of the production volumes is EPEE's HFC Outlook Model[9].

The tonnages were calculated as follows: A representative HVACR compressor model was chosen that currently has the highest volume production in the EU and the weights of the mechanical (non-electronic) fluoropolymer parts were determined. This value was then multiplied by a factor of two to accommodate the unknown amount of fluoropolymers in electronics and other miscellaneous mechanical parts outside of the compressor. This likely resulted in a conservatively high number because the fluoropolymers used in electronics are more microscopic in nature compared to the bulk mechanical parts, such as bearings and seals. The data below also shows the estimated amounts for two years, 2020 and predicted 2025. The data also shows the tonnages with and without automotive HVACR sector applications. Note, the tonnages for automotive will also be conservatively high, because the reference compressor model chosen for these calculations is physically much larger than the typical automotive compressor (larger equipment models typically have larger individual fluoropolymer-containing components). The existing equipment category shows the tonnage of fluoropolymers in equipment in operation that was installed prior to the year shown, while the new equipment category shows the tonnage of fluoropolymers used in HVACR equipment that will be installed that year. The retired equipment category shows the tonnage of fluoropolymers that many enter the waste stream in a given year as equipment is decommissioned.

Table 4. Estimated fluoropolymer use in the EU HVACR Sector (Values are in metric tons/year). Production volumes of equipment from which these values were derived are based on EPEE's HFC outlook model.

2020	Existing Equipment	New Equipment	Retired Equipment
Without Automotive	12,447	948	789
With Automotive	20,476	1,470	1,083
2025	Existing Equipment	New Equipment	Retired Equipment
Without Automotive	12,510	1,050	837
With Automotive	22,308	1,586	1,222

Due to the closed-loop and hermetically sealed nature of HVACR equipment, the risk of environmental or human exposure is very limited during normal operation. The consumer will likely never come in contact with the fluoropolymers and professional HVACR service technicians rarely come into contact with fluoropolymers, if at all. This is because the fluoropolymers in the HVACR sector are utilized in discrete solid plastic parts that are embedded (i.e., hidden) inside component assemblies in the end products — which are hermetically sealed from the outside.

When evaluating the environmental or health effects of a chemical, it is important to analyze both the hazard and exposure. REACH should consider chemicals that are "contained" within HVACR equipment as having minimal exposure risks or emissions potential.

At the end of a product lifecycle, HVACR equipment can be disassembled, at which time any fluoropolymer components can be physically separated, removed, and/or recovered for destructive processing or re-use (described herein). Given the high metal content of HVACR equipment — which includes valuable copper wiring in the motors and lead wires — HVACR equipment is typically recovered and dismantled for economic reasons already. Therefore, the additional step of the removal of fluoropolymers during this recovery stage should be convenient and feasible.

In summary, the fate of fluoropolymers at the end of life in the HVACR sector is manageable. That is, they can be physically removed with minimal effort from the HVACR equipment and then processed in any one of the manners described herein. If recycling and reuse legislation were enacted for commercial and industrial products — as the Waste Electrical and Electronic Equipment (WEEE) Directive (Directive 2012/19) was established for household electronic products — this would encourage and standardize enforcement and recovery of fluoropolymers within the HVACR sector.

Methods for end-of-life management of HVACR equipment, including fluoropolymer components, are listed below:

- **Incineration:** Several studies suggest that PTFE, the most stable fluoropolymer, undergoes complete thermal decomposition at a temperature of about 850 °C [10]. This supports the assumption that many other fluorine-containing polymers may also thermally decompose completely at that temperature. Directive 2000/76/EC, the European Parliament's directive for the incineration of waste, requires incinerators to be operated at 850 °C or 1,100 °C, depending on what is being incinerated. Thus, all fluoropolymers should fully degrade when incinerated [11]. The Performance Fluoropolymer Partnership under the American Chemistry Council is also conducting a scientific study on the incineration of fluoropolymers. The study aims to identify optimum combustion conditions of fluoropolymers to achieve a "controlled emissions state" and ensure fluoropolymers get completely mineralized. Furthermore, suppliers of fluoropolymers have recently carried out research on this topic which confirms that fluoropolymer waste can be safely incinerated without the generation of small PFAS molecules [12].
- **Landfills:** Fluoropolymers are inherently safe, non-mobile, non-bioaccumulative and non-toxic. Fluoropolymer waste is chemically inert and therefore, fluoropolymers disposed in landfills do not pose any substantive threat to human health or the environment.
- **Recovery and Recycling:** A potential solution is to expand the scope of EU Directive 2012/19 on WEEE to include commercial and industrial products in addition to household items — similar to what France has done. In addition, solid fluoropolymer waste can be mechanically recycled by being ground and reintroduced into the manufacturing cycle of polymer composite products wherever possible. Certain fluoropolymers are also candidates for chemical recycling. Given the inertness and long-lasting nature of fluoropolymers, many applications may be able to directly re-use them.

3.2 Topic 6b: The key functionalities provided by PFAS for the relevant use.

HVACR systems are hermetically sealed and according to EPEE's HFC Outlook Model typically have a lifespan (on average) between 12 to 26 years, depending upon the specific application. Some systems in certain large industrial applications have been known to operate up to 35 years.

Because of the mechanical rigors and harsh internal environments of HVACR equipment and systems, materials must be able to withstand these conditions and retain sufficient mechanical and physical integrity throughout prolonged use. Although several metals and ceramics work well in these environments, polymers are particularly susceptible to degradation. This challenge makes it more difficult to find alternatives with the necessary endurance for long-term use in HVACR applications. Not only have fluoropolymers been proven to have the necessary properties, but they have also been widely used in HVACR applications for approximately five decades.

Moreover, fluoropolymers provide an unmatched combination of key high-performance properties that deliver the required reliability and functionality to components in HVACR equipment. Although alternative materials may have one or more of the required properties, they are not capable of covering all the component material requirements, whereas **fluoropolymers satisfy several essential properties for the HVACR sector simultaneously.**

3.2.1 HVACR System Schematic

All applications in the HVACR sector are based on a design layout similar to what is demonstrated in Figure 1. HVACR systems operate with hermetically sealed circuits that transfer heat, resulting in either cooling or heating, depending on the need.

In Figure 1, an evaporator coil emits either cold air for indoor AC or heated air under reverse operation (HP mode). The very same function can be provided by a hydronic circuit (i.e., under-floor systems or radiators/convectors), which emits heated or cold air as needed. Fluoropolymers are used in several components in these systems, for both electrical and mechanical functions. For example, Figure 2 shows a cross-section of a scroll compressor and the areas where fluoropolymers are used – which are numbered and listed in Table 5.

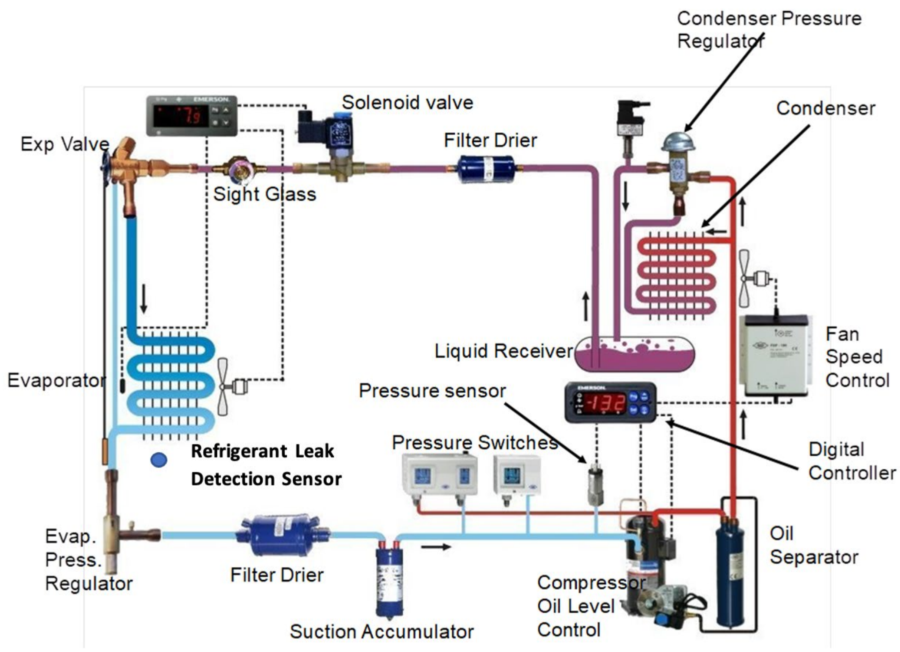


Figure 1. *Copeland diagram showing the various components that may comprise an HVACR system for air conditioning, refrigeration, or heat pump applications*

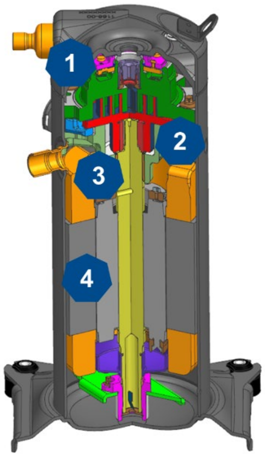


Table 5. Parts in a compressor containing fluoropolymers

Number on Diagram	Component
1	Floating lip seal assembly
2	Upper drive sleeve bearing
3	Main sleeve bearing (some models)
4	Motor electronic components and wire insulation

Figure 2. *Cross-section of a compressor diagram with labels indicating where fluoropolymers are used*

Table 6 contains a more detailed description of the fluoropolymer components used throughout HVACR systems, including their required functional properties in various applications.

Table 6. Uses of fluoropolymers in HVACR equipment

Component Containing Fluoropolymers	Fluoropolymer Types	HVACR Equipment Examples	Functional Properties *(Multiple properties are often required simultaneously, and are not always the same between applications — even within the same system)*
Sleeve bearings 	• PTFE • PFA	Compressors 	• Chemical resistance (refrigerants and oils) • Low intrinsic friction • High-temperature degradation resistance • Sufficient bearing conformability • Sufficient contamination embeddability • Rapid gas decompression resistance with refrigerants • Ability to transfer itself to opposing wear surface
Seals (O-rings, lip seals, face seals, gaskets, etc.)  	• PTFE • FKM • FFKM • FEP • FEPM • PCTFE	External and internal fittings, heat pump reversing valves, thermal expansion valves, floating compression gas seals	• Low-temperature ductility retention • Chemical resistance (refrigerants and oils) • High-temperature degradation resistance • Low intrinsic friction • Rapid gas decompression resistance with refrigerants
Cable and wiring insulation, motor   	• PTFE • ETFE • PFA • FEP • PVDF	Most HVACR equipment, motors, variable- speed drives; facility system controls and monitoring; heating controls; sensing and protecting devices; thermostats	• High electrical resistance • Low dielectric constant • Flexibility in refrigerants and oils • Chemical resistance (refrigerants and oils) • High-temperature degradation resistance • Low flammability
Electronics (PCB, capacitors, LCD)   	• PTFE • PVDF • Potentially other fluoropolymers	Most HVACR equipment, motors, variable- speed drives; facility system controls and monitoring; heating controls; sensing and protecting devices; thermostats	• High electrical resistance • Low dielectric constant • Chemical resistance (refrigerants and oils) • High-temperature degradation resistance • Low flammability • Water repellence

3.2.2 Functional Requirements of Fluoropolymers in HVACR Applications

3.2.2.1 Sealing

Fluoropolymers are used in sealing applications in HVACR equipment to prevent the release of refrigerant into the atmosphere or into rooms that may be occupied by people. **Refrigerant leakage is a potential safety concern from both asphyxiation and flammability perspectives, with the latter being a relatively new concern given that some modern low-GWP refrigerants are flammable unlike their predecessors.**

The ability to remain conformable (i.e., not become brittle) at low temperatures is critical to HVACR seals. Seals must remain resilient so that they conform to the mating surface and seal effectively. The same requirement must be met for high temperatures, where the seals must not excessively soften or thermally degrade, which would likewise adversely affect seal integrity. The chemical inertness of these materials is also a key factor in sealing, as changes in material properties — such as softening or hardening due to chemical interactions — can lead to greater leakage and potentially seal failure.

3.2.2.2 Temperature and Pressure Resistance

Compression of the refrigerant in the system causes high gas pressure and temperature swings, and refrigerant phase changes cause both liquid and vapor states to exist. Temperatures can range from -50 to 175 °C, and pressures can range from near a vacuum up to 45 bar in R-410A systems, or up to 120 bar in CO_2 systems. Under these conditions, the refrigerant can penetrate into and/or be absorbed by polymeric materials. If there is a sudden reduction in pressure in the system, a rapid gas decompression event can occur and cause blistering, cracks, and/or failure of components constructed with polymeric materials (see Figure 3).

Figure 3. *Before and after pictures of an elastomer that underwent rapid gas decompression*

3.2.2.3 Flame Retardancy

Compared to many other polymer types, fluoropolymers are intrinsically flame retardant. That is, they generally do not require additives to supply flame retardancy. This is a beneficial trait for human health and safety because certain past-used flame-retardant additives have been found to be problematic and even toxic or environmentally unfriendly in some cases. Moreover, given that many new low-GWP refrigerants are flammable, flame retardancy of materials will become very important in systems using those refrigerants. Note, the fluoropolymer PTFE is often even added to other plastics to boost their flame retardancy [11].

3.2.2.4 Chemical Inertness

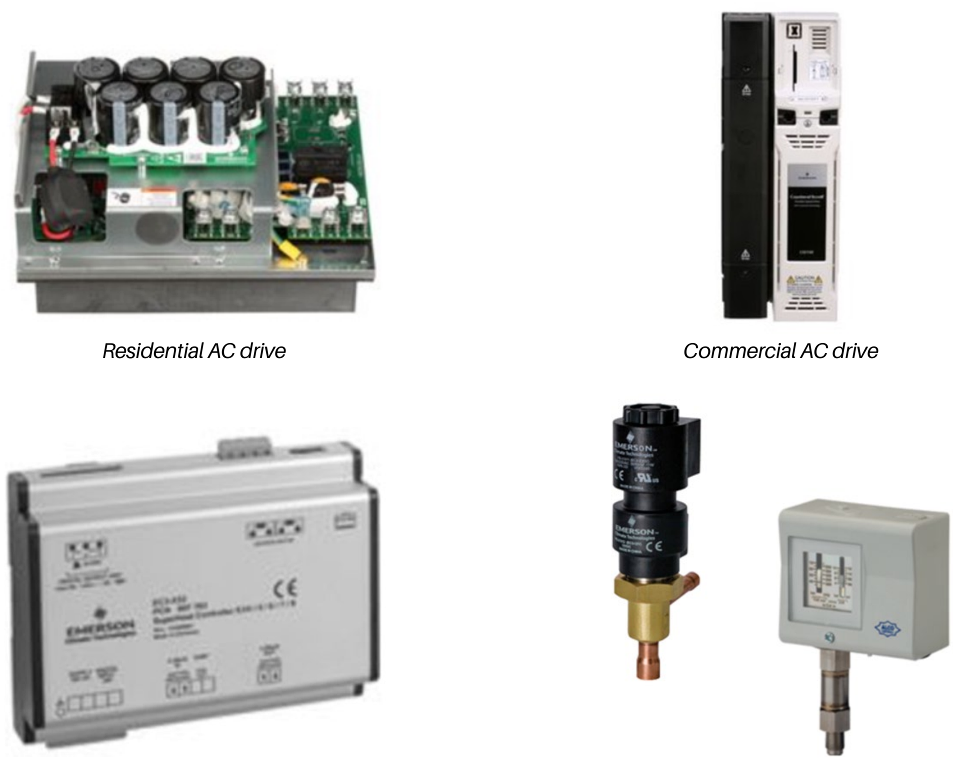
The chemical inertness and strong carbon-fluorine bonds of fluoropolymers make them especially compatible with HVACR systems, where they must withstand direct contact with metals, oils, and refrigerants in liquid and gaseous phases. The overall combination of these operating conditions can cause several destructive events to polymers, such as: brittleness (hardening), softening, swelling, and cracking.

3.2.2.5 Overall Persistence/Longevity

Persistence is a term with negative connotations that is often used when referring to fluoropolymers. However, the combination of properties that leads to these materials' persistence is the very reason the HVACR industry uses them. **As a general descriptor, persistence also encompasses many positive attributes — such as chemical inertness and temperature resistance — which enable fluoropolymer-based components and the products that contain them to have long, useful lives.** Products with greater longevity produce less waste since they do not need be replaced/disposed of as frequently. Thus, materials used in HVACR systems must be very resistant to aging and be able to provide years of prolonged use when exposed to refrigerant, oil, high temperatures, and high pressures — all of which can accelerate polymer aging. **Therefore, in many harsh applications that use fluoropolymers, like HVACR, any alternative materials would also likely need to be persistent to provide the same level of performance as the materials they would be replacing.**

3.2.2.6 Electrical Properties

Currently, fluoropolymers permeate many of the electronic and electrical devices used within the HVACR sector, some of which are shown in Figure 4.



Residential AC drive

Commercial AC drive

EEV controls

Adjustable safety pressure controls for CO_2 applications

Figure 4. *Electronic devices used in HVACR*

Electronic devices within HVACR systems perform many important system management functions, many of which are safety related. They also serve essential monitoring and control purposes, such as thermostats, fans, safety leak detection sensors, and variable-speed drives for heat pumps and cooling applications. For example, fluoropolymers are found in the following HVACR components and products (not an exhaustive list):

- Safety pressure protectors
- High-temperature safety cutoff protectors
- Motor materials of construction
- Wire and cable insulation
- PCB as a component (PFAS are used as a fiber-reinforced fluoropolymer layer)
- LCD and display manufacturing
- Film capacitors

Leak detection sensors are required in many HVACR applications per IEC 60335-2-40 and IEC 60335-2-89 product safety standards, or according to risk assessment under EN378, especially for low-GWP flammable refrigerants. We cannot speak for the material composition of products that meet the aforementioned standards, but we believe it is possible that they could contain fluoropolymers as well. At a minimum, this should be investigated further in order to better understand the potential impacts of the proposed REACH restriction. Leak detection sensors are considered essential to maintaining maximum system performance and ensuring application safety, especially given the emergence of low-GWP, natural, and flammable refrigerants, such as CO_2, A3 (propane), and A2L refrigerants.

As an end user of electronics, Copeland does not often specify how electronic products are manufactured or which materials of construction are used. Rather, we focus on the electrical properties of components (e.g., resistance, capacitance, etc.) and what functions the end electronic assembly will serve. To the best of our current knowledge, the following functional properties are required of fluoropolymers used in electrical and electronic components in HVACR equipment – this is not an exhaustive list:

- Low dielectric constant
- Low intrinsic flammability
- Water and general corrosion resistance
- Stable physical and mechanical property retention in the presence of typical HVACR working environments (i.e., no blistering, softening or hardening; tensile strength; compressive strength; ductility/flexibility; etc.)
- Ability to function and remain durable over time in the presence of high-pressure and -temperature gradients

Manufacturers of these components must ultimately understand the requirements for their materials of construction, especially in cases where the component is external to the HVACR system and not exposed to an oil and refrigerant environment. Copeland supports any reasonable derogation proposed by the electronics and electrical components industry, as these components are critical to the operation of HVACR equipment. Any halt in their production would debilitate not only the critically essential HVACR industry, but many other sectors as well.

3.2.2.7 Low Friction

Another unavoidable and challenging situation that exists in HVACR systems is that the refrigerant acts like a solvent that dilutes the oil. Oil is critical in many industry sectors because it reduces friction, wear, and mechanical power requirements — thereby helping to ensure higher energy efficiencies. In the HVACR sector, oils are chosen based on their tendency to be miscible with a given refrigerant. Miscibility between oil and refrigerant is needed to allow any oil that has escaped the compressor and leaked into the rest of the HVACR system to return to the compressor where it belongs. An unfortunate consequence of the miscibility of oil and refrigerant (whether in the liquid or vapor phase) is that it has the tendency to reduce the oil's viscosity, which in turn reduces the oil's ability to lubricate moving parts.

There are many moving parts inside an HVACR system (e.g., compression mechanism, valves, fans, etc.), and fluoropolymer components are uniquely qualified to maintain low friction, even during times of oil dilution and viscosity reduction. Low friction is important because it prevents mechanical wear, increases product life, and reduces friction-induced power losses (i.e., less energy use). Hence, fluoropolymer bearings and seals are key contributors to the long lifespan and energy efficiency of HVACR systems because they are intrinsically low-friction materials.

In addition, the low friction inherent to fluoropolymers compensates for the reduction in oil viscosity. This oil dilution effect is somewhat unique to the HVACR industry because the refrigerant exists in both the vapor and liquid states. Although liquid state refrigerant is particularly prone to causing oil viscosity reduction, vaporized refrigerant can also lower oil viscosity. By contrast, the oil viscosity inside automotive engines is typically only affected by one variable: temperature. In this case, a simple relationship exists between temperature and oil viscosity because there is no dilution effect caused by pressurized refrigerant.

Figure 5 demonstrates this simple relationship in a non-HVACR application for an ISO 46 Centistoke oil. The X axis is temperature in degrees Celsius and the Y axis is the oil's viscosity in units of centistokes (cSt).

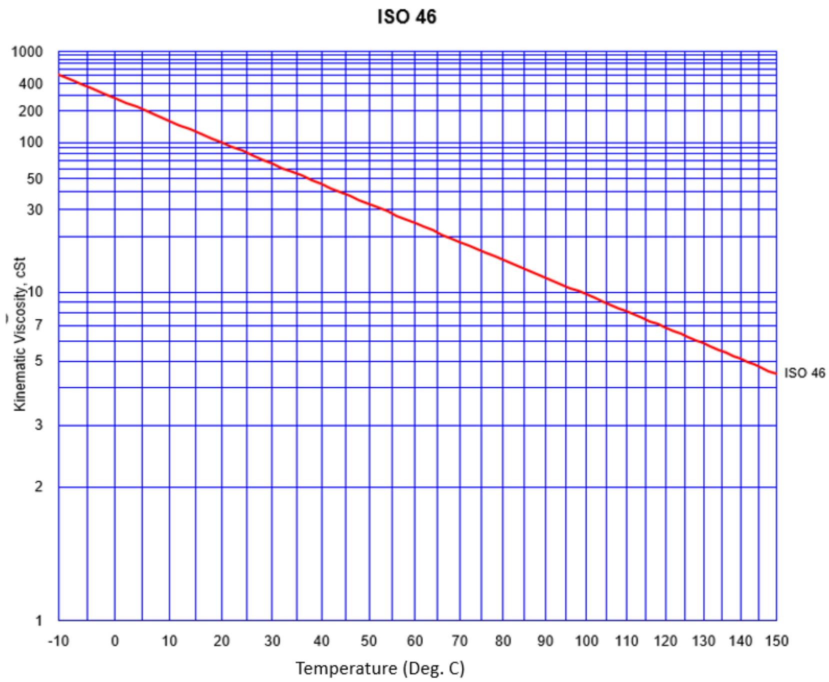


Figure 5. *Viscosity of ISO 46 Centistoke oil at different temperatures (Source: Shrieve Chemical Co.)*

To illustrate the more complex influences of viscosity in HVACR applications, Figures 6 and 7 present the same relationship, including the presence of refrigerants — Figure 6 with F-gas R-1234yf, and Figure 7 with R-290 (propane). Both charts reflect the use of the same ISO 46 oil. You can see that oil viscosity is dependent not only on temperature, but also on pressure and percent of refrigerant. This shows that oil viscosity can vary greatly in HVACR equipment, placing stress on bearings and seals — all of which may cause great wear and friction, resulting in higher energy usage (i.e., lower efficiency), and in some cases, a reduction in the reliability and useful life of components and systems. Again, the low intrinsic friction of fluoropolymers allows them to tolerate this wide variation in oil viscosity. Thus, bearings and seals in the HVACR sector depend heavily on the use of fluoropolymers.

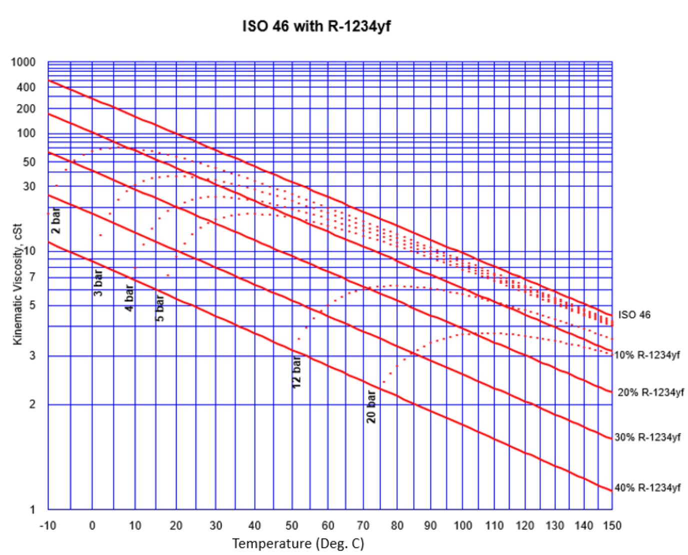


Figure 6. *Viscosity of ISO 46 Centistoke oil with different amounts of R-1234yf at different pressures and temperatures (Source: Shrieve Chemical Co.)*

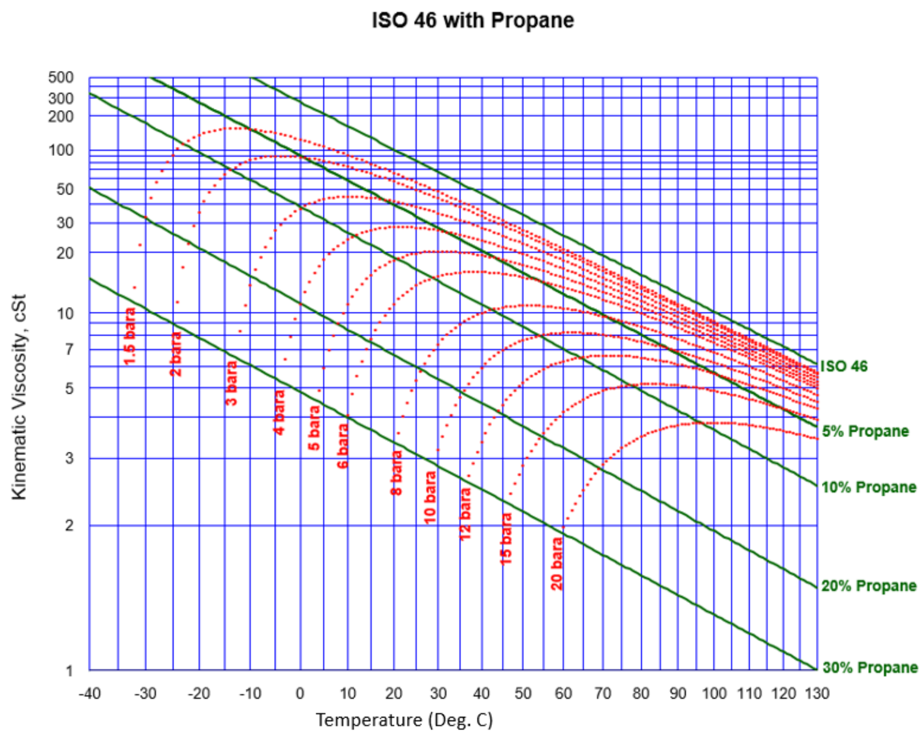


Figure 7. *Viscosity of ISO 46 Centistoke oil with different amounts of propane (R-290) at different pressures and temperatures (Source: Shrieve Chemical Co.)*

Stribeck curves can be useful for visualizing the effect that viscosity has on friction. The curve dictates that under constant load and speed, bearing friction increases exponentially as the viscosity of the oil decreases to a low level. That is, at some point when the viscosity decreases, the lubrication conditions shift away from a fully lubricated (hydrodynamic) regime, where instead of an oil layer preventing parts from touching, parts start to touch and cause high friction. An example of a Stribeck curve is shown in Figure 8. Notice that there is a very rapid increase in friction in the dark gray portion of the plot as oil viscosity is reduced.

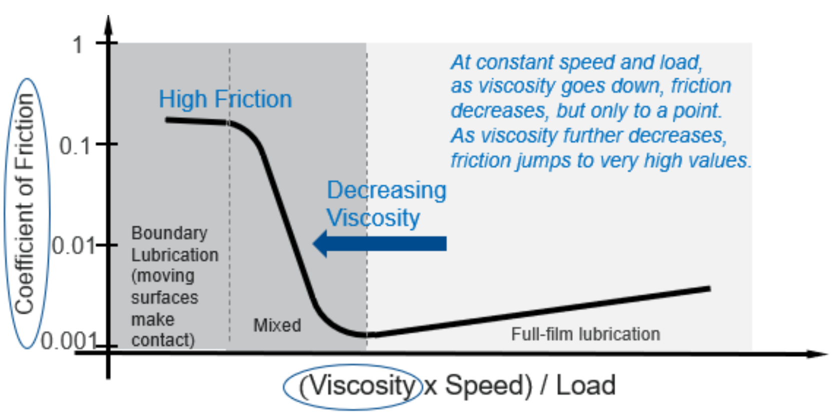


Figure 8. *Stribeck Curve showing viscosity and coefficient of friction*

The Combined Effects of RoHS and REACH on Bearing Technology

Also relevant to the discussion of low-friction applications in HVACR systems is the relatively recent ban on the use of lead metal (Pb) in bearings by the Restriction of Hazardous Substances in Electrical and Electronic Equipment (RoHs) Directive. Prior to the ban, these bearings contained a fluoropolymer matrix (i.e., primarily PTFE) with lead added to provide exceptional lubricity (i.e., very low friction). Although replacements for lead have since been identified, they are not as effective as solid metallic lubricants. Therefore, the HVACR industry is now heavily dependent upon the use of fluoropolymers in current-day bearings to overcome the frictional challenges in HVACR applications. However, if fluoropolymers are also banned by REACH, there will be virtually no other high-performing material options to produce the required low friction-bearing materials used in HVACR. Hence, significant R&D would then be needed to discover bearing materials without lead or fluoropolymers — if such materials even exist.

In summary, the robust and intrinsically low-friction properties of fluoropolymers — combined with their ability to transfer themselves to the mating surface (i.e., transferability) — are critical to essentially compensate for the refrigerant-induced viscosity reduction inherent in HVACR systems. Note: this more complicated relationship affecting viscosity exists in all HVACR refrigerants, regardless of refrigerant type (i.e., natural hydrocarbons, CO_2, or fluorinated synthetic gases).

3.3 Topic 6c: The number of companies in the sector estimated to be affected by the restriction.

15,000+ companies are estimated to be affected by the PFAS restriction, including: HVACR system equipment OEMs, service contractors, installers, and distributors.

For reference, the number of member companies in trade organizations that are related to the HVACR sector are estimated to be as follows:

- AREA (HVACR installers/contractors) — 13,000 member companies representing 110,000 people
- EPEE — 50 member companies representing 200,000 people
- Eurovent — 1,000 member companies representing 150,000 people
- EHPA — 200 member companies representing 117,000 people

Not all HVACR-related companies are members of these associations, so the quantities are likely underestimated.

3.4 Topic 6d: The availability, technical and economic feasibility, hazards and risks of alternatives for the relevant use, including information on the extent (in terms of market shares) to which alternative-based products are already offered on the EU market and whether any shortages in the supply of relevant alternatives are expected.

Currently, Copeland is not aware of any suitable drop-in alternatives for fluoropolymers that would fulfil the needs of the HVACR sector. Given the severity of the conditions inside HVACR systems and the safety concerns if there is a malfunction, using incorrect materials presents significant personal and environmental risks. These risks are mentioned several times throughout this document but are summarized below for ease of reference:

- Some modern low-GWP refrigerants are flammable. If the sealing materials do not perform well enough (i.e., caused by gas permeability, low chemical resistance, poor high- or low- temperature resistance, etc.), it increases the potential for combustion. It is also not recommended to inhale refrigerants, which can have certain side effects in higher concentrations and potentially cause asphyxiation in enclosed and/or confined spaces.
- HVACR systems often see high pressures – up to 45 bar for R-410A refrigerant and 120 bar for CO_2.The failure of a component, such as a seal, in a high-pressure area of a system could result in a sudden release of pressure that could cause a safety concern for anyone who may be standing near the equipment. The broken component and potentially other broken pieces of equipment could be jettisoned away from the system at high speeds, along with any oil and refrigerant that might be released.
- Energy consumption could increase without the use of fluoropolymers. Fluoropolymers have very low friction, which reduces the amount of energy required by moving parts. Additionally, if there is higher friction, parts will wear out more quickly and shorten the lifespan of HVACR components — increasing waste, customer costs, and energy used in manufacturing. This is counterproductive to the EU's goals of reduced energy consumption and decarbonization.
- In general, a rushed transition to improper alternatives will lead to lower product reliability and increase the likelihood of product failures, thereby increasing the overall amount of waste produced by the HVACR sector.

3.5 Topic 6e: For cases in which alternatives are not yet available, information on the status of R&D processes for finding suitable alternatives, including the extent of R&D initiatives in terms of time and/or financial investments, the likelihood of successful completion, the time expected to be required for substitution (including any relevant certification or regulatory approvals) and the major challenges encountered with alternatives which were considered but subsequently disregarded.

3.5.1 Studies Demonstrating the Current Lack of Viable Alternatives for Fluoropolymers in the HVACR Sector

The following comparative studies are summarized from independent sources outside of Copeland, highlighting the exceptional properties of fluoropolymers and the difficulty of finding a material to replace them. **Note: Copeland's research into qualifying potential alternative materials for certain applications is discussed in the Section V Confidential Attachment of this submission.**

3.5.1.1 Comparative Case Study 1: Friction Under Dry Sliding Conditions and Material Transfer [13]

Figure 9 — which was compiled by Habib Benabdallah in *Friction wear and acoustic emissions of some plastics sliding against* Si_3N_4 — shows friction testing in dry conditions with no lubrication (i.e., very severe conditions). In many industrial applications, lubrication is absent, either by a random occurrence or by design. In this test, a fixed ball is sliding against a flat plate made from various polymers. The shaded bars show the results for a ball made of SAE 52100 steel, and the white bars represent the results for a ball made of silicon nitride ceramic. The results indicate that the fluoropolymer PTFE exhibits the lowest friction among the other (i.e., non-fluoropolymer) materials. Note, the polymer HDPE is nearly as low in friction; however, its high-temperature degradation threshold is much lower than PTFE (120 °C vs. about 425 °C for PTFE), which severely restricts the applications where it can be used.

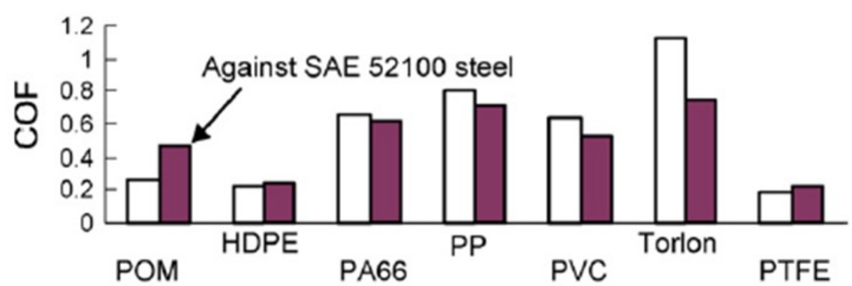


Fig. 1. Friction coefficient for $L = 10$ N, $V = 0.1$ m/s and $s = 500$ m.

Figure 9. *COF of a ball made of silicon nitride ceramic (white) and SAE52100 steel (red) sliding along a surface of different polymeric materials [Source: Habib Benabdallah (2008)]*

This same study also demonstrates how fluoropolymers, such as PTFE, have the unique ability to transfer to the opposing surface. During transfer, PTFE now exists on both sides of the wear couple, reducing friction even further. This phenomenon is made possible by the fact that fluoropolymers have low compressive and yield strength within a wide temperature range, thus enabling the material to smear onto the opposing surface. Figure 10 — which is an electron micrograph — illustrates the PTFE layers from this study that have transferred to the opposing moving surface. The resultant friction reduction leads to lower power requirements (i.e., energy reductions). Many rotating bearing systems rely on this unique property of fluoropolymers to increase their useful life, reliability, and performance. This is especially true for HVACR products, where the refrigerant tends to reduce the oil's lubricating properties. An arrow designates the direction of rotation on the transferred PTFE layer in the image.

The benefits of the low yield strength attribute are also evident in crankshaft-bearing combinations. If the bearing is not able to conform to the crankshaft during misalignment — which is a common phenomenon — it will make severe point or line contact (i.e., high unit loading), causing reliability concerns. Conversely, if the bearing can conform to the crankshaft, it will create a larger area of contact which will reduce unit loading.

The Benabdallah paper also describes that many of the other (non-fluoropolymer) plastics that were tested had less thermal resistance and melted, thereby causing poorer frictional results. Fluoropolymers have better high-temperature resistance than many other polymer families.

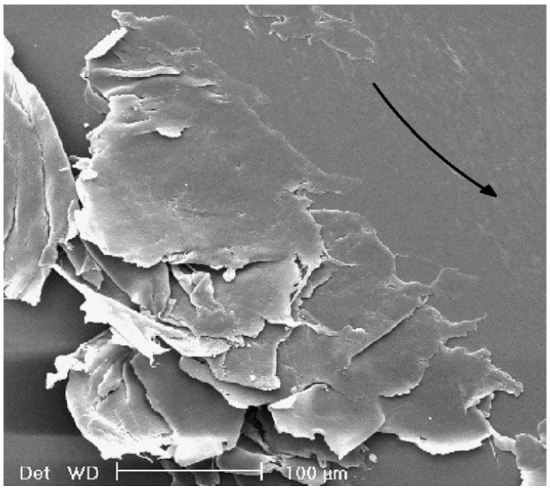


Figure 10. *Scanning electron image of PTFE that had transferred and attached to the opposing ceramic surface [Source: Habib Benabdallah (2008)]*

3.5.1.2 Comparative Case Study 2: Coefficients of Friction for Different Pairs of Materials [14]

This study shows several combinations of materials in moving (sliding) contact with each other and the resulting COF. In Figure 11, the blue bars are more applicable to HVACR, since the orange bars used an aluminium oxide counter face during testing, which is not common in this industry.

The results indicate that the lowest COF (0.06) occurs with the combination of steel and PTFE. This material combination is very common in HVACR, where steel is representative of the rotating crankshaft, and the PTFE represents the material in the sleeve bearings (i.e., making sliding contact with the crankshaft). A steel/PTFE combination is common within many other industries as well.

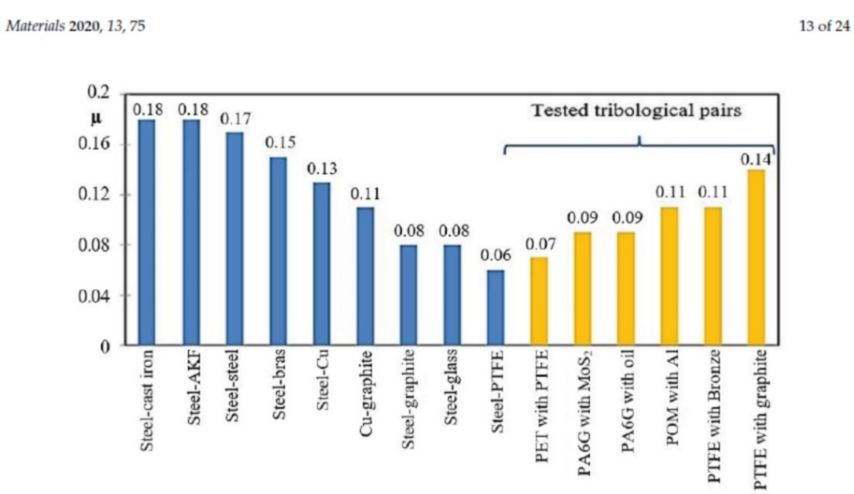


Figure 11. *COF of common opposing material combinations. Note: the lowest value (0.06) is the combination often used in HVACR for steel crankshafts rotating against PTFE-containing bearings. The second image is that of the wear testing machine and samples used during the ball-on-disk testing. [Sources: Jozwik, J., Dziedzic, K., Barszcz, M., & Pashechko, M. (2019)]*

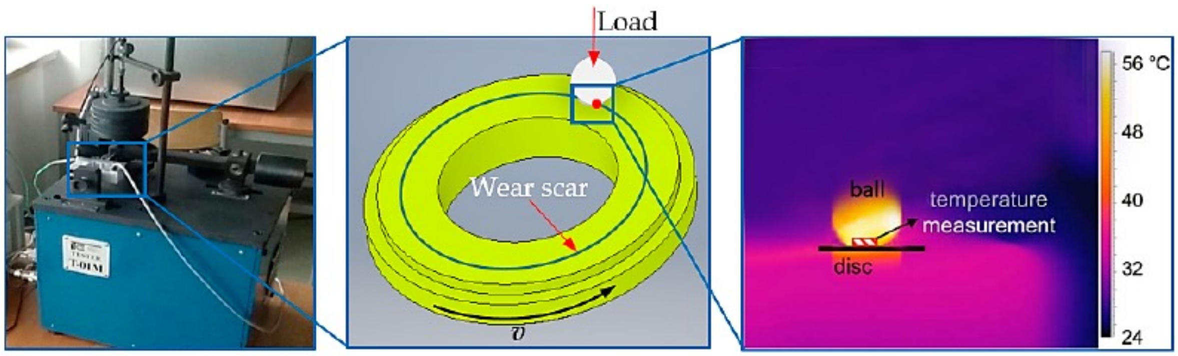


Figure 12. *The instrument used for measurements, the bearing and its wear, and the temperature on the surface and how it is measured [Source: Jozwik, J., Dziedzic, K., Barszcz, M., & Pashechko, M. (2019)]*

3.5.1.3 Comparative Case Study 3: Friction Testing of Bearing Materials With and Without Lubrication

Rheinmetall AG, a third-party supplier of bearings, conducted independent tribological testing on four types of common bearing materials, including one that is used in the HVACR industry. The testing was performed both with and without lubricant (i.e., dry). The dry testing was used to simulate oil washout due to liquid refrigerant, which periodically occurs with certain HVACR applications or operating conditions. These tests were performed on a bench tribometer. The testing conditions are shown on Figures 13 and 14. The ordinate axis for both charts is the percentage of friction increase relative to a typical PTFE-containing bearing (called PTFE-basis on the chart) used in HVACR equipment. Two other bearing materials were engineered composite polymers (i.e., PVDF and PEEK) and one was an aluminium alloy.

Figure 13 shows the results for lubricated testing. Note the dramatic increase in friction of the other three bearing materials relative to the PTFE-containing option. Lower friction is preferred for several reasons within the HVACR industry, one of which is lower power requirements. Bearings with higher friction require more energy. Additionally, higher friction makes the bearings — and consequently, the entire system — wear out sooner, which increases waste that is generated and energy that is used to manufacture and install new systems.

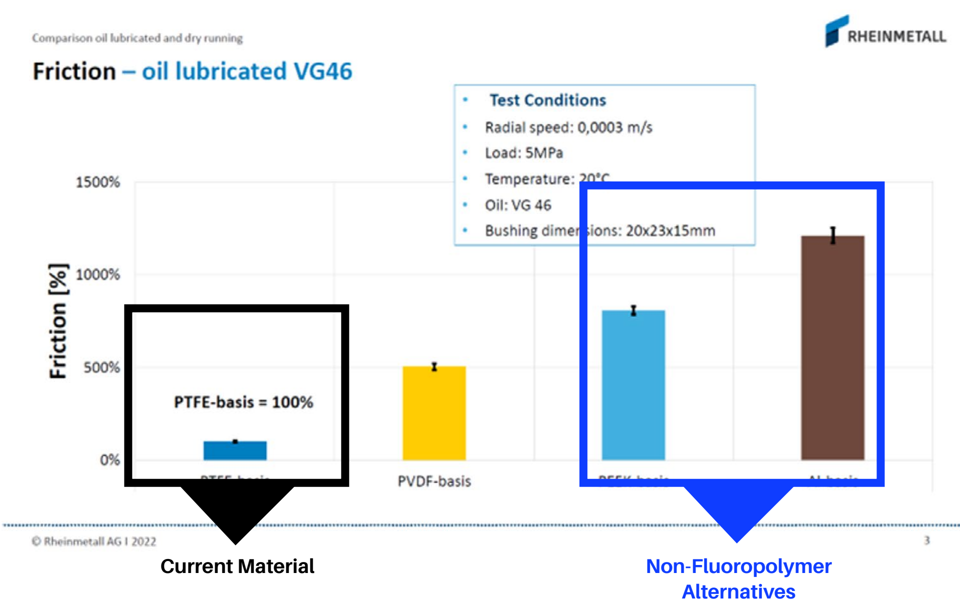


Figure 13. *Relative friction when lubricated compared to PTFE (Source: Rheinmetall AG)*

Figure 14 shows the results for the dry running conditions. Again, the PTFE-containing bearing material had the lowest friction and did not seize. However, the aluminium alloy bearing material — represented by the brown bar in Figure 13(denoted Al-basis) — quickly seized during this test and hence is not even displayed on the chart in Figure 14.

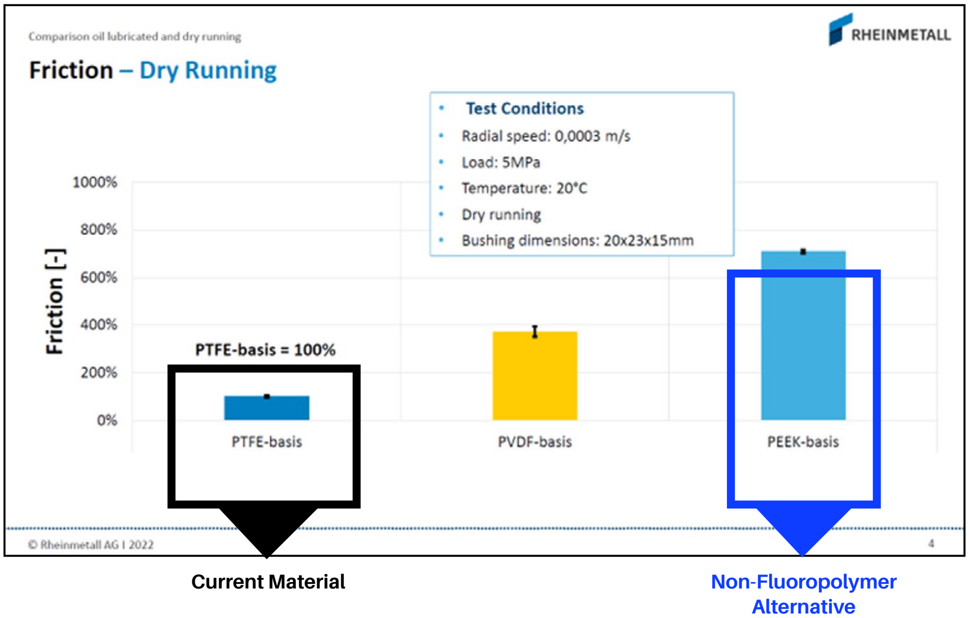


Figure 14. *Relative friction without lubrication compared to PTFE (Source: Rheinmetall AG)*

Rheinmetall AG is a division of KS Gleitlager GmbH. KS Gleitlager submitted a document to this public consultation providing additional detail on the importance of fluoropolymers in bearings on 26 May 2023. The reference number for their submission is 4307, and additional discussion of this study can be found in the attachment provided with their submission.

3.5.1.4 Comparative Case Study 4: Dielectric Constant and Maximum Service Temperatures

This study provides a comparative example of polymers for use in electronics that was assembled using ANSYS Granta's Materials Selector Software. To be used in electronics, polymers need to have a low dielectric constant and must be able to be used at high temperatures. It is difficult to find a material that possesses the optimal combination of those properties that is not a fluoropolymer. The bubble chart in Figure 15 shows the advantage of the fluoropolymers PTFE, FEP and PCTFE (circled in red) over other polymers.

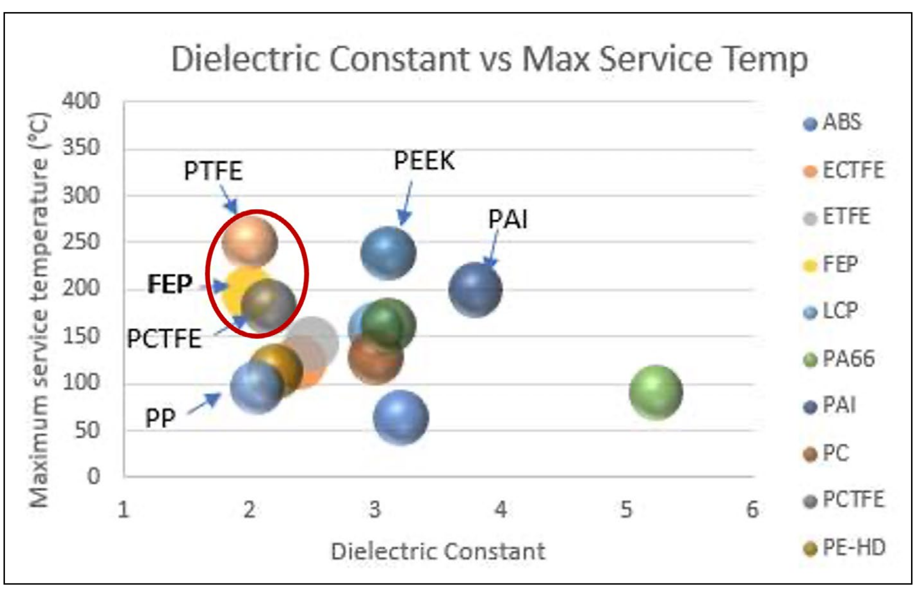


Figure 15. *Dielectric constant and maximum service temperature of different polymers (Source: ANSYS Granta Materials Selector)*

3.5.1.5 Comparative Case Study 5: Temperature Range of Polymers for Short- and Long-Term Use [15]

Figure 16 is a bar chart that compares many non-fluoropolymers with two fluoropolymers (i.e., PTFE and PVDF) in terms of their acceptable service temperature range. The darker shaded upper bar denotes longer-term use, and the lighter shaded lower bar denotes short-term use. For the HVACR sector, only the upper bar should be considered, given the long operational lives of products.

Although this chart only shows a single property (i.e., temperature tolerance), the advantage of the fluoropolymer PTFE over most non-fluoropolymers is clear. The fluoropolymer PVDF has less temperature resistance, but in HVACR products is mainly used for electrical applications when the use temperatures are not as extreme.

Recall that most HVACR applications require more than one property to be present simultaneously. For example from Figure 15, the service temperature range of PI (polyimide, a non-fluoropolymer) is superior to PTFE. However, PI has deficits: It is harder (i.e., less compliant) and would therefore have sealing application limitations (e.g., leakage prevention in HVACR valves or compression sealing). Additionally, the frictional properties of PI relative to PTFE are not equivalent; PI shows higher average friction than PTFE (see the data shown in Comparative Case Study 6 relative to PI).

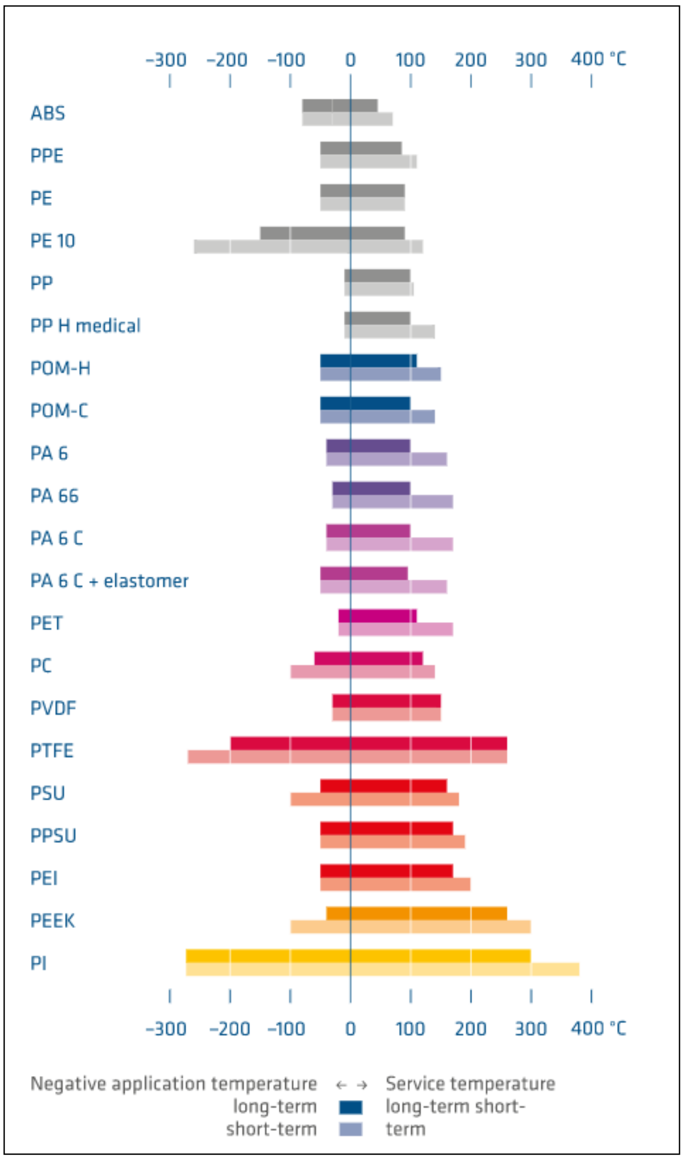


Figure 16. *Service temperature range of several polymers [Source: Ensinger (n.d.)]*

3.5.1.6 Comparative Case Study 6: Frictional Behaviour of Seals [16]

Ran Gong, Meng Liu, He Zhang and Yi Xu conducted an experimental investigation on the frictional behaviors of different composites for seal applications. The study compared PTFE, PEEK and PI seals and their coefficients of friction. In the study, the seal was used to keep oil in place. In HVACR applications, seals are used to prevent the release of oils and refrigerants into areas of the product where they should not be present and/or to the external environment. The PTFE consistently had a lower COF than the other materials, while PI seals had the highest, especially at higher speeds. Note that HVACR compressors often run at these higher speeds, greater than or equal to 3,000 RPM.

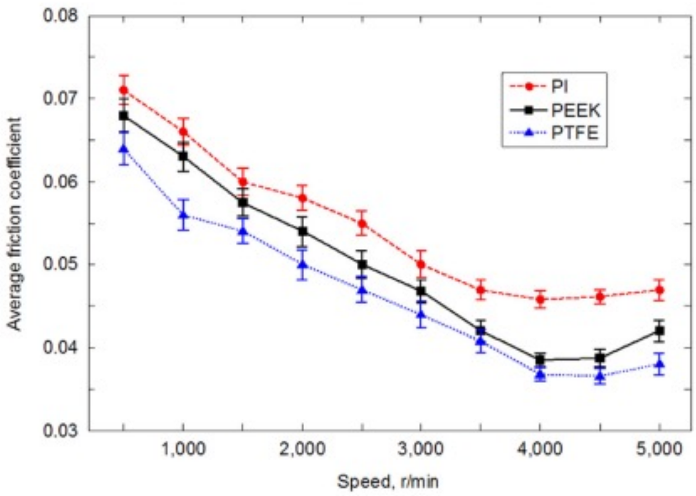


Figure 17. *The COF at different speeds of different sealing materials [Source: Ran Gong, Meng Liu, He Zhang and Yi Xu (2015)]*

3.5.1.7 Comparative Case Study No. 7: Valve Packing Material Selection[17]

Valve packing is used in rising stem and rotary valves for isolation and process control to prevent leaks between a dynamic stem or shaft and the valve body. Because the prevention of leaks and the use of seals that work well are important, Emerson Electric Co. published an article on best practices for stem seals. Several factors must be considered when choosing a valve packing material, i.e., fugitive emission standards, chemical resistance, temperatures, and pressures. Among the potential material options are PTFE and standard graphite. PTFE has significantly lower fugitive emissions than graphite.

Using parameters provided in the International Organization for Standardization (ISO) 15848-1, the study referenced here calculated the time it would take for a two-liter bottle to fill with helium due to valve packing leaks:

- PTFE: 1.42 years
- Graphite: 0.014 years or 5.1 days

The study demonstrated that PTFE provides two orders of magnitude of improved emissions control over graphite. Removal of fluoropolymers, such as PTFE, may potentially result in increased emissions of refrigerants.

Figure 18. *PTFE valve packing example*

3.5.2 Timing and Costs for Research and Product Qualification

General

Copeland does not know of any current drop-in alternatives to fluoropolymers in HVACR applications. Because of this, we will be relying heavily on chemicals/materials producers to develop new materials that can be used in place of fluoropolymers. The unique strength of the carbon-fluorine bond will likely make this a very challenging task. Once a viable alternative is developed, it will need to be qualified by the entire supply chain of the HVACR sector. Occasionally, materials being tested in this qualification process could fail to meet the requirements for use in an HVACR system, which will then trigger a material reformulation and retesting of the reformulated/new alternative. Any new material or process needs to be studied in this cyclic manner. Even after an acceptable material is discovered, one must consider that all manufacturing processes vary, and that considerable time may be required to understand and accommodate the variation in quality for any new materials manufacturing process.

All this effort takes a significant amount of time and funding, as has been well-documented with the RoHS Directive's treatment of lead in bearings and bushes. In this example — which is explained in more detail herein — a renewal of the RoHS exemption was required due to the materials substitution process taking more than 15 years to complete. It is also worth noting that in cases where mechanical redesigns may be possible (i.e., eliminating the need for a fluoropolymer component by eliminating the component from the system entirely), a requalification process of a similar time duration would be required.

Equipment conversions in the HVACR industry take several years. HVACR and water heating equipment must go through rigorous testing at Nationally Recognized Testing Laboratories (NRTLs) for both safety and energy efficiency when changes are made. This process alone can take approximately 18 months and must be done to validate each of the thousands of models of compressors that must go through this process from every manufacturer. Furthermore, OEMs are just now learning about this required change and have not yet had sufficient time to discuss this issue with suppliers or ensure that they will have access to the fluoropolymer-free replacement parts needed to begin the process of testing for regulatory compliance. Regulatory certainty is critical for this industry because of the lengthy development and approval cycles.

3.5.2.1 Estimated Overall Timeline

The required steps and estimated timeline needed to convert the HVACR industry to non-fluoropolymers are shown in Figure 19. These include major events that must take place to complete a substantive change, such as replacing fluoropolymers in all the electrical and mechanical systems within HVACR concurrently.

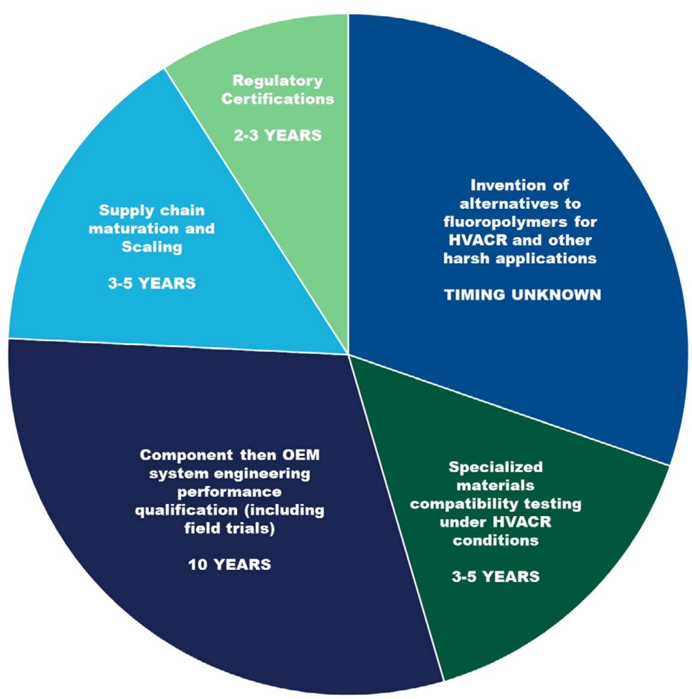


Figure 19. *Key activities needed and approximate timing required to convert the HVACR sector to alternatives to fluoropolymers. Note that some of these activities may occur concurrently.*

3.5.2.2 Timeline Detail

Invention of Alternatives

Currently, many industries use fluoropolymers. From an HVACR perspective, it is unclear whether alternatives to fluoropolymers will ever be invented for its harsh applications. Thus, it is very difficult to estimate a time frame for invention. It is assumed that less harsh applications (such as food packaging and cosmetics) will find an alternative in a reasonably short time frame. Figure 20 shows the status of current-day alternatives and the future states of materials research needed to adequately supply non-fluoropolymers to a wide range of industries.

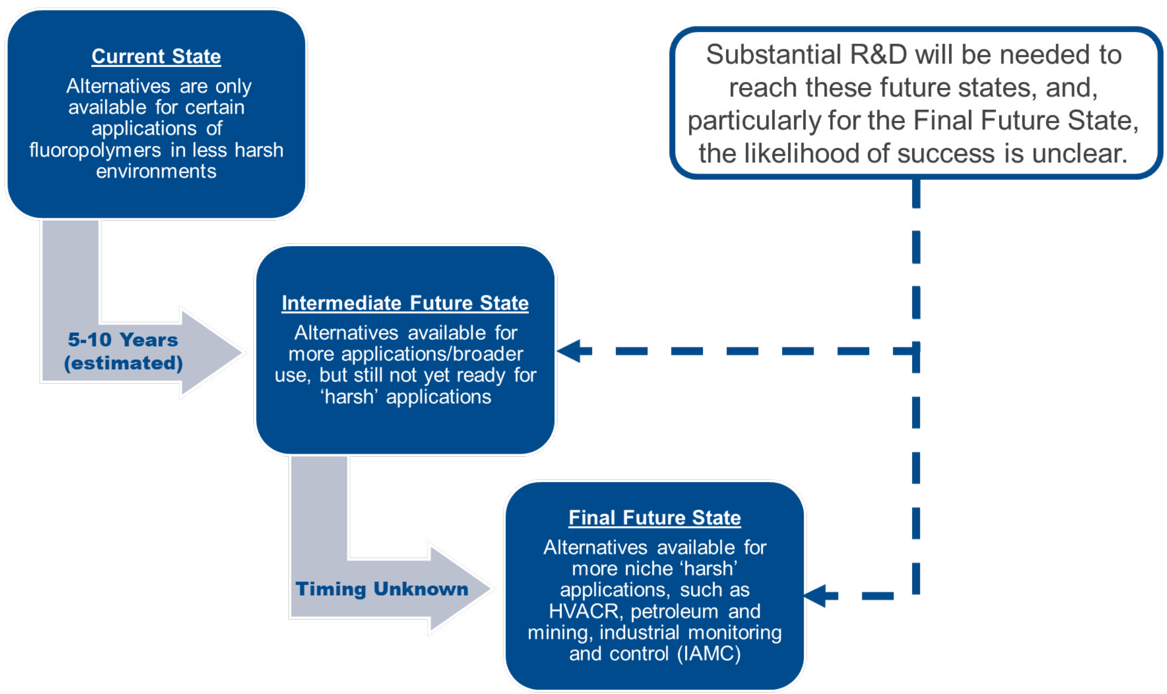


Figure 20. *Timing estimation for the stepwise invention of fluoropolymer replacements*

There is currently a substantial gap in both time and effort to broadly qualify acceptable non-fluoropolymer alternatives in the HVACR sector. Based on current knowledge, the requested minimum of a 20-year derogation is a good starting point to assess the status of invention and then address all the other stages of the alternative qualification process presented herein.

Specialized Materials Compatibility Testing Under HVACR Conditions

Regulatory agencies require very specialized and unique empirical testing to qualify materials for use in HVACR systems to ensure the safety of end users. This qualification of materials includes any potential alternatives to fluoropolymers. Very dedicated research studies are needed to find alternative materials that match the properties of fluoropolymers historically used in the HVACR industry.

Materials compatibility testing, and therefore materials selection, in the HVACR sector is often a lengthy and costly endeavour. Large studies have been performed by AHRI several times over the past few decades to assess the chemical and thermal compatibility of HVACR equipment materials of construction with refrigerants and oils. Driven first by efforts to move away from ozone depleting substances and now motivated by the effort to reduce global warming (vis-a-vis the F-Gas Regulation), new refrigerants and oils have been invented each year as the GWP criteria become stricter and the industry strives to minimize the impacts of any accidental refrigerant releases into the environment. **Therefore, there are several refrigerant and oil combinations on the market that need to be tested for compatibility with the multitude of material types currently used inside HVACR systems before those combinations of refrigerant, oil, and material can be used. Currently, these studies**

are not meant to identify replacements for fluoropolymers. Their goal is to simply ensure that the new refrigerant and oil combinations are compatible with legacy materials of construction, especially polymers.

Currently, many refrigerants and oil combinations are in use — all of which will need to be assessed with the multitude of materials being used in HVACR equipment. This creates a very large combinatorial test matrix.

Broadly speaking, this testing is twofold:

- **Chemical stability** assesses the effect of the materials of construction on the stability of the refrigerants and oils. The question answered in this testing is: Does combining them in the high pressure and temperature HVACR environment cause an adverse degradation of the refrigerants or oils over time? This is very important to know, given the long use-lives of HVACR equipment.
- **Materials compatibility** involves exposing the plastic or metal material to oil and refrigerant and heating them for a two-week period under pressure. Measurements and observations are made by comparing the "before" and "after" properties of the materials (i.e., mechanical, physical, visual, and electrical properties are assessed).

For example, Table 7 shows what a typical matrix for testing would be for the current landscape of low-GWP refrigerants, oils, and materials.

Table 7. Estimated number of necessary chemicals stability and materials compatibility tests

	Number of Refrigerant and Oil Combinations	Number of Materials	Number of Individual Tests
Chemical stability test	49	15	735
Materials compatibility test	30	31	930
Grand Total			1,665

Note that these studies only supply a general guideline for OEMs. **OEMs must also do their own testing when using different grades of materials than those that were assessed in public studies.**

These studies represent a large body of work. On average, these tests take about two years at a cost of about $1.3 million U.S. Another in-progress AHRI materials compatibility study includes the most recent low-GWP refrigerants. Again, this is to test the compatibility of legacy materials with these new refrigerants, and not to find alternatives to fluoropolymers. The next large-scale study will likely take place approximately 10 years from now. A summary of a previous AHRI study is available to the public [18].

OEM Systems and Component Qualification (Including Possible Field Trials)

This activity involves qualification at the functional level for both full end-use systems and their components. Testing must be performed to prove that no reduction in functionality has occurred due to the elimination of fluoropolymers. Functionality in this context means assessing the product performance including component functionality (e.g., valve sealing), end-use system energy efficiency, heating/cooling capacity, sound and vibration, and finally, durability.

It is a two-stage and serial process: component suppliers must complete qualification testing and then the OEMs must qualify their end- products that the components are used in. In converting to non-fluoropolymers, several electro-mechanical parts must be changed, so this will be a very complex and lengthy endeavour. Therefore, a 10-year duration for these steps is a logical starting point.

Supply chain maturation and scale

Copeland currently has more than 2,000 suppliers, of which approximately 110+ are known to currently supply fluoropolymer-containing components. If fluoropolymers are eliminated, some existing suppliers will be able to supply components utilizing non-fluoropolymers alternatives once they are discovered, and others will not; in these cases, new suppliers will need to be found. This applies up and down the supply chain — from raw materials suppliers to parts-makers. In many cases, new materials will require new processes to make them. These new processes will require development and fine-tuning to understand variability and effects on quality. Process capability development takes time, and suppliers must communicate with their customers and achieve approval.

The number of approved suppliers must be sufficient to handle the production volumes. This affects economies of scale and market pricing. The estimated time required to achieve all of this is 3–5 years.

Required Regulatory Certifications (Safety Codes and Standards)

HVACR products must comply with many regulatory certifications including energy efficiency and safety standards, as shown in Table 8. Testing must be performed to ensure compliance with each of these standards, which can be very time-consuming, especially when certain standards are dependent on the oil and refrigerant combination being used in each system. If fluoropolymers are required to be replaced in HVACR systems, time would be needed to test any new material and/or design alternatives to ensure the products comply with all applicable standards.

Table 8. HVACR regulatory standards

Standard Type	Standard Number	Standard Description
Components standards	EN IEC 60335-1	Household and similar electrical appliances – Safety – General requirements
	EN IEC 60335-2-34	Household and similar electrical appliances – Safety – Particular requirements for motor compressors
	EN 12693	Refrigerating systems and heat pumps – Safety and environmental requirements – Positive displacement refrigerant compressors
	ISO 21922	Refrigerating systems and heat pumps – Valves – Requirements, testing and marking
	ISO 14903	Refrigerating systems and heat pumps – Qualification of tightness of components and joints
	ISO 13971	Refrigeration systems and heat pumps – Flexible pipe elements, vibration isolators, expansion joints and non-metallic tubes – Requirement and classification
	EN 14276	Pressure equipment for refrigerating systems and heat pumps
	EN 12178	Refrigerating systems and heat pumps – Liquid level-indicating devices – Requirements, testing and marking
	EN 12263	Refrigerating systems and heat pumps – Liquid safety switching devices for limiting the pressure – Requirements, tests
	EN IEC 60079-0	Explosive atmospheres – Equipment – General requirements
	EN IEC 60079-7	Explosives atmospheres – Equipment protection by increased safety "e"
	EN IEC 60079-11	Explosive atmospheres – Equipment protection by intrinsic safety "i"
	EN IEC 60079-15	Explosives atmospheres – Equipment protection by type of protection "n"
	IEC 60730	Automatic electrical controls – Part 1: General requirements
Rail application	EN 45545-1	Environmental conditions for equipment – Rolling stock and on-board
	EN 45545-2	Fire protection on railway vehicles – requirement for fire behaviour of material
	EN 50153	Protective provisions relating to electrical hazards
Equipment standards	EN IEC 60335-2-89	Household and similar electrical appliances – Safety – Part 2-89: Particular requirements for commercial refrigerating appliances with an incorporated or remote refrigerant unit or compressor
	EN IEC 60335-2-40	Household and similar electrical appliances – Safety – Part 2-40: Particular requirements for electrical heat pumps, air-conditioners, and dehumidifiers
Systems	EN 378	Refrigerating systems and heat pumps – Safety and environmental requirements
	ISO 5149	Refrigerating systems and heat pumps – Safety and environmental requirements

3.6 Topic 6f. For cases in which substitution is technically and economically feasible but more time is required to substitute:

i. the type and magnitude of costs (at company level and, if available, at sector level) associated with substitution (e.g. costs for new equipment or changes in operating costs);

ii. the time required for completing the substitution process (including any relevant certification or regulatory approvals)

iii. information on possible differences in functionality and the consequences for downstream users and consumers (e.g. estimations of expected early replacement needs or expected additional energy consumption);

iv. information on the benefits for alternative providers.

For the HVACR sector, this question is currently not applicable. No feasible substitutes are currently known.

3.7 Topic 6g: For cases in which substitution is not technically or economically feasible, information on what the socio-economic impacts would be for companies, consumers, and other affected actors. If available, please provide the annual value of EU sales and profits of the relevant sector, and employment numbers for the sector.

Per EPEE, the HVACR sector has manufacturing, administrative, and R&D facilities across the EU value chain. These HVACR companies realize a turnover of over 30 billion euros and employ more than 200,000 people in Europe. Since this also creates indirect employment through a vast network of small- and medium-sized enterprises — such as contractors who install, service and maintain equipment — the total estimated employment is well over 200,000 in the EU. Copeland alone has 18 locations in the EU, with 1,500+ employees and 18,000+ employees worldwide.

As explained previously, the HVACR industry plays a vital role in society. It provides critical climate control across several key societal functions, including but not limited to:

1. Refrigeration for perishable goods ranging from food to medicine.

2. Human comfort such as maintaining habitable temperatures in hospitals, homes, and cars.

3. Critical industrial processes that require extreme temperatures.

The HVACR industry has been continuously changing and re-evaluating the refrigerants it uses since the debut of the Montreal Protocol in 1987. Over the past 10 years, it has been preparing for the conversion to lower-GWP refrigerants in order to support the goals of the Regulation (EU) No 517/2014 (i.e., the F-gas regulation). Compared to their predecessors, some of the new low-GWP fluorocarbon refrigerants have a degree of flammability (i.e., A3 and A2L refrigerants), so government agencies and corporations have funded research to develop new residential and commercial safety standards and building codes with international standards groups (i.e., IEC and ISO). The changes to the codes and standards for this transition are still ongoing and companies in the HVACR sector are constantly adjusting to new regulations. The biggest safety concern is leakage of flammable refrigerant into an occupied space. Fluoropolymers have good chemical, temperature, and pressure resistance, which make them excellent sealing materials and strong candidates for preventing leaks, and consequently, any related safety concerns.

3.7.1 Decarbonization

The biggest contribution of the HVACR industry to the European Green Deal and RePowerEU is to move heating and cooling away from fossil fuels and towards efficient heat pump equipment based on renewable energy. EPEE — one of the primary EU-wide HVACR trade associations — has conducted modeling that shows abated CO_2 in 2050 from heat pump systems will be 47 times greater than their direct (i.e., refrigerant leaking) and indirect (i.e., electricity) GHG emissions. **This modeling demonstrates the major role the transition from fossil fuel heating to electric heat pumps will play in achieving the EU's 55 percent decarbonization target by 2030.**

Figure 21 underscores the importance of HVACR heat pumps in achieving this environmental decarbonization goal.

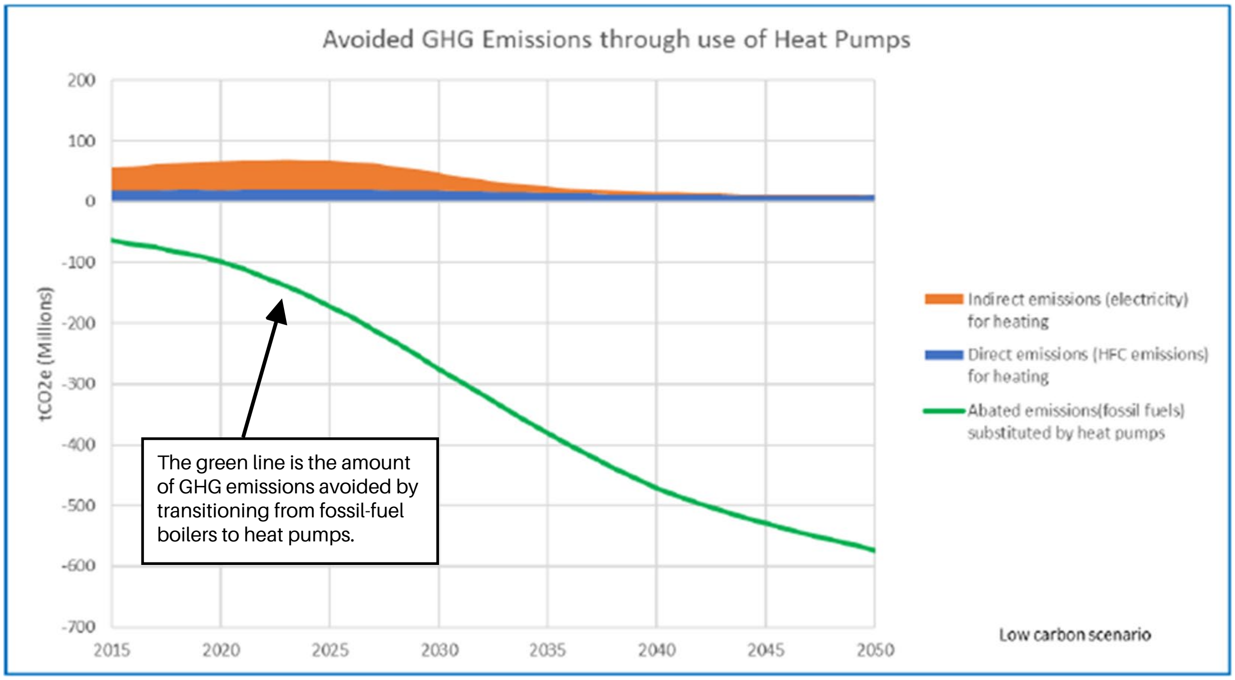


Figure 21. *The effect of using heat pumps on GHG emissions [Source: EPEE 2022, March]*

The above figure shows that "indirect emissions (i.e., electricity) for heating" will decrease over time, even if the number of HP installations are increasing drastically, since the share of renewable electricity (i.e., wind, solar, etc.) is increasing over time and replacing fossil fuel use for electricity generation.

The "direct emissions (hydrofluorocarbon emissions) for heating" are much smaller than any indirect emission, since the HP systems are predominantly hermetically sealed, and refrigerant is recovered at the equipment's end of life.

"Abated emissions (fossil fuels) substituted by heat pumps" are the most important contributor in the EU and elsewhere to support the decarbonization of society and industry. They show how much fossil fuels are saved (in tons of CO_2 equivalent) by replacing a fossil-fuel boiler with a heat pump — potentially a significant environmental benefit.

One example of where heat pumps can be employed to contribute to decarbonization efforts is district heating and cooling applications. Heat pumps can be used to harvest waste heat from data centers, metro tunnels, industrial facilities, and electrolyzers. Additionally, per the IEA:

"One high-potential waste heat source that is available everywhere – particularly in urban areas, where building heat demand is mostly concentrated – is wastewater. A recent study shows that almost 4 000 wastewater treatment plants in Europe are located less than 2 km away from a district heating network. These plants combined could deliver 175 TWh of heat to the networks per year using heat pumps, equal to one-fifth of current district heating supply in Europe.

A successful example is the Katri Vala Heating and Cooling plant in Helsinki, Finland, operating since 2006. It employs large heat pumps which have a heating capacity of 126 MW using wastewater for space and water heating in residential buildings, as well as a cooling capacity of 80 MW using cool seawater for cooling office spaces." [8]

Efficient bearing performance (i.e., low friction) in HVACR equipment is needed to make this heat pump implementation as successful as possible. Lower friction promotes energy efficiency by reducing the power required to operate the equipment, which then avoids additional stress on electricity generation capacity as well as the electrical grid infrastructure. Equipment with high energy efficiency is needed for the EU to reach climate neutrality in 2050.

3.7.2 Potential Societal Impacts of Inadequate Time to Transition to Alternative Materials

The following table is illustrative in nature and meant to emphasize the importance of the HVACR sector and the potential disruptions of banning fluoropolymers before suitable alternatives are found. It describes the potential impact of "non-use" relative to the HVACR sector in the event that no derogation is permitted. Even a small perturbation due to the unavailability of fluoropolymers would create substantial impacts on access to critical products for the population.

Table 9. Effects of a PFAS ban without a derogation for the HVACR sector

Potential Implications of a Near-Term PFAS Ban With No Derogations	Rationale
No fluoropolymers = Interruption in the food chain	• Food and beverage preservation will be affected by lack of available refrigerated transportation and storage within the cold chain (truck, trailer, ship containers, reach-in and walk-in coolers, household refrigerators). • HVACR compressors and other important components rely on the use of fluoropolymers in their bearings, seals and electrical equipment.
No fluoropolymers = Higher risk of flammable refrigerant leakage into occupied building spaces and higher indirect global warming emissions	• Fluoropolymers deliver an ideal compressive modulus and creep resistance for maintaining adequate sealing. • HVACR refrigerants do not have an odor, which adds to the safety risk associated with leaks.
No fluoropolymers = Slower adoption of sustainability initiatives	• Heat pumps are a subset application of the HVACR sector. They rely on the same system components as other uses (compressors, valves, etc.). Fluoropolymers are used in several components within a heat pump system. • Heat pumps are an alternative to fossil fuel for heating both air and water (to replace fossil boilers). The use of heat pumps is factored into achieving the Green Deal's timeline for decarbonization.
No fluoropolymers = Interruption of comfort cooling, air quality/humidity control and heating of essential buildings (hospital air quality, elder care facilities, homes, schools, etc.)	• Same as above. The same HVACR systems and their components are used. • The use of inferior replacement materials to fluoropolymers may affect system performance, reliability and useful life.
No fluoropolymers = Interruption in medical specimen temperature control	• Same as above. The same HVACR systems and their components are used. • Many medical sample types (vaccines, etc.) rely on refrigeration to maintain their efficacy and shelf life.
No fluoropolymers = Higher rate of solid waste emissions	• Less reliability of equipment and longevity of equipment (reduction of useful life).

4. RoHS and HVACR: A Success Story

The first restrictions on lead in electrical and electronic equipment came into force in early 2003. Several HVACR-specific exemptions were permitted, including those for lead as an alloying element in steel containing up to 0.35 percent lead by weight (Exemption 6[a]), aluminium containing up to 0.4 percent lead by weight (Exemption 6[b]), and as a copper alloy containing up to 4 percent lead by weight (Exemption 6[c]) as well as lead in certain solders (Exemption 7[a]).

The recast of RoHS in mid-2011 tightened the lead restrictions and lead in bearings received an exemption:

"Lead in bearing shells and bushes for refrigerant-containing compressors for heating, ventilation, air conditioning and refrigeration (HVACR) applications" (Exemption 9[b])

The HVACR industry started working on alternatives for lead in bearings shortly after restrictions entered into force in 2003 — well before 2011. The next RoHS review (EU) 2017/1010 resulted in a more specific time-limited exemption. The reason for this exemption was that:

"Lead provides low friction in the bearing by acting as a solid lubricant in case of inadequate lubrication. (3) Though lead-free bearings are viable, they still cannot reliably substitute lead bearings for the refrigerant-containing compressors with a stated electrical power input of 9 kW or lower."

Thus, exemptions 9(b) and 9(b)-(I) were enacted as follows:

"Lead in bearing shells and bushes for refrigerant-containing compressors for heating, ventilation, air conditioning and refrigeration (HVACR) applications. Applies to categories 8, 9 and 11; expires 21 July 2024 for category 11 – (non-household HVACR)" (Exemption 9[b])

"Lead in bearing shells and bushes for refrigerant-containing hermetic scroll compressors with a stated electrical power input equal or below 9 kW for heating, ventilation, air conditioning and refrigeration (HVACR) applications. Applies to category 1 (Large household appliances); expires on 21 July 2019." (Exemption 9[b]-[1])

The RoHS directive, therefore, succeeded in balancing being successful in reducing lead without raising the targets to a non- achievable level for industry. **The total time frame needed to eliminate lead in bearings — one material in a specific application — was around 15 years. For fluoropolymers in HVACR, there are multiple substances in multiple applications to address, and no feasible alternatives have yet been identified per current knowledge. Therefore, it is reasonable to assume a minimum of 20 years is needed before a replacement can be found and qualified in all HVACR products.** Assuming a potential alternative substance to replace fluoropolymers is found in the next few years, it should be evaluated by the end of the 20-year time frame, and at least partially introduced.

This success with removing lead from bearings shows that when alternatives are available to chemicals of concern, industry can properly and effectively substitute the materials of concern when given the appropriate time frame to make the substitution. Therefore, if the competent authorities believe it is necessary to ban all PFAS, it is important they give the appropriate derogations, requested herein, to allow industry enough time to properly qualify and substitute effective alternative materials.

5. Conclusion and Request Summary

Copeland recognizes the importance of the PFAS restriction and is committed to compliance with all applicable environmental laws and regulations in the countries in which we operate. Copeland supports a science-based approach to the regulation of PFAS-containing products based on evaluating actual hazards and risks balanced with other priorities and policies, such as the goal of decarbonization.

To that end, it is hoped that the input given herein is sufficient to grant the HVACR industry sector a minimum of a 20-year derogation for fluoropolymers, including those used in aftermarket and spare parts, which must be included in the derogation to ensure reparability as well as the reliability and longevity of existing HVACR equipment. Even though the derogations described in the PFAS restriction proposal are limited to a maximum of 12 years (plus 18 months from entry into force), Copeland believes that there are grounds to provide a longer derogation for the HVACR sector. We understand that there is a regulatory precedent under REACH for this request, based on CARACAL discussions, even if based on the authorisation process [19]. Please note that if no suitable alternatives are found within this timeframe, the duration of the derogation may need to be revisited. Copeland is amenable to a review period prior to the expiration of the derogation with the goal of assessing the state of fluoropolymer alternatives.

To review, the key points justifying this request are:

- Derogating only polymers of low concern
- Emissions during use are negligible
- Emissions at end-of-life are manageable
- Negligible human contact with fluoropolymers during use
- No known alternatives exist that can function inside the harsh HVACR operating conditions
- The essentiality and socioeconomic importance of the HVACR sector, including but not limited to:
    - Refrigeration for perishable goods ranging from food to medicine.
    - Human comfort such as maintaining habitable temperatures in hospitals, homes, and cars.
    - Critical industrial processes that require extreme temperatures.
    - The decarbonization of heating via electric heat pumps.

This submission is a living document and as such Copeland may submit one or more addendums prior to the end of this public consultation period.

6. Contact Information

If you have any questions regarding this document, please reach out to Dina Koepke, Director of Governmental Affairs at Copeland, at [redacted]@copeland.com.

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