

Use of PFAS in high-voltage switchgear

Hitachi Energy response to ECHA PFAS restriction dossier

Summary

Hitachi Energy recognizes the need to avoid emissions of substances with known toxicological concerns in order to best protect human health and the environment. This goal needs to be achieved by employing a risk-based regulatory approach in a sustainable manner, ensuring product reliability and achieving critical targets such as the green energy transition. To do so, any restriction of PFAS needs to be appropriately differentiated: the group of PFAS is a large and inhomogeneous group of substances with very different physical and chemical properties, coming with vastly different levels of hazards. The human health and environmental implications of those substances are also different and depend on the nature and level of control of their use. Thus, sustainable regulation of PFAS should identify differentiated risk management measures in consideration of the risk of a specific substance in a specific use with its relevance for society.

Hitachi Energy acknowledges and fully supports the risk management of substances which are detected as environmental pollutants and potentially linked to negative effects on human health. Examples of such materials are PFOS, PFOA, PFHxS, PFNA, C9-C14 PFCAs, any of the PFAS substances on the REACH list of Substances of Very High Concern (SVHC), any of the priority substances of potential toxicological concern within the PFAS workstream of the European Human Biomonitoring project (HBM4EU), and any precursors of those substances.

High-voltage switchgear uses two types of PFAS differing fundamentally from the above in their impact on humans, animals and plants. The two specific PFAS categories used in the equipment for their unique combination of properties are:

- Dilute mixtures of Heptafluorobutyronitrile (C4-FN, CAS No. 42532-60-5), a single fluorinated gas, identified as the most efficient and reliable replacement for sulfur hexafluoride gas (SF₆) thanks to its insulation characteristics, with concentrations ranging from 3 - 5%.
- Fluoropolymers for bearings, gliding rings and lubricants and the essential arcing nozzle made from polytetrafluoroethylene (PTFE, CAS No. 9002-84-0) used to contain and guide the hot, gaseous plasma in each gas circuit breaker.

The above two PFAS materials categories used are different from other PFAS such as fluorinated surfactants (which have been under regulatory scrutiny for their toxicological concerns) in the following ways:

- The dilute C4-FN mixture used in SF₆-free high-voltage equipment is not classified as toxic. This has been determined through professional toxicological and ecotoxicological assessments.^{1,2}
- C4-FN does not accumulate in water, plants, or the soil and has an average atmospheric lifetime of 30 years².
- High-voltage equipment is extremely gas-tight by design as required by international standards³. The C4-FN concentration ranges between 3 - 5%. Equipment tightness is assured in order to fulfill the functionality and maintenance is done by educated professionals. Even if the gas ever escapes, due to leakages (that are kept minimum due to constant monitoring through sensors to ensure functional integrity of the equipment) or rare handling mistakes during maintenance, only amounts of 1-2 tons per year will be emitted as a total from the complete installed base of equipment in all of Europe (see below).

- Emitted C4-FN gas from dilute mixtures will evenly spread in the atmosphere and decompose into naturally present, geogenic trifluoroacetic acid, with a proven very small environmental risk (“...risks from current and future releases of TFA from the use of fluorinated precursors regulated under the Montreal Protocol to aquatic and terrestrial plants are *de minimis*.”).⁴
- More than 96% of globally used fluoropolymers, including PTFE and fluorinated elastomers, fulfill the widely accepted criteria for polymers of low concern as per OECD definitions.^{5,6,7}

Note that 3 - 5% C4-FN mixtures replace the much more harmful emissions of pure, 100% SF₆, with a global warming potential (GWP) 24,300 times higher than that of CO₂ and an atmospheric lifetime of 1000 years. There is a wide consensus in the industry and by regulators on the need for an SF₆ phase-out as quickly as possible. Replacing SF₆ technology with C4-FN based switchgear was shown and validated by third party experts to be the most sustainable solution compared to other proposed solutions from a total life cycle point of view^{8,9,10}. Indeed, it allows to keep the compact size of the equipment drastically reducing the use of raw materials and space (and related carbon emissions). No alternative exists that would allow the same performances (including in areas like cities where the space and size of buildings are limited) and reliability. Other alternatives are not able to allow the retrofit and retrofill of SF₆ equipment.

In addition to the above material characteristics, high-voltage equipment is only accessible to trained maintenance and service personnel following well-defined operating procedures. The solid fluoropolymers, like PTFE nozzles components are either recycled or incinerated after decommissioning.

The descriptions above, backed with the technical details and references presented in this document, demonstrate why this group of PFAS materials used in high-voltage equipment should not be subject to the proposed restrictions, established on the risk-based approach according to Article 68(1) REACH and substance-based approach according to Article 69 REACH.

1 Introduction to PFAS use in high-voltage switchgear

Hitachi Energy is a global technology leader, headquartered in Switzerland employing more than 40,000 employees. The company’s legacy dates to 1883 when Asea was founded in Sweden and to 1891 in Switzerland with BBC. Hitachi Energy is committed to advancing a sustainable energy future for all. With its roots in Europe, Hitachi Energy currently has 36 manufacturing facilities and 4 R&D centers in Europe, employing more than 16,000 people across the continent, with a widespread EU presence that includes Sweden, Italy, Spain, Germany, Poland, Czech Republic, Belgium and Bulgaria amongst others.

Through the Hitachi Energy “Sustainability 2030” plan and targets, the company has defined its strategy, which combines innovative solutions with a diverse and inclusive company culture, to contribute to a more sustainable society – aligned with the UN’s Sustainable Development Goals (SDGs), advancing the world’s energy system to be more sustainable, flexible, and secure. Our commitments include a 25% reduction target of hazardous substances and chemicals by 2030, compared to the 2022 baseline.

High-voltage switchgear (> 52kV) is the essential component of the electricity network. It includes circuit breakers, disconnectors, instrument transformer, surge arresters and other components assuring safe operation of the power grid so that society can benefit from continuous availability of electricity. To give an order of magnitude and context, a single 420kV high-voltage switchgear is securing electricity supply for about 2 million people. Reliability is a core element for these technologies. The use of strategic grid technologies is essential to the decarbonization of the EU – such as expansion of renewables – and must be ensured to avoid missing the 2030 targets and 2050 net zero objective.

PFAS subgroups have very different physical, chemical, and biological properties. For example, they may or may not mix with water, and they may or may not be volatile. The terminal degradation product in the environment is not common for all PFAS, and they may degrade quickly and locally or in a diffuse mode after being globally dispersed. Use in consumer products implies a lower level of control at decommissioning compared to high tech infrastructure applications. The proposed restriction of all PFAS does not adequately take into consideration the extreme diversity of decisive

substance properties, including their toxicity and the risk profiles of their respective uses. A more differentiated regulatory approach that is risk-based according to Article 68(1) REACH and substance-based according to Article 69 REACH in of paramount importance

In high-voltage switchgear, PFAS are used for their unique combination of properties, chemical stability and tribological performance at elevated temperatures. They allow the equipment to be reliable and operate stable across its minimum expected lifetime of 40 years.

Two groups are commonly used in high voltage equipment:

- Dilute mixtures of Heptafluorobutyronitrile (C4-FN), a single fluorinated gas, identified as ideal replacement for sulfur hexafluoride gas (SF₆), due to its outstanding dielectric insulation capabilities and comparatively low global warming potential (GWP).
- Fluoropolymers, used for a variety of different components such as bearings, sealings, gliding rings and lubricants and insulation components including the essential arcing nozzle, a core component used to contain and guide the hot, gaseous plasma in each gas circuit breaker, made from polytetrafluoroethylene (PTFE).

1.1 Use of C4-FN as insulation gas

For almost half a century, high-voltage switchgear relied heavily on the unique properties of SF₆, used for its excellent insulation and switching capabilities. However, it has a global warming potential (GWP) per unit of weight 24,300 times higher than that of CO₂ and contributes approximately 0.3% to the current global temperature increase. The atmospheric lifetime of SF₆ is extremely long, 1000 years or more, so the industry and regulators agree that SF₆ in current equipment must be contained to the possible extent and phased out from new equipment as quickly as possible⁹.

The most effective and eco-efficient way to replace sulfur hexafluoride in high-voltage gas-insulated switchgear is to replace it with a gas mixture using C4-FN. As an example, a life cycle assessment⁸ comparing different concepts for 145kV gas-insulated-switchgear has shown C4-FN to be superior to other solutions, such as vacuum/air technology (as reviewed and confirmed by the IVL Swedish Environmental Research Institute Ltd, see separate attachment). In the case of Hitachi Energy's products, it is made of 96.5% natural gases, such as carbon dioxide and oxygen, plus 3.5% C4-FN, a fluorinated nitrile. The use of such a gas mixture has several major benefits: it allows high-voltage equipment to keep the performance ratings and margins of safety for all high-voltage levels by providing a readily scalable technical solution, while the reliability and size of the high-voltage equipment stays the same compared to today's SF₆-based technology. Scalability and high reliability are important because combined, they address a large share of the equipment demand covered by SF₆ technology today, in a timely manner, without compromising the availability of electricity supply. Compact size is important, because especially gas-insulated equipment is used in locations where space is very limited, e.g., in urban areas or generally where land use for the electrical equipment needs to be minimized.

In addition, the use of C4-FN based gas mixtures enables *retrofit* and *retrofill* concepts. For *retrofill*, SF₆ is replaced in already installed high-voltage equipment with a C4-FN mixture, while the key parts of the high-voltage equipment like enclosures, conductors, and insulators stay in service. A pilot *retrofill* installation with C4-FN mixtures was executed for gas-insulated lines (GIL) in the United Kingdom. This technology has the potential to remove large amounts of SF₆ from the grid with low on-site effort, minimal outage time, extremely low consumption of new material and therefore high availability of the power supply and low carbon footprint.¹⁰ For *retrofit* the whole installation or some selected parts, where *retrofill* is not possible, is replaced with similar or identical sized equipment, ensuring the existing infrastructure and buildings continue to be used and in essence keeping the footprint stable, a critical requirement for densely populated metropolitan areas around the world. Both concepts help to avoid further emissions of SF₆ from already installed equipment.

1.2 Use of Fluoropolymers

1.2.1 PTFE as insulation nozzle

The behavior of the electric arc in high-voltage switchgear is controlled by a specially designed nozzle made of PTFE. During operation, the intense heat of the arc causes the PTFE nozzle material to sublime, contributing to cooling the arc. This interaction between the nozzle material and the arc plasma is crucial for interrupting the electric current. The sublimating nozzle material combines with the insulating gas, creating a gaseous mixture that extinguishes the arc, allowing safe interruption. Of critical importance is that during the sublimation process and after cooling down, the PTFE surface retains the required insulating properties.

Since its introduction in the 1950's and 1960's, PTFE has remained the sole and enduring choice as the nozzle material for gas circuit breakers. PTFE was specifically chosen and has continued to be the preferred material due to its outstanding properties. This combination of SF₆ gas and PTFE as the nozzle material has proven to be highly effective in achieving efficient interruption of electrical currents and ensuring the reliable operation of gas circuit breakers in high-voltage applications. This holds true not only for SF₆ but also for alternative gases being used in modern gas circuit breakers. Over decades, extensive research and development efforts were conducted to investigate different nozzle materials. However, PTFE remains the only material suitable for this purpose. Systematic studies and experiments have shown that PTFE composites offer the required performance and reliability.³⁷

1.2.2 Other fluoropolymers

In addition to the aforementioned critical uses of PFAS for circuit-breakers, there are a variety of other applications in high-voltage switchgear. Most commonly they are fluoropolymers or fluoropolymer-based composite materials or fluorinated elastomers.

In high voltage equipment, there are overlapping requirements of high temperature resistance, high durability, chemical stability, and electrical insulation.

Examples for such applications include:

- Bearings made from fluoropolymers or fluoropolymer-composites, without additional lubrication, able to reliably operate even after 40 years in service and long periods of idle time
- Guiding elements made from fluoropolymers or fluoropolymer-composites, lubricated or without additional lubrication, able to operate after 40 years in service and in presence of continuously elevated temperatures
- Fluorinated lubricants or fluoropolymer containing lubricants for highly stressed mechanical components and electrical connections to ensure mechanical endurance for 40 years while limiting thermal losses incurred due to contact wear
- Fluorinated elastomers used to seal insulation oils used in oil-insulated capacitors or transformers, requiring chemical stability against the oils while preventing gas permeation and corrosion

2 PFAS Emissions of high-voltage switchgear

Two major characteristics and requirements for high-voltage switchgear are its reliability and its long service life. Different from consumer products, these products must last for decades. They are routinely maintained and continuously monitored by specialized professionals due to their importance in ensuring consistent and continuous access to electrical power for society. High-voltage equipment is very gas-tight because the functional performance and reliability depend on the constant operating pressure of the insulating gas. Consequentially, any emissions of insulation gas are rapidly identified and corrected.

As described in the previous section, the main types of fluorinated alkyl substances used in high-voltage switchgear are fluorinated polymers (including fluorinated elastomers), fluorinated oils and C4-FN, a specific fluorinated gas.

Health and safety properties of fluorinated polymers

The health and safety aspects and properties of fluorinated polymers and oils have been well researched over the last decades, confirming that most fluoropolymers including fluorinated elastomers meet the OECD criteria for polymers of low concern^{11,12}. Those studies conclude that although fluoropolymers fit the PFAS structural definition, they have very different physical, chemical, environmental and toxicological properties compared to other substances in the PFAS class. Fluoropolymers are insoluble solids too large to migrate through cell membranes, making them nonbioavailable, and are therefore of “low concern from a human and environmental health standpoint”.

Recycling and incineration of PTFE

Beyond recycling, which is well known and established for many fluoropolymers including PTFE¹³, a recent study from 2021 performed by the Dutch National Institute for Public Health and the Environment (RIVM) shows that most PFAS treated in waste incineration processes will degrade: “...most of the PFASs will largely degrade during the incineration process and then be removed when the flue gases are cleaned. The remaining PFASs are expected to be removed during the recovery of the carbon dioxide¹⁴.”

Health and safety properties of C4-FN mixtures

C4-FN is a registered REACH substance. The pure C4-FN gas (which is not present at the substation because only the mixture is used) is classified as “harmful if inhaled”, and this is the lowest classification under the EU CLP regulation. It is given to many substances which are in everyday household use such as gasoline and acetic acid. The REACH dossier shows in full detail the large number of professional toxicological and ecotoxicological studies which have been executed to substantiate the low classification for C4-FN².

The dilute C4-FN mixture used in SF₆-free high-voltage switchgear is not classified as toxic¹⁵. This has been determined through professional toxicological and ecotoxicological assessments according to the EU regulation on classification, labelling and packaging of substances and mixtures (EU-CLP) and is documented in the safety data sheet of the gas mixture¹⁶.

Emissions of SF₆ alternative insulation gases

Modern high-voltage switchgear, designed to fulfill the stringent requirements of applicable, international standards³ are required to limit gas leakages to < 0.5% per year.

In eco-efficient switchgear, each 1000 kg of SF₆ is substituted by 80 kg of C4-FN. This ratio can serve to estimate the C4-FN emissions to be expected when such eco-efficient switchgear is widely adopted. Modern high-voltage switchgear, using state-of-the-art design, assembly methods, testing procedures and gasket-materials achieve leakage rates of 0.1% / year. Conservative assumptions based on currently installed base and across all potential leakage-sources like gas handling and maintenance result in a total leakage rate of ca. 0.2% / year of the installed C4-FN quantity.

Based on available data about the complete installed base of high-voltage switchgear in Europe, which emits an estimated 60 tons of SF₆ annually today (with an average leakage rate of 1.0% typical for equipment installed in the last decades), – *if it had been fully substituted by eco-efficient gas mixtures* – would emit roughly 1 ton of C4-FN (at a leakage rate typical for modern equipment of 0.2%). With the atmospheric conversion rate²⁸, this would correspond to globally diffuse annual emissions of trifluoroacetic acid of 0.6 tons (globally about 2 tons), **see Figure 1. The amount of emitted C4-FN and consequentially released trifluoroacetic acid (TFA) is significantly lower compared to any other source.**

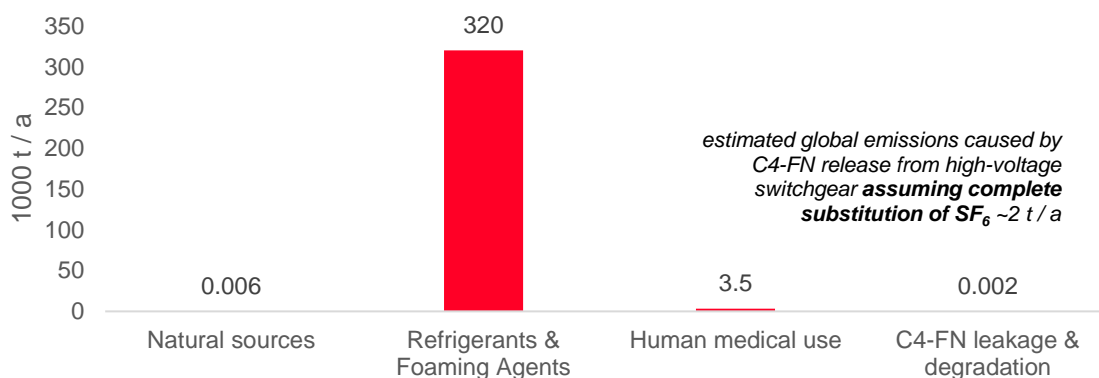


Figure 1 – Global annual emissions of TFA from various sources⁴

Environmental properties of C4-FN mixtures and atmospheric fate

C4-FN cannot accumulate in water, plants, or the soil. This is a direct consequence of the vapor pressure curve and the extremely limited water solubility of C4-FN, established by measurements for the REACH registration dossier^{2,17}. Any C4-FN escaping from its fixed enclosure can only go to the atmosphere whatever the weather conditions at the time, and just as any other gas it will spread globally until it decomposes.

The atmospheric fate of C4-FN is well studied, based on accepted standards for environmental impact and risk assessments and covered by high-quality scientific publications^{18,19,20,21}. C4-FN has an average atmospheric lifetime of 30 years. It decomposes through the reaction with OH radicals and through unstable intermediates into TFA, CO₂ and other molecules of natural origin. The dominant portion of the global TFA present in nature is of natural, geogenic origin and has accumulated in the oceans^{22,23}.

Trifluoroacetic acid as main degradation product of emitted PFAS from high-voltage switchgear

The Effects Assessment Panel of the United Nations Environment Program considers TFA a very small environmental risk compared to other environmental priorities (“...risks from current and future releases of TFA from the use of fluorinated precursors regulated under the Montreal Protocol to aquatic and terrestrial plants are *de minimis*.”)²⁴.

Recycling of C4-FN

At the end of life of the high-voltage equipment, the gas mixture is reclaimed into gas tight containers. Due to the large difference in boiling point, the C4-FN component of the gas mixture can be easily separated from the CO₂ and O₂ in the mixture. The result is recycled C4-FN gas that is suitable for reuse in the next generation of high-voltage equipment. The recycling procedure is established and commercially available²⁵, in parallel, international standardization is progressing well to establish a common gas quality definition for reuse²⁶.

Above considerations support the outcomes of many studies and reviews concluding that grouping all PFAS together does not reflect the individual risk potential of different substances. For example, the OECD concludes that PFAS as a definition only describes a class of diverse molecular structures with diverse physical, chemical, and biological properties and recommends that such diversity be properly recognized and communicated in a clear, specific and descriptive manner. Using PFAS as a descriptor is broad and generic and does not inform whether a compound is harmful²⁷.

Similarly, an independent study²⁸ came to several key conclusions: While the lack of information for the majority of PFAS presents challenges for mixtures’ risk assessment, it agreed that “all PFAS” should not be grouped together for risk assessment purposes. “Persistence” alone is not sufficient for grouping PFAS for the purposes of assessing human health risk and it is inappropriate to assume equal toxicity/potency for PFAS without confirmatory information.

The use of PFAS in high voltage equipment is highly specialized and limited to the strict need of reliability and durability. Therefore, it is very likely that any potential new replacement material identified would inherit the persistency property of the currently used materials. This emphasizes the importance of risk and data-based differentiation of materials and applications, instead of the persistence-based restriction alone.

3 Availability, limitations, and risks of alternative technologies

3.1 Vacuum circuit breakers and air insulated switchgear

It has been suggested that it is preferable to replace SF₆ in high-voltage switchgear exclusively with technical air and the use of vacuum circuit breakers, instead of using gas circuit breakers with different insulation gas mixtures. Attempts to replace gas circuit breaker technology with vacuum (air) interrupters go back to the 1970's for 72.5 kV. In the early 2000's those efforts were extended to 145 kV, but the technical solutions available today, more than 20 years later, are still limited in their capabilities and potential to substitute gas circuit breaker technology.

Furthermore, such approach is not without substantial environmental and socio-economic downsides, significant technical risks, and is by no means an obvious "no-regret" option:

- 1) Eco-efficient diluted mixtures of C4-FN are available now for the relevant voltage levels where the biggest quantities of SF₆ are used (for example voltage levels of 420 kV in the backbone of the European power grid). In contrast to that, 420 kV solutions based on technical air insulation and vacuum circuit breakers are at concept level. The restriction of diluted C4-FN mixtures for high-voltage would mean a prolonged significant SF₆ use and operational obstacles to the expansion of the grid related to the increase of renewable energy production.

In addition, there are major technical risks related to employing vacuum circuit breaker technology in high voltage ratings. Intrinsic performance limitations of vacuum circuit breakers are their inability to reliably perform capacitive back-to-back as well as inductive switching duties. These characteristics are known in the high voltage industry and well documented in technical papers as well as in CIGRE technical brochures^{29,30,31,32}. At the same time, the increasing share of renewables in the European power grid will cause a significant increase in the capacitive and reactive switching demand to keep the grid stable and minimize losses. Therefore, a limitation to a potential vacuum interrupter technology would hamper and prevent grid maintenance or extensions necessary for reliable integration of renewable sources. Research and development to improve the inductor and capacitor switching performance of vacuum circuit breakers has been ongoing for decades with limited success for 145 kV³¹. For the important transmission rating of 420 kV, no solution is available. In open condition, vacuum interrupters generate X-ray emissions. Vacuum interrupters are therefore considered stray radiation sources and dose rate limits are imposed to ensure safety of workers for operation and testing scenarios. While these limits seem to be fulfilled for the 145 kV voltage level, the dose rate grows exponentially with higher voltage³³. It is therefore not clear if the limits can be adhered to for a 420 kV solution.

- 2) While the reliability of gas circuit breakers in general is well established, regardless of the known insulation gas used, there are significant uncertainties regarding the reliability of vacuum circuit breakers at higher voltages. A blackout caused by a failure of 420 kV switchgear would incur multiple billions of Euros in indirect commercial damage per each event³⁴. Today, vacuum circuit breaker-based products up to 145 kV are in the introductory phase and already at this voltage level "challenges regarding small particles and high pressures" are reported by the equipment operators installing the new equipment³⁵. For 420 kV, even higher pressures (12 bar instead of 8 bar) and much larger installations are likely to compound these issues.
- 3) Gas insulation with technical air implies a substantial increase for the size of substations (see Figure 2), about a factor of two for 420 kV³⁶. Consequently, the use of carbon intensive and critical raw materials is increased, and the product life cycle assessment shows an inferior environmental performance compared to eco-efficient solutions using dilute C4-FN mixtures. Space itself is also a valuable environmental and socio-economic resource, both in cities and the countryside.
- 4) The larger size also implies an increase in capital costs. From the doubling of the material weight one can infer a doubling of the capital cost. For new Gas Insulated Switchgear installations in Europe this would correspond to additional costs of about 1 billion Euro to be passed on to EU's electricity consumers.

420 kV GIS based on an SF₆-free gas mixture

420 kV GIS based on air & vacuum circuit-breaker



Figure 2 - Size comparison of typical substation for the 420 kV backbone of the European power grid, scaling consistent with Hitachi Energy product (left side) and a 420 kV air & vacuum circuit breaker concept presented in³⁶

3.2 Alternative materials for circuit breaker nozzles

Hitachi Energy has conducted a comprehensive investigation in which various materials were evaluated for their suitability as nozzle materials. The selection process considered several criteria³⁷, including the following:

- Mechanical Strength: Evaluating the material's ability to withstand mechanical stresses and maintain its structural integrity during the operation of the circuit breaker.
- Temperature Stability: Assessing the material's resistance to high temperatures generated during switching operations, ensuring its stability and performance under extreme thermal conditions.
- Surface and Volume Conductivity: Examining the material's conductivity properties to minimize the formation of surface currents and prevent unintended electrical discharges.
- Chemical Compatibility: Considering the material's interaction with insulating gases and its ability to maintain its properties in the presence of gaseous components within the circuit breaker.
- Electrical Breakdown Strength: Evaluating the material's ability to withstand high electric fields without experiencing electrical breakdown, ensuring reliable insulation performance.
- Processability: Considering the material's suitability for manufacturing processes, such as molding, machining, and shaping, to enable efficient and cost-effective production of the nozzle components.

A screening of ~30 different polymers and composites based on those criteria resulted in a preliminary selection of ~10 materials. These materials were then subjected to laboratory-scale experiments. Laboratory experiments involving these materials failed to identify any suitable alternatives to PTFE as a nozzle material³⁸.

Similarly, systematic investigations were conducted at the Institute for High Voltage Technology at RWTH Aachen University. Extensive description of the interaction of the electric arc with different types of nozzle materials, including thermoplastics, ceramics and composites can be found in the relevant literature³⁹. Potential candidates were examined for their impact on switching behavior. PTFE emerged as the most suitable material by a significant margin, according to the findings described⁴⁰. Based on the established physical relationship between nozzle material and high-voltage arc, no other type of material is reasonably able to substitute fluoropolymers in this use.

4 Socio-economic impact of alternative technology limitations or non-availability

In the previous sections we have shown the uses of PFAS in high-voltage switchgear as well as the expected risks and limitations of proposed substitute technologies. Together with the expected increase in demand for more high-voltage equipment, there are several significant risks to the European economy and its population that should be carefully

considered and weighted against the proposed regulation and the potential PFAS emission reduction from removing PFAS from high-voltage switchgear. This was independently validated by a 3rd party study (see separate submission “*Impact Assessment of a potential restriction of PFAS: The use of PFAS in High Voltage Gas-Insulated Switchgears*”).

4.1 Risk to equipment availability, endurance, and reliability

Based on the available evidence laid out in the previous section, there are considerable concerns that vacuum-based switchgear can substitute the existing SF₆ based technology already at 145kV. For higher voltage levels, which are even more sensitive and important to ensure consistent and reliable availability of electricity across Europe, a capable replacement technology is simply not available.

In addition to the critical functionality provided by fluorinated insulation gases and fluoropolymer nozzles in high-voltage circuit breakers, there is a multitude of components that depend on the exceptional mechanical and tribological performance of PTFE based materials and composites. If the growing demand for reliable high-voltage equipment cannot be met, key components of the European Green Deal, like the electrification of transportation, residential heating and industrial processes as well as the strategic growth of renewable energy sources become impossible to achieve.

4.2 Impact of unavailable spare parts and replacement components on installed equipment

Just as critical as the availability of new equipment, a lack of spare parts and replacement parts would jeopardize the large installed base in Europe. There are more than 300'000 high-voltage circuit breakers in service across the European economic area with an average age of 20 years. Since the common lifetime of such equipment is at least 40 years but likely more if properly maintained, a truly massive replacement effort would be needed while the equipment is operating. It would be an enormous waste of material to discard fully functional equipment because simple but critical spare parts suddenly become unavailable. At the same time, and as mentioned before, it is expected that the demand for additional equipment will continue to increase. Finally, the associated costs would be staggering.

4.3 Economical risks due to increased likelihood of power outages

Following the impact on equipment availability, lifetime, and reliability it is obvious that there is a significant risk for an increase in the occurrence and duration of power outages across the European economic area, driven by the proposed restriction.

Even time limited outages, if unplanned, can lead to massive economic damage for the affected regions⁴¹. Prolonged outages can lead to destabilization and unrest. In 2011, the Office of Technology Assessment of the *German Bundestag* has laid out such a scenario⁴². The assessment shows that almost all critical infrastructure heavily relies on its power supply. Should a widespread and prolonged power blackout occur, a massive disruption to supply chains, economic damage, and risks to public safety would be the consequences. The analysis concludes that such a power outage would be “*akin to a national disaster*”.

More recently, the economic consequences of rising energy prices have been shown to be a major driver of rising inflation, severely impacting economic growth in the European economic area and globally⁴³.

5 Assessment and conclusion

Hitachi Energy recognizes the need to avoid emissions of substances with known toxicological concerns in order to best protect human health and the environment. This goal needs to be achieved by employing a risk-based regulatory approach in a sustainable manner, ensuring product reliability and achieving critical targets such as the green energy transition. To do so, any restriction of PFAS needs to be appropriately differentiated: the group of PFAS is a large and inhomogeneous group of substances with very different physical and chemical properties, coming with vastly different

levels of hazards. The human health and environmental implications of those substances are also different and depend on the nature and level of control of their use. Thus, sustainable regulation of PFAS should identify differentiated risk management measures in consideration of the risk of a specific substance in a specific use with its relevance for society.

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- Fluoropolymers for bearings, gliding rings and lubricants and the essential arcing nozzle made from polytetrafluoroethylene (PTFE, CAS No. 9002-84-0) used to contain and guide the hot, gaseous plasma in each gas circuit breaker.
- The dilute C4-FN mixture used in SF₆-free high-voltage equipment is not classified as toxic. This has been determined through professional toxicological and ecotoxicological assessments.^{44,45}
- C4-FN does not accumulate in water, plants, or the soil and has an average atmospheric lifetime of 30 years².
- High-voltage equipment is extremely gas-tight by design as required by international standards⁴⁶. The C4-FN concentration ranges between 3 - 5%. Equipment tightness is assured in order to fulfill the functionality and maintenance is done by educated professionals. Even if the gas ever escapes, due to leakages (that are kept minimum due to constant monitoring through sensors to ensure functional integrity of the equipment) or rare handling mistakes during maintenance, only amounts of 1-2 tons per year will be emitted as a total from the complete installed base of equipment in all of Europe (see below).
- Emitted C4-FN gas from dilute mixtures will evenly spread in the atmosphere and decompose into naturally present, geogenic trifluoroacetic acid, with a proven very small environmental risk (“...risks from current and future releases of TFA from the use of fluorinated precursors regulated under the Montreal Protocol to aquatic and terrestrial plants are *de minimis*.”).⁴⁷
- More than 96% of globally used fluoropolymers, including PTFE and fluorinated elastomers, fulfill the widely accepted criteria for polymers of low concern as per OECD definitions.^{48,49,50}

Note that 3 - 5% C4-FN mixtures replace the much more harmful emissions of pure, 100% SF₆, with a global warming potential (GWP) 24,300 times higher than that of CO₂ and an atmospheric lifetime of 1000 years. There is a wide consensus in the industry and by regulators on the need for an SF₆ phase-out as quickly as possible. Replacing SF₆ technology with C4-FN based switchgear was shown and validated by third party experts to be the most sustainable solution compared to other proposed solutions from a total life cycle point of view^{51[66]}. Indeed, it allows to keep the compact size of the equipment drastically reducing the use of raw materials and space (and related carbon emissions). No alternative exists that would allow the same performances (including in areas like cities where the space and size of buildings are limited) and reliability. Other alternatives are not able to allow the retrofit and refill of SF₆ equipment.

In addition to the above material characteristics, high-voltage equipment is only accessible to trained maintenance and service personnel following well-defined operating procedures. The solid fluoropolymers, like PTFE nozzles components are either recycled or incinerated after decommissioning.

The descriptions above, backed with the technical details and references presented in this document, demonstrate why this group of PFAS materials used in high-voltage equipment should not be subject to the proposed restrictions, established on the risk-based approach according to Article 68(1) REACH and substance-based approach according to Article 69 REACH.

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