# Wärtsilä's response on Per- and polyfluoroalkyl substances (PFAS) restriction proposal, technical report

**Content**

## 1 Executive summary

### Importance of PFAS containing fluoropolymer materials in Wärtsilä technology

Wärtsilä is a global leader in innovative technologies and lifecycle solutions for the marine and energy markets. We emphasise innovation in sustainable technology and services to help our customers continuously improve their environmental and economic performance. Wärtsilä employs **8.700** people in **19** EEA countries, headquartered in **Helsinki, Finland.**

Wärtsilä technologies are playing a key role in supporting societies' **critical infrastructure**, including electrical power generation, combined heat and power generation (CHP), energy storage, and fuel storage, handling, and distribution systems. In marine sector, Wärtsilä technologies **enable transport** of passengers and goods (**over 80%** of the volume of international trade in goods is carried by sea), and provide essential technology for fishing vessels, navy, tugs, dredging vessels and offshore support / construction vessels.

Wärtsilä uses extensively PFAS containing fluoropolymer materials (e.g., FKM, FFKM, PTFE, ETFE, PVDF) in high-performing components to guarantee the **safety and reliability** of the products. PFAS materials are essential in **eliminating leakages** of highly flammable or toxic fuels, **preventing fires** in electrical systems, securing the **energy generation** in critical applications (e.g., nuclear plants, hospitals, airports, and data centres) and ensuring **manoeuvrability of marine vessels**. Failures in these critical components could lead to catastrophic consequences, impacting **human lives and the environment severely.**

PFAS materials have been selected due to the properties for chemical and temperature resistance, long-durability (thermal aging), abrasion / wear resistance, oil & water repellence, withstanding pressure, oxygen tolerance, low permeation, lubrification, insulation, and fire resistance. In many Wärtsilä applications **more than one** of these properties are needed **simultaneously**, and only PFAS materials can currently fulfil these material requirements. Without PFAS containing materials, majority of Wärtsilä technologies **can no longer operate safely and reliably**. Therefore, the current PFAS restriction proposal will have a **major impact and disruption** on Wärtsilä´s customers' assets, which are already subject to strict regulations to ensure safety of operational conditions and emission control in EU.

Wärtsilä is committed in developing technologies **supporting EU and global decarbonisation goals** (European Green Deal, etc). Wärtsilä already has and is further developing technologies and solutions that enable the transition to decarbonised shipping and 100% renewable power systems. PFAS containing materials are needed to enable these technologies to work safely and reliably. As an example, PFAS containing fluoropolymer materials are required for storage and handling of **carbon-neutral fuels**, like methanol, ammonia, and hydrogen, for the **lithium-ion batteries** in energy storage systems, as well as in **carbon capture** technologies.

The core technologies containing PFAS materials for **marine sector** are:

- main and auxiliary engines, generating sets, turbochargers and related auxiliary systems
- onboard fuel supply systems
- technology for hybrid or all-electric shipping (battery powered)
- propulsors, gears (such as water jets and thrusters), and shaft line solutions
- exhaust gas treatment (SOx, NOx, particulates, and black carbon) and carbon capture
- ballast water systems
- cargo handling, reliquefication, regasification and VOC recovery systems to gas carriers and FSRUs.

Wärtsilä is a market leader in medium speed main engines, with **69 GW** of engines installed in marine vessels, **17.5 GW** under service agreement, and over **43,000** Wärtsilä equipment installed in **18,000** vessels.

The core technologies containing PFAS materials for **energy sector** are:

- gas, liquid fuel and multifuel engine power plants
- auxiliary technologies for power plants, including exhaust treatment, fuel storage and supply systems and electrical and automation installations
- large scale energy storage (battery) systems
- power-to-X, liquefaction, and biogas solutions

On land-based installations, Wärtsilä has delivered **76 GW** power plant capacity and over **110** energy storage (battery) installations in **180 countries** around the world.

## Wärtsilä´s position on the proposed PFAS restriction and derogations

Wärtsilä is committed to seeking alternative materials in co-operation with the component/material suppliers in case PFAS materials enters the REACH authorisation or restriction schemes. However, based on the Wärtsilä´s assessment, there are **no alternative materials available today** to replace many of the PFAS containing materials (fluoropolymers) for both our innovative and critical applications. For many use cases, the period required for a conversion **cannot be meaningfully determined** due to a lack of technically mature alternatives. In case a potential alternative material(s) is identified, the process to replace a safety critical component(s) in a large-scale industrial installation is a long process. The technology is needed to be **redesigned, tested in laboratory, tested in-situ, certified and approved** by class-society (marine vessels) or by national regulatory bodies (land-based installations) to fulfil all the safety and reliability requirements. As the fluoropolymers are present in a large-scale installation in hundreds of different critical components and applications, it would require a complete re-design and new technology development in case new materials would be identified, and this would take minimum 10 years.

Wärtsilä is requesting **maximum derogation time** for fluoropolymers and perfluoropolyethers in:

- applications affecting the proper functioning related to the safety of **transport vehicle** (potential derogation marked for reconsideration after the Annex XV report consultation, 6 o.)
- applications affecting the proper functioning related to the safety of **engine power plants, energy storage systems, power-to-X and fuel storage, handling, and distribution systems** (major use cases missing, and no derogation proposal in the Annex XV report)

Wärtsilä also requests developing a **mechanism to prolong** the derogation time if alternative materials have not been found when the derogation time ends.

Wärtsilä product´s life expectancy is **from 30 to 50 years,** and our company is required to **guarantee spare parts** for products with long service life. Wärtsilä is requesting **a full exemption for the spare parts** both for 'transport' and 'energy' sector technologies which are placed into market before PFAS restriction would enter into force and/or a specific derogation would expire. Wärtsilä sees that the "**repair as produced**" principle shall be respected in PFAS restriction. In Wärtsilä case it´s practically **impossible** to perform redesign, in-situ testing, certification, approval, and conversion with new materials, as it would require unreasonably long downtimes for critical installations / vessels. As an example, there are hundreds of different PFAS containing seals in engine systems and replacing them with new materials in existing customer installation is extremely difficult.

In overall, Wärtsilä is concerned about the **ability of its suppliers and sub suppliers** to continue operating and providing the materials and components needed in the assembly and maintenance of Wärtsilä products, should the PFAS restrictions come into effect. Wärtsilä is in this response focusing on PFAS use cases in Wärtsilä´s technologies, but there is no visibility how the restriction would impact on the PFAS material producers and Wärtsilä´s suppliers or sub-suppliers. Wärtsilä considers that if the PFAS restriction comes into force (without proper derogations for the whole supply chain), a significant portion of the spare parts needed in operating and maintaining the equipment currently installed in vessels, power plants, and processing facilities, will become **unavailable and make these installations inoperable**.

## 2. Collection of PFAS information

This document details what types of PFAS are used in Wärtsilä technologies and why, and whether there are non-PFAS alternatives available.

In Wärtsilä, PFAS containing components/materials are purchased from a global supplier network and Wärtsilä incorporates these components/materials into large scale industrial products and installations. Wärtsilä has established a robust way of collecting information of REACH Substances of Very High Concern (SVHC) as part of the supplier onboarding and material purchasing process, as required by the REACH regulation. Majority of the specific PFAS in Wärtsilä products (fluoropolymers) **are not identified as SVHC**, so there has not been previously any regulatory data collection requirement for most of the PFAS. Due to this, a full investigation of the whole supply chain was not possible to be carried out within the given consultation period starting 22 March 2023.

Wärtsilä conducted a targeted supplier survey to selected suppliers to understand PFAS containing supplies, criticality of the PFAS materials and potential for alternative materials. In addition, Wärtsilä engaged extensively company´s material and technology experts to analyse internal material data, use cases, design criteria and alternative materials. As a on outcome, Wärtsilä was able to have a **satisfactory overview** of PFAS applications and available alternative materials. This overview is provided in section 3.

## 3 PFAS applications in Wärtsilä

### 3.1 Transport sector

#### 3.1.1 Identified uses and criticality

Table 1 contains information of PFAS uses in product and component level within Wärtsilä technologies in **Marine vessels** (‘transport vehicle’). It´s also explained the reason why PFAS materials (fluoropolymers) are used, as well as the safety criticality of using PFAS material for this technology.

**Table 1**

| Product level | Component | PFAS | Why PFAS | Safety criticality |
|---|---|---|---|---|
| Internal combustion engine and auxiliary systems | Fuel & oil system seals and gaskets | FKM, FFKM, FEPM | High chemical and temperature resistance. (Required to tolerate up to 250 °C), slow thermal aging | Prevents leakages of flammable and toxic chemicals |
| | Injectors, solenoids and connected cables | ETFE | High chemical and temperature resistance, slow thermal aging | Prevents engine failures impacting engine’s reliability |
| | Solenoid valves | FKM | High chemical and temperature resistance, slow thermal aging | Prevents engine failures impacting engine’s reliability |
| | Sensors | FKM | High chemical and temperature resistance, slow thermal aging | Prevents engine failures impacting engine’s reliability |
| | Bearing bushes | PTFE | Wide operating temperature range -200°C/+280°C, low friction | Prevents engine failures impacting engine’s reliability |
| | Turbo charging system | FKM, FFKM, PTFE | High chemical and temperature resistance, slow thermal aging | Prevents oil and gas leakages |
| | Generator bearings, diodes/thyristors, cables, seals, sensors | PTFE, FEP, PFA, FKM, FFKM, FVQM, FEPM, ETFE | High temperature and pressure resistance, abrasion / wear resistance, electrical insulation | Reliability of the generator, fire protection |
| Exhaust treatment system | Tubes, seals | FKM, PTFE | High temperature and chemical resistance | Prevents gas and chemical leakages |
| Fuel supply systems | Heat exchangers, valves, electrical components, seals | PTFE, PCTFE | Low temperature resistance, chemical resistance, leakage prevention, oxygen tolerance | Prevents leakages of flammable and toxic chemicals |
| | Cryogenic applications | PTFE | Wide operating temperature range -200°C/+260°C, chemical resistance - PH 0-14, long lifetime, leakage prevention | Prevents leakages of flammable and toxic chemicals |
| | Compressors | PTFE | High temperature and chemical resistance, long | Prevents leakages of |

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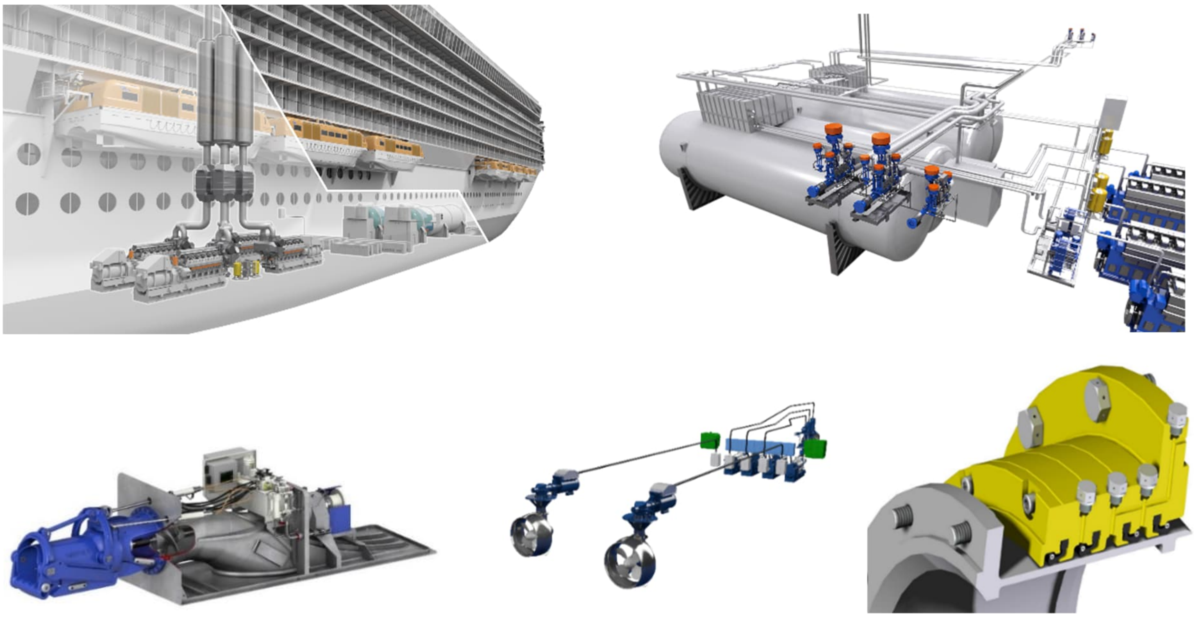
|---|---|---|---|---|
| | | | lifetime, leakage prevention, withstands pressure, abrasion / wear resistance, tribological issue, low permeation | flammable and toxic chemicals |
| | Sensors | FKM | High chemical and temperature resistance, slow thermal aging | Reliability of the control systems |
| | Cylinders, valves, seals, hoses, solenoid valves, actuators | PTFE, PFA, PVDF, ETFE, PCTFE, FKM, FFKM/FFPM, FVMQ | High chemical and temperature resistance, slow thermal aging | Prevents leakages of flammable and toxic chemicals |
| Propulsors and gears | Seals, gaskets, bearings, electronic components | FKM, FFKM | Wide operating temperature range, chemical resistance, long lifetime, leakage prevention, insulation properties, suitable for Environmentally Acceptable Lubricants (EAL) | Preventing oil leaks and spills into the environment, reliability of the propulsion & navigation system |
| Shaft line solutions (separate report, annex A) | Seals | FKM | High temperature resistance and slow thermal aging: required to withstand 130°C to 150°C for at least 5 years. Resistance to oil and saltwater without swelling, low compression set, abrasion resistance | Preventing oil leaks and spills into the environment, reliability of the propulsion & navigation system |
| | Bearings and face seals | PTFE | Chemical resistance, high temperatures, lubrification | Reliability, preventing leaks |
| Ballast water treatment | Filters | PFA, FKM | Chemical resistance | Prevent the risk of leakages |
| Carbon capture technology | Seals, gaskets | FFKM, PTFE | Chemical resistance at high temperatures | Prevent the risk of leakages |
| Cargo handling, reliquefication, regasification and VOC recovery systems | Seals, pumps, compressors, valves | FKM, FFKM, PTFE | Low temperature resistance, chemical resistance, leakage prevention | Prevents leakages of flammable and toxic chemicals |



Picture 1. Wärtsilä is providing a large portfolio of technologies to marine vessels. PFAS containing materials are used in critical components to guarantee the safety and reliability of the marine installation.

### 3.1.2 Alternative materials

Wärtsilä is committed to seeking alternative materials in co-operation with the component/material suppliers in case PFAS materials enters the REACH authorisation or restriction schemes. However, based on the Wärtsilä´s assessment, there are **no alternative materials available today** to replace many of the PFAS containing materials (fluoropolymers) for both our innovative and critical applications. For many uses, the period required for a conversion **cannot be meaningfully determined** due to a lack of technically mature alternatives. In case a potential alternative material(s) is identified, the process to replace a safety critical component(s) in a large-scale industrial installation is a long process. The technology is needed to be **redesigned, tested in laboratory, tested in-situ, certified and approved** by class-society (marine vessels) to fulfil all the safety and reliability requirements. As the fluoropolymers are present in a large-scale installation in hundreds of different critical components in different type of applications, it would require **a complete re-design and new technology development** in case new materials would be identified, taking minimum 10 years.

Wärtsilä marine technologies need to fulfil the requirements of International and EU maritime safety and pollution prevention regulations, such as the International Convention for the Safety of Life at Sea (SOLAS), Directive 2014/90/EU on marine equipment, IGF and IGC Codes for vessels using and carrying gases or other low flashpoint fuels, International Convention for the Prevention of Pollution from Ships (MARPOL) and specific regulatory requirement like the Vessel Incidental Discharge Act (VIDA) for the vessels entering into waters of United States. **These requirements cannot be met with non-PFAS materials.**

Wärtsilä refers to some EU industry associations, which have also analysed in detail available alternative materials for similar technologies like in Wärtsilä marine applications. The associations responding to the PFAS restriction consultation are:

- EUROMOT (European Association of Internal Combustion Engine Manufacturers)
- RECHARGE (Advanced rechargeable and lithium batteries association in Europe)

- ESA (European Sealing Association)
- Europump (The European Association of Pump Manufacturers)

#### 3.1.3 Derogations

Annex XV restriction report, proposal for a restriction, has a **derogation point 6. o** which is marked for reconsideration after the consultation

*o. [applications affecting the proper functioning related to the safety of transport vehicles, and affecting the safety of operators, passengers, or goods until 13.5 years after EiF].*

Wärtsilä considers that information provided in the 3.1.1 and 3.1.2 is sufficient to guarantee a maximum transition period. However, Wärtsilä would like to acknowledge that if at the end of maximum transition period no alternative material is found, there should be developed **a mechanism to extend the derogation time**.

Wärtsilä is requesting **a full exemption for the spare parts** for ‘transport’ sector technologies which are placed into market before PFAS restriction enters into force and/or a specific derogation expires. Wärtsilä sees that the “**repair as produced**” principle shall be respected in PFAS restriction. In Wärtsilä case it´s practically **impossible** to perform redesign, in-situ testing, certification, approval, and conversion with new materials in operating vessel, as it would require unreasonably long downtimes for marine vessels. As an example, there are hundreds of different PFAS containing seals in engine and propulsion systems and replacing them with new materials in existing vessel is extremely difficult. It would require docking the vessel for a long period time, and this would have a major impact on the global marine logistics, as there would not be even docking capacity available.

### 3.2 Energy sector

#### 3.2.1 Identified uses and criticality

Table 2 contains information of PFAS uses in product and component level within Wärtsilä technologies in ‘**Energy sector’** including engine power plants, energy storage systems, power-to-X and fuel storage, handling, and distribution systems. It´s also explained the reason why PFAS materials (fluoropolymers) are used, as well as the safety criticality of using PFAS material for this technology.

**Table 2**

| Product level | Component | PFAS | Why PFAS | Safety criticality |
|---|---|---|---|---|
| Internal combustion engine and auxiliary systems | Fuel & oil system seals and gaskets | FKM, FFKM, FEPM | High chemical and temperature resistance. (Required to tolerate up to 250 °C), slow thermal aging | Prevents leakages of flammable and toxic chemicals |
| | Injectors, solenoids and connected cables | ETFE | High chemical and temperature resistance, slow thermal aging | Prevents engine failures impacting engine’s reliability |

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|---|---|---|---|---|
| | Solenoid valves | FKM | High chemical and temperature resistance, slow thermal aging | Prevents engine failures impacting engine's reliability |
| | Sensors | FKM | High chemical and temperature resistance, slow thermal aging | Prevents engine failures impacting engine's reliability |
| | Bearing bushes | PTFE | Wide operating temperature range -200°C/+280°C, low friction | Prevents engine failures impacting engine's reliability |
| | Turbo charging system | FKM, FFKM, PTFE | High chemical and temperature resistance, slow thermal aging | Prevents oil and gas leakages |
| | Flexible hoses | PTFE, FKM | High temperature resistance, fire safety | Prevents leakages of flammable chemicals |
| | Valves | PTFE, FKM | High temperature and chemical resistance, durability, leakage prevention | Prevents leakages of flammable or toxic chemicals |
| | Pumps | PTFE, FKM | Chemical resistance, durability, leakage prevention | Prevents the risk of cooling water leakages |
| | Filters | PTFE, FKM | Durability, high temperature and chemical resistance, pressure resistance, leakage prevention | Prevents the risk of leakages |
| | Heat exchanger | FKM | Chemical resistance, leakage prevention | Prevents the risk of leakages |
| | Gasket and sealing materials | PTFE, FEP, PFA, VDF, HFP, FKM | High temperature and chemical resistance, electrical resistance | Guarantee the safety of high energy density and chemically aggressive environments. |
| | Generator bearings, diodes/thyristors, cables, seals, sensors | PTFE, FEP, PFA, FKM, FFKM, FVQM, FEPM, ETFE | High temperature and pressure resistance, abrasion / wear resistance, electrical insulation | Reliability of the generator, fire protection |
| Exhaust treatment system | Tubes, seals | FKM | High temperature and chemical resistance | Prevents gas and chemical leakages |
| Energy storage (battery systems) | Valves, gaskets, seals, pumps | FKM, PTFE, FEP, PFA, VDF, HFP | High temperature and chemical resistance, durability, pressure resistance | Reliability and fire safety |
| Lithium-ion Battery Module | Electrodes, electrolyte, separator, gasket, sealings | PVDF, PTFE, PFA, VDF, HFP, FKM | Thermal and mechanical stability | PFAS prevent the risk of toxic electrolyte leakages, thermal runaway, and fire. |
| Power-to-X, liquefaction, and biogas solutions | Seals, pumps, compressors, valves, sensors | FKM, FFKM PTFE | Low temperature resistance, chemical resistance, leakage prevention | Prevents leakages of flammable and toxic chemicals |


Picture 2. Wärtsilä delivers large-scale energy systems to support societies' critical infrastructure and industrial sites. PFAS containing materials are used in critical components to guarantee the safety and reliability of the installation.

### 3.2.2 Alternative materials

Wärtsilä is committed to seeking alternative materials in co-operation with the component/material suppliers in case PFAS materials enters the REACH authorisation or restriction schemes. However, based on the Wärtsilä´s assessment, there are **no alternative materials available today** to replace many of the PFAS containing materials (fluoropolymers) for both our innovative and critical applications. For many uses, the period required for a conversion **cannot be meaningfully determined** due to a lack of technically mature alternatives. In case a potential alternative material(s) is identified, the process to replace a safety critical component(s) in a large-scale industrial installation is a long process. The technology is needed to be **redesigned, tested in laboratory, tested in-situ, certified and approved** by national regulative bodies to fulfil all the safety and reliability requirements. As the fluoropolymers are present in a large-scale installation in hundreds of different critical components in different type of applications, it would require **a complete re-design and new technology development** in case new materials would be identified, taking minimum 10 years.

Land based engine power plants, energy storage systems, power-to-X and fuel storage, handling, and distribution systems located within EU area are regulated by the Directive 2006/42/EC (machinery directive), Directive 2014/68/EU (Pressure equipment directive) and 2012/18/EU (Seveso-**III** Directive, control of major-accident hazards involving dangerous substances). Large energy battery systems installations need to be certified to fire testing standards (such as UL9540 and UL 9540A). These regulatory requirements can be only fulfilled by selecting high performing, tested and certified materials for safety critical components. **These requirements cannot be met with non-PFAS materials.**

Wärtsilä would like to refer to some EU industry associations, which have analysed in detail available alternative materials for similar technologies in co-operation with Wärtsilä or Wärtsilä´s suppliers. The associations responding to the PFAS restriction consultation are:

- EUROMOT (European Association of Internal Combustion Engine Manufacturers)
- EUGINE (European Engine Power Plants Association)
- RECHARGE (Advanced rechargeable and lithium batteries association in Europe)
- ESA (European Sealing Association)
- Europump (The European Association of Pump Manufacturers)
- Hydrogen Europe (European Association representing hydrogen industry)

#### 3.2.3 Derogations

Wärtsilä is requesting **maximum derogation time** for fluoropolymers and perfluoropolyethers in applications affecting the proper functioning related to the safety of **engine power plants, energy storage systems, power-to-X and fuel storage, handling, and distribution systems.**

However, Wärtsilä would like to acknowledge that if at the end of maximum transition period no alternative material is found, there should be developed **a mechanism to extend the derogation time**.

Wärtsilä is requesting **a full exemption for the spare parts** for 'energy' sector technologies which are placed into market before PFAS restriction enters into force and/or a specific derogation expires. Wärtsilä sees that the "**repair as produced**" principle shall be respected in PFAS restriction. In Wärtsilä case it´s extremely difficult to perform redesign, in-situ testing, certification, approval, and conversion with new materials in operating power plant, energy storage, power-to-X or fuel supply system, as it would require unreasonably long downtimes for the installation and consequently disruption in energy generation and supply. This is unacceptable for technologies supporting critical infrastructure (e.g., hospitals, airports, nuclear power plants).

## 4 Emissions during use and end-of-life

### 4.1 Use phase

Wärtsilä is a downstream user of PFAS substances and as such is not PFAS manufacturer. There are no expected emissions during the assembly process of PFAS containing components and materials, or during the final installation of the products at the customer site / installation.

The PFAS materials used within Wärtsilä technologies are located inside large-scale equipment with no direct user access and fluoropolymer materials are in solid, inert, state. If PFAS containing components are accessed for maintenance purposes, components are handled with professional care according to maintenance and installation instructions.

Wärtsilä has defined specific replacement cycles e.g., for fluoropolymer seals and gaskets preventing excessive wear & tear of the components, and further minimizing any emissions to the environment. There are also instructions how to handle thermally deformed seals in exceptional situations to protect the maintenance personnel during the replacement operation.

## 4.2 End-of-life

PFAS containing fluoropolymers are durable and reliable materials reducing the waste that would derive from premature failures and extend the device life expectancy. In Wärtsilä manufacturing sites and service workshops, PFAS containing waste materials (e.g., seals) are handled professionally according to national regulations.

Considering the waste generated at the customer installations, customer is responsible of arranging the waste handling for components which become obsolete according to the national regulation. It should be noted that the weight of the PFAS containing components is low compared to the whole weight of the Wärtsilä large-scale industrial products, as the PFAS components are used only in the critical parts of the machinery – so also the waste streams are low.

Considering battery energy storage systems, battery recycling has been mandatory since 2006 in EU according to the Battery Directive and will remain mandatory with higher recycling targets in the upcoming, covering also PFAS containing materials.

Wärtsilä would like to highlight having a **full preparedness** to incorporate PFAS containing materials into Supplier-Wärtsilä-Customer communication process for hazardous substances in case EU enhances the REACH classification for PFAS, e.g., including to Candidate list, enhancing PFAS hazardous substance labelling, or through waste regulations, e.g., considering the preferred waste handling methods for PFAS materials.

## 5. Socio-Economic analysis

The socio-economic analysis separately for Energy and Marine Power business available in a confidential attachment.

## Appendix A

**Wärtsilä Shaft Line Solutions**

***Comments on ECHA proposal for PFAS restrictions***

### 1. Scope

In the marine industry, PFAS (per- and poly-fluoroalkyl substances) containing materials have been widely used for the manufacturing of composite face seals and bearings which are essential components of water lubricated systems and are also used in wide range of oil lubricated propulsion applications that play a pivotal role in preventing discharges into the marine environment.

Wärtsilä Shaft Line Solutions business manufactures products that include marine sealing systems, Shaft-Line bearings and integrated Shaft-Line systems - including associated fluid handling and control systems. Most of the delivered equipment comes under the category of transportation equipment, which includes also all relevant military applications. This equipment is critical to the safe and reliable operation of the vessels to which it is fitted. Within such a definition of safe operation is included the safety of the vessel, its occupants and cargo, and the safety of the maritime environment in which those vessels operate with respect to pollution risk.

### 2. PFAS containing materials

The term PFAS refers to a wide range of substances which include a carbon-fluorine (C=F) molecule, whose inherent strength renders the substance extremely resilient to harsh chemical and thermal environments. This resilience is part of the reason why the materials are so successful in high duty wear type applications, but it also means that the material can leave a persistent contamination footprint if released into the environment.

The shipping industry is responsible for more than 80% of world trade and is the most efficient means of heavy-lift transportation. A key element of container ships is the propulsion system, with the propeller shaft rotating in a metal tube and supported by white metal plain bearings. Elastomer rubber seals ensure the integrity of the hull by preventing oil leaks and spills into the environment.

Seal replacement is a major, time-consuming overhaul that requires seals to be safe and durable over time. With increasing and conflicting demands for high temperatures, oil resistance, and water resistance, selecting the best materials for seals in terms of long-term durability is a critical issue. Seals are typically made of an annular rubber material and must be resistant to oil as well as water environments.

As such, PFAS containing materials are widely used in the maritime industry, and in propulsion equipment in particular.

Within SLS scope, PFAS are used as friction modifiers in lubricants, within the tribological elements of seals and bearings, within the formulation of static elastomeric elements (O-rings, seal cords, hoses etc), as insulation materials, surface coatings - and indeed a wide range of other practical engineering applications. It is also highly likely that PFAS are used as a pre-cursor or process medium in the production of finished items which themselves are not PFAS containing, and so the supply chain implications are extremely far reaching.

## 3. Operating conditions of Wärtsilä Shaft Line Solutions products

### 3.1 Lip seals

The seal is based on the basic concept of a rubber lip seal, which is asymmetrical due to the hinged lip and the position of the circumferential garter spring, so the seal must be correctly fitted. The contact edge with the shaft is formed at the intersection of two conical surfaces, and the angle of each seal is left to the discretion of the designer. The contribution of the elastomer is adjustable, depending on its elastic modulus and stiffness, the cross-sectional shape of the lip, and its interference with the shaft. Garter springs are installed not only to apply load but also to compensate for the permanent deformation, creep, wear, and thermal friction that elastomers undergo when subjected to permanent strain. For newly manufactured seals, the seal edges are sharp. After a rubber seal is installed on a shaft, the contact surface is flattened by the seal load. Stationary rubber seals in contact with a rotating propeller shaft are subjected to friction and consequently heat. Replacing these seals is a major, time-consuming overhaul that requires seal safety and durability for **at least** five years.

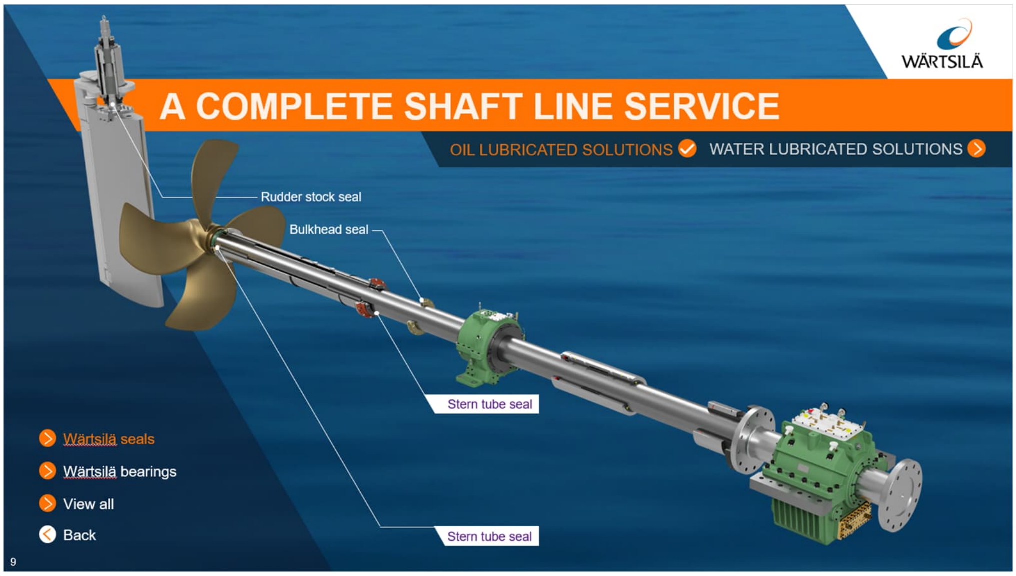


*Figure 1. Our Shaft line Service Oil Lubrication Solution*

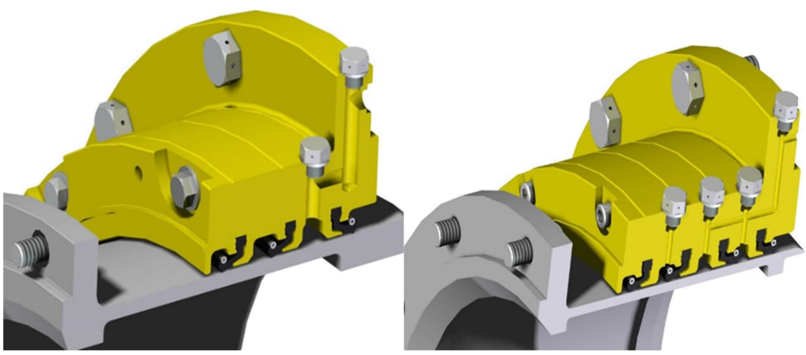

*Figure 2. stern tube sealing system*

Based on the ship's 5-year standard maintenance overhaul schedule and the corresponding expected high performance of the seals, rubber usage conditions for the use of these seals in the shipping sector are:

- The seals must be able to withstand the maximum temperatures (130°C) that may occur during their operation for at least 5 years, well above the maximum temperatures that may occur during their operation for at least 5 years.
- Long-term resistance to oil and (salt) water: limited or preferably no swell.
- Sufficient mechanical properties: tensile strength, tear strength, fatigue strength, abrasion resistance.
- Low compression set (compression set, creep) at operating temperatures of various durations.
- Brittleness temperature ≤ -5°C in marine applications.

Continuous service temperature cannot be determined in isolation without reference to its service conditions.

The load and duration of the load, whether the temperature is continuous or intermittent, the action of the surrounding environment (in this case oil and (sea) water), and whether it is in air- all play a decisive role. Most importantly, the time over which the heat acts, plays an important role with respect to the actual upper temperature limit required. Different industries have adopted different criteria to define the ability to withstand the highest achievable temperature. In conclusion, the data indicates that high temperatures (130°C to 150°C) are required for rubber seals to perform well for as long as five years.

### 3.2 Use of composites

#### 3.2.1 Composites for face seals

A face seal operates by creating a secure and effective barrier between two mating surfaces, preventing leakages. When the two sealing components are brought together, they make direct contact. This contact generates compression forces that deform the seal slightly, creating a sealing effect. This deformation causes the seal material to press against the mating surfaces, effectively closing off any potential leak paths.

The design of the face seal ensures that the pressure is distributed uniformly across the sealing surfaces, minimizing the risk of gaps or weak points. The seal material's properties, such as resilience and chemical compatibility, contribute to its ability to withstand operational conditions. This controlled deformation and contact forces maintain the seal's integrity, even in the presence of vibrations, pressure fluctuations, or movement.

The choice of materials for the face seal, the contact materials, the dynamic part and the static part, is critical. The seal material should have the right combination of resilience, durability, and chemical compatibility to withstand the operational conditions of the vessel. Materials with high resistance to pressure, temperature, are needed. These materials were meticulously chosen over the course of several years, drawing upon decades-worth of accumulated knowledge and encompassing thousands of hours of rigorous dynamic testing.

#### 3.2.2 Composite bearings

Composite bearing operates within a shaft line to provide support, reduce friction, and allow rotational motion between the vessel structure and the shaft line when the lubrication of the stern tube is water instead of oil. It is a critical component that helps minimize wear and tear, ensures smooth operation, and extends the lifespan of the system. With the benefits that a water lubricated system imply for the environment, avoiding oil leakages in the seawater, the composites are the materials that allow the supporting of the shaft line, reducing friction, and enabling rotational motion in this propulsion systems. Its design and proper functioning contribute to the efficiency, longevity, and reliability of the system. These materials were meticulously chosen with the same criteria and testing as the composite for the face seals.

## 4. Analysing alternative materials

### 4.1 Putting the search into historical context

In 1964, stern tube bearings lubricated with oil were adopted for the first time in Japanese merchant ships. This had a structure in which a lip seal ring made of synthetic rubber hugged a rotating special cast stainless steel liner to seal oil and water. Over the next three years, the stern tube sealing system was adopted by more than 100 Japanese merchant ships, and around 1975, the stern tube sealing system was replaced with one for "oil" instead of "seawater. However, for larger vessels, actual cases have arisen where it is questionable whether the original design can maintain its performance. The seal ring is made of thermosetting NBR, and there were many cases where the tip of the sliding lip hardened against the belly, causing axial cracks or circumferential cracks in the seal ring attachment area or diaphragm. In May 1967, the Japan Shipowners' Association, the Shipbuilders' Association of Japan, and the Nippon Kaiji Kyokai established the "Committee for Stern Tube Oil Seal Damage Countermeasures," which requested the cooperation of companies specializing in rubber seals to find solutions that went back to the basics, including whether the seal ring rubber material itself had problems and whether the ring's shape mechanism had problems. In November 1967, the "Improved Device" published as "Report on Improvement of Stern Tube Oil Seal System" adopted fluorine rubber (FKM), which has a high heat resistance temperature, for the seal ring rubber material and a support ring (backup ring) on the back side of the sliding lip of the seal ring to prevent belly contact. The "Seal Ring Lip Sliding Area" was proposed to prevent belly contact by providing a support ring (backup ring) on the backside of the lip sliding area of the seal ring. Subsequent improvements were made, and it was confirmed that the FKM had superior oil sealing performance. This is how NBR was replaced by FKM.

### 4.2 Comparing alternative materials performance

The rubber materials envisioned for seals applications are three types of rubber (NBR, H-NBR, and FKM):

- *Oil resistance:* The higher the ACN content in NBR and H-NBR, the better the oil resistance: H-NBR and NBR have comparable ACN content grades and comparable oil resistance; However, FKM has even better oil resistance than NBR and H-NBR due to the presence of fluorine atoms in the polymer main chain.
- *Service temperature:* FKM has a continuous service temperature of about 100°C higher than NBR and very high abrasion resistance.

A common failure mechanism of seals is the formation of small blisters on one or both sides of the seal lip and shaft contact surface. Although this phenomenon has been extensively studied, its causes remain controversial.

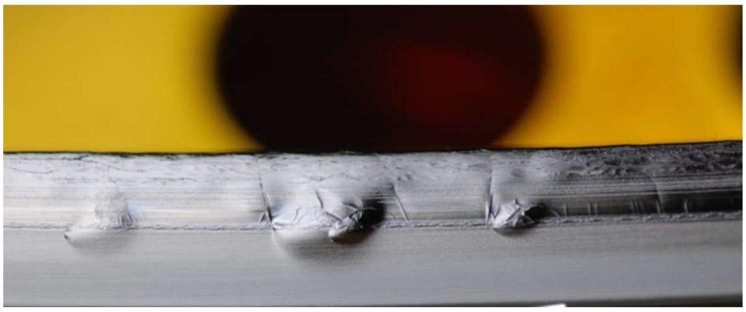

*Photo 1: Blisters formed on the seal sliding surface*

In the case of NBR, blister formation requires a longer time at a lip contact temperature of 130°C. FKM has much better thermal stability and outperforms NBR. FKM seals are overall more chemical resistant and chemically resistant than NBR seals.

The choice of elastomer material for such seals may be between NBR (nitrile rubber) and FKM (fluoroelastomer).

Over the years, the increasing size and tonnage of ships has resulted in increased thrust, leading to larger and faster rotation of screw shafts in fixed seals. For this reason, NBR has gradually fallen out of use and FKM is now used almost exclusively; FKM has better resistance and inertness to oil, surfactants, and (sea) water.

Based on the performance requirements for the use of these sealing materials in ships as described above and past experiences, can be concluded that currently there is no realistic alternative to FKM and at least many years of research would be required to find and develop a new material or sealing solution.

### 4.3 The challenge of validating new materials

While the concerns regarding PFAS are legitimate, it is crucial to acknowledge that finding suitable PFAS free alternatives poses a significant challenge. Developing PFAS-free alternative materials for water and oil lubrication systems is a challenging task, given the exceptional performance and durability of current composites and fluor elastomers used in these applications.

Identifying alternative materials that possess similar characteristics without compromising the safety and efficiency of the systems remains a complex task.

To validate new composites, a dynamic test must be performed for each material combination on a test bench. However, since the test bench is limited to one at a time, various combinations of materials cannot be tested simultaneously. As a result, a **minimum of six months** of testing is required for each material combination.

Combinations that pass the test on the test bench are then subjected to sea trials in a vessel to evaluate their performance in a real-world maritime environment. The time between selecting a suitable vessel and completing the installation can extend to **more than a year**. Subsequently, the sea trials themselves may last a minimum of **one to two years** to ensure comprehensive testing of the materials' suitability.

Considering all above, it becomes evident that a **minimum of 7 to 8 years is required to obtain PFAS-free material combinations that could potentially offer comparable performance without compromising system safety and efficiency of the installations,** and collaboration between Wärtsilä, suppliers, customers (shipyards and vessel owners) and relevant Class Societies and/or Government Agencies is mandatory to get relevant approvals, permits and international certifications.

### 4.4 Example of timeline for PFAS elimination for water lubricated propeller shaft bearing

Each of the specific PFAS applications identified has its own unique requirements and considerations, and thus the barriers to effective substitution; and the associated timescales, implementation costs and resultant product performance impact, will be quite different in each case.

Some of the applications, for example the O-rings and other elastomeric gasket type applications, are widely used across many industrial sectors and so it should be possible to leverage multi-sector collaboration to share the workload and cost burden, and thus reduce the impact upon individual sectors and businesses.

However, at the other end of the scale, some applications are sector/business unique and hence the burden will fall most heavily. To illustrate this point, the following table outlines a potentially realistic timeline of **around 10 years** for developing and proving a **replacement water lubricated propeller shaft bearing**.

Indicative investment from Wärtsilä would be circa **€5-7 million** and the ultimate proving trials would require a large-scale industry collaboration involving a consortium of Wärtsilä and supply chain, shipyard, vessel owner(s) and relevant Class Societies and/or Government Agencies.

| | Year 1 | | Year 2 | | Year 3 | | Year 4 | | Year 5 | | Year 6 | | Year 7 | | Year 8 | | Year 9 | | Year 10 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Paper Study | | | | | | | | | | | | | | | | | | | | |
| Candidate Selection | | | | | | | | | | | | | | | | | | | | |
| Small Batch Sample Production | | | | | | | | | | | | | | | | | | | | |
| Screening Tests (TRL4) | | | | | | | | | | | | | | | | | | | | |
| Final Down-Selection | | | | | | | | | | | | | | | | | | | | |
| Scale Production | | | | | | | | | | | | | | | | | | | | |
| Scale Demonstration (TRL5-6) | | | | | | | | | | | | | | | | | | | | |
| Full Scale Production | | | | | | | | | | | | | | | | | | | | |
| Pilot Vessel Trials (TRL7-8) | | | | | | | | | | | | | | | | | | | | |
| Class Society Approval (TRL9) | | | | | | | | | | | | | | | | | | | | |

*Replacement Water Lubricated Bearing Development Timeline*

A similar program for the development and proving of replacement tribological interfaces for stern seals can also be inferred, with a likely shorter timeline of around 7 years.

Most importantly, it should be noted that there is no guarantee that any replacement technology will perform to an equivalent standard of reliability or service life or will not have unintended environmental consequences which will only reveal themselves at a later stage.

## 5. Risks and consequences of failure to replace PFAS containing products

Given the ubiquitous nature of products such as lubricants and elastomeric components (O-rings, gaskets etc) it is highly likely that cross sector collaboration will find at least minimally viable alternative solutions to current PFAS containing products. These solutions will inevitably come at a price premium, at least initially, and consumption/replacement intervals could be adversely affected, but the ship propulsion sector will undoubtedly survive with economic adjustments rippling through the value stream.

However, at the other end of the spectrum and using the shaft bearings as an example, a failure to develop a viable and performance matching PFAS free alternative to current hard composite shell bearings would significantly and adversely impact the marine water lubricated propulsion Shaft-Line market by eliminating most current options. The alternative would be to reconfigure the entire propulsion Shaft-Line to one mounted on compliant nitrile rubber bearings, but this option is a major architectural change to the vessel and would be prohibitively costly and time consuming in most cases.

## 6. Compatibility and performance on the use of oils and lubricants

In December 2013, the use of environmentally acceptable lubricants (EAL) became mandatory for large vessels navigating U.S. coastal waters. The EAL label can only be held by a biodegradable, non-Four base oils are allowed in EAL formulations, each with its own characteristics.

Replacing PFAS based with new materials may lead to issues concerning compatibility and performance.

Wärtsilä Shaft Line Solutions have conducted compatibility tests with rubber materials on 285 varieties of mineral oil from 34 companies, 99 varieties of environmentally friendly lubricating oil (EAL) from 23 companies, and 16 products of environmentally friendly lubricating grease from 11 companies for each lubricating oil manufacturer.

Currently there are nearly 400 types of lubricants in use, including mineral oils and environmentally friendly lubricants. Changes in both Wärtsilä products (rubber material) and changes in composition of oils and lubricants (by suppliers), would require additional chemical analysis to validate the compatibility with the products listed, which is not realistic due to the enormous cost and time.

## 7. Spare parts and warranty period

It cannot be ignored that the expected lifetime of a vessel can vary from 15 to 50 years or more according to the use that it is given to it. Wärtsilä Shaft Line Solutions provides spare parts to its customer-based installations regularly, that are compatible with the systems in operation.

According to the Japan Shipowners' Association, there are approximately 88,000 vessels of 100 gross tons or more in the world, of which about 46,000 are merchant ships (cargo ships and passenger ships), excluding fishing boats and work ships. Wärtsilä Shaft Line Solutions market share is about 25% (about 12,000 vessels), of which 80% are oil-lubricated stern tube sealing devices.

Changes in material composition would lead to changes in the portfolio, and consequently would require extensive tests and trials to ensure compatibility of new developed materials with existing installations. This means that specifications of the stern tube sealing devices of about 10,000 vessels will potentially have to be changed.

If a potential design solution to substitute PFAS containing products on new installations would be feasible by deep research and development in collaboration with suppliers, customers, classification societies and other industries, this would not apply to existing vessels on our service portfolio, where shape back compatibility and operating characteristics are mandatory.