JP4EE Annex 9 Unfeasibility of other possible substitutes in actual EEE
- Review of “possible substitutes” in ChemSEC Guide

As of 22 September 2023

Note: The applications of PFAS in EEE have not been investigated in the dossier in details, and possible alternatives described in the dossier is very few. We provided the results of our review for them as our Annex 2, "The unfeasibility of “possible substitutes” in the dossier in the actual EEE". (Reattached as sheet 2 of this excel.)
On the other hand, as long as we know, the most collective available information on this matter would be “A guide to PFAS in electronics” by ChemSEC, and we suppose that ECHA may refer to it.
However, from the point-of-view from the actual manufacturers of EEE, the listed “possible substitutes” seem to be (still) unfeasible to attain the EEE performances needed in current IT society. Therefore, we prepare this Annex for the legislators’ reference.
ChemSEC： “A guide to PFAS in electronics”：
https://chemsec.org/reports/check-your-tech-a-guide-to-pfas-in-electronics/

Category of use	Function performed	Product(s)	PFAS identified	Contained in the product?	Actively used?	Alternatives available?	Alternatives Identified	Additional Comments	References	Comments on ChemSec-Electronics-Guide
Electrical Devices	Structure/low dielectric constant/insulation	Printed Circuit Boards (PCB)/ Printed Wiring Board (PWB)	6:2 FTSA (27619-97-2) Perfluorooctane sulfonamid (754-91-6) PFOS (1763-23-1) PFBA (375-22-4) PTFE (9002-84-0) ethene,1,1,2,2-tetrafluoro-, polymer with 1,1'oxybis[ethene] (102646-47-9)	Yes[1,2]	Confirmed[3]	Yes	FR-4 epoxy, Polyimide laminates, liquid crystal polymer, polyester, polyethylene naphthalate (PEN), bismaleimide triazine (BT), cyanate ester, ceramics [4] ⇒cyanate ester	PFOS and PFOA are banned so considered unlikely to be still be used for this function. The alternative FR4 contains brominated flame retardants, which might lead to a case of regrettable substitution [62] Noted by industry [62] that for existing designs, PTFE cannot be easily substituted in PCB/PWB without a complete redesign of the equipment (including the mechanical dimensions of the product) and not feasible for spare parts.	1,2,3,4, 62	All of the materials listed as alternatives have a high relative permittivity (square root proportional to transmission loss), and especially the dissipation factor (proportional to transmission loss) is very large, so it is not a substitute for high-frequency printed circuit boards. This difference in properties will have a significant impact on the social demand for reduced power consumption in the carbon-neutral era, as well as on the dramatic reduction of power consumption for the transmission of millimeter wave band mobile communications (5G/6G) and digital data communications in high-speed servers (224/448 Gbps) that are expected in the future.
Electrical Devices	Final Coating/protection/waterproofing	Printed Circuit Boards (PCB)/ Printed Wiring Board (PWB)	6:2 FTSA (27619-97-2) Perfluorooctane sulfonamid (754-91-6) PFOS (1763-23-1) PFBA (375-22-4) PTFE (9002-84-0) ethene,1,1,2,2-tetrafluoro-, polymer with 1,1'oxybis[ethene] (102646-47-9)	Yes[5]	Confirmed[6]	Yes	Acrylic Resin, Epoxy, Urethane resin, silicone resin [7]		5,6,7	The substances listed in the alternatives identified cannot be substituted for all applications. For example, epoxy resin is hard and cannot be used for flexible substrates. In addition, even if it can be used, urethane resin and acrylic resin are inferior to PFAS in moisture-proof, so it is necessary to increase the film thickness to obtain the necessary moisture-proof properties. Silicone resin cannot be used in the vicinity of relays, mechanical switches or membrane switches, where the silicone resin has a risk that siloxanes that deteriorate and release the silicone accumulate on the conduction part and cause conduction failure and may cause malfunction due to contact failure. For details, please refer to the high-speed communication section of Annex 6, Smartphone and Protective Coat.
Electrical Devices	Liquid impregnates	Capacitors	Aliphatic perfluoroalkane (355-42-0) Perfluoromethylcycloalkane (1805-22-7, 255-02-2) Perfluoro-1,3-dimethylcycloalkane (355-27-3) Perfluorotrialkyl amine (311-89-7) Perfluorinated cyclic ethers (?)	Yes[1]	Unconfirmed	Yes	Mineral oils, vegetable oils, silicone oils, and biodegradable synthetic oils.[8]		1,8	We have no information.
Electrical Devices	Dielectric films	Capacitors	PTFE (9002-84-0) PVDF (24937-79-9)	Yes[8]	Unconfirmed	Yes	Various other polymers such as polypropylene (PP), polyethylene (PE), polystyrene (PS), polycarbonate (PC), PEN, polyphenyl sulfide (PPS), polyester imides (PEI), polyethyleneterephthalate (PET), polybutyleneterephthalate (PBT), polyetheretherketone (PEEK), polyvinylchoride (PVC), polyimides (PI), polyamides (PA), and polymethylmethacrylate (PMMA)		1	We have no information.
Electrical Devices	Electrical signal; Piezoelectrical material	Acoustical Equipment	PVDF (24937-79-9) Copolymers with trifluoroethylene	Yes[1]	Confirmed[9]	Yes	Piezoelectric films seem to all be made of PVDF, but there are other piezoelectric materials that can be used depending on the application, such as ceramic piezoelectric materials or piezoelectric crystals[10]		1,9,10	Ceramics have been proposed as alternatives to piezoelectric elements, but they are fragile and limited in shape, making it difficult to form large areas.
Electrical Devices	Acoustic vent membranes	Acoustical Equipment	Not specified	Yes	Unconfirmed	No	No alternatives identified	Alternatives for moist protection do not seem to be available.	*REF for this one?*	We cannot comment on PFAS or alternatives because there are no examples.
Electrical Devices	Dipole moment	LCDs(Liquid Crystal Displays)	Fluoropolymers	Yes[1,11]	Unconfirmed	Yes	Can use other screen technologies instead of LCD		1,11	OLEDs (organic light-emitting diode) cannot replace all LCDs. Compared to LCDs, OLEDs have some challenges to solve such as higher power consumption (contrary to energy saving), shorter life, and inability to repair (high cost). Therefore, it is impossible to replace the LCDs during the proposed five-year grace period. It took 20 years for OELDs to reach their current status, so we think that it will take at least 12 years to solve such challenges and replace LCDs.
Electrical Devices	Protective coating	LCDs(Liquid Crystal Displays)	PCTFE (9002-83-9)	Yes[1]	Unconfirmed	Yes	Can use other screen technologies instead of LCD		1	We have no information.

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Electrical Devices	Electrical Insulation/dust repellent	Flat panel display	Tetrabutylphosphonium perfluorobutane sulfonate (220689-12-3) Tetrabutylphosphonium perfluoromethane sulfonate Tetrabutylphosphonium perfluorohexane sulfonate Tetrabutylphosphonium perfluorooctane sulfonate	Yes[1]	Unconfirmed (patent)	Yes	Various other polymers such as polyester and polycarbonate		1, 12, 13	In flat panel display materials, the required performance (optical properties) of the product can be satisfied by introducing fluorine atoms to the functional molecules in the material. Alternative substances must have the characteristics of "low surface tension", "high wettability to the base material", and "hydrophobicity" equivalent to fluorine, but no substitute substance has been found that satisfies these sufficiently. In addition, general-purpose polymers are listed as alternatives, but as described above, polymers alone cannot meet the required performance (optical properties) and some alternatives have fluorine introduced, so they are considered inappropriate as non-PFAS alternatives.
Electrical Devices	Not specified	Razors	PTFE (9002-84-0)	Yes[1]	Unconfirmed	Uncertain	Unconfirmed		1,14	PFAS are used for lubricity, durability, and antifouling requirements.
Electrical Devices	Not specified	Various (Switches, Vacuum cleaners, Coffee makers, Keyboards, Screens, TVs	Not specified	Yes[1]	Unconfirmed	Uncertain	Unconfirmed		1,14	We have no information.
Electrical Devices	Coating	Electroluminescent lamps in commercial/safety signs	PCTFE (9002-83-9)	Yes[1]	Unconfirmed	Uncertain	Unconfirmed		1	We have no information.
Electrical Devices	Insulation/Fire prevention	Wiring and cable insulation	PVDF-HFP copolymer (9011-17-0) FEP (25067-11-2) ETFE (68258-85-5) ECTFE (25101-45-5) PCTFE (9002-83-9) PTFE (9002-84-0)	Yes[1]	Confirmed[15]	Yes	Plastics (PVC, PE, PP, etc.) Rubbers (neoprene, silicone, etc) [16,17,18]	Industry note that, in practice PVC is favoured for this use, so in fact PFAS could be used if PVC is not possible. Other materials mentioned as alternatives have some drawbacks [62].	1,15,16,17,18	Flame retardant cables used in harsh conditions must have very good fire resistance. PVC as a flame-retardant material is not satisfactory, and safety cannot be guaranteed at all with other PFAS alternatives.
Electrical Devices	Insultation / heat resistant	Wiring and cable insulation	PTFE (9002-84-0)	Yes[62]	Confirmed [62]	Yes[62]	Rubbers (neoprene, silicone, etc)	Industry association [62] note that rubbers have less mechanical strength and less abrasion resistance. Thicker insulation might be needed or additional mechanical support. Might lead to partial redesign to accomodate for the additional space required.	62	Flame retardant cables used in harsh conditions must have very good fire resistance. PVC as a flame-retardant material is not satisfactory, and safety cannot be guaranteed at all with other PFAS alternatives.
Electrical Devices	Insultation / heat resistant in combination with specific sensors	Wiring and cable insulation	PTFE (9002-84-0)	Yes[62]	Confirmed [62]	Yes[62]	Rubbers (neoprene, silicone, etc)	Industry association [62] note that silicone insulation will lead to chemical deposition on the sensors, making them malfunction.	62	Special sensors used in harsh conditions are required to be heat-resistant, chemical-resistant, and durable. Neoprene rubber has lower characteristics than PFAS. In addition, silicone rubber deteriorates and separates siloxanes, which may cause conduction failure of the contacts.
Electrical Devices	Insulation / chemical resistant	Wiring and cable insulation	PTFE (9002-84-0)	Yes[62]	Confirmed [62]	No[62]	No alternatives identified	Industry association [62] note that no alternative available when chemical resistance is required.	62	Insulated cables used in acidic or alkaline atmospheres and environments where chemicals come into contact are required to have excellent chemical resistance, and no material other than PFAS has been identified that can ensure safety.
Electrical Devices	High frequency electrical insulation	Wiring and cable insulation	PTFE (9002-84-0)	Yes[62]	Confirmed [62]	Uncertain[62]	Unconfirmed	Industry association [62] note thatPTFE has a very low dielectric constant. There is no comparable alternative.	62	No alternatives for high frequency electronic insulating materials have been identified.
Electrical Devices	Insulating spacers locate conductive components	(Coaxial) cable	PTFE (9002-84-0)	Yes[62]	Confirmed [62]	Uncertain[62]	Unconfirmed		62	In the insulated spacers in coaxial cables, PFAS alternatives cannot be identified.
Electrical Devices	High voltage insulator	Connectors and other parts in submarine long distance telecommunication cable applications	PTFE (9002-84-0)	Yes[62]	Confirmed [62]	Uncertain[62]	Unconfirmed		62	No alternative to PFAS has been identified in high-voltage insulators used in connectors and other components for submarine long-distance communication cable applications.
Electrical Devices	Additive in plastic resins (e.g. PC/ABS)	Plastic Enclosures	PTFE (9002-84-0)	Yes[62]	Confirmed [62]	Uncertain[62]	Unconfirmed		62	We have no information.
Electrical Devices	V0 flame retardancy plastics	Adapters, PSUs, wiring	PTFE (9002-84-0)	Yes[62]	Confirmed [62]	Yes[62]	(Unspecified) BFRs, CFRs [62]	PTFE as an additive (3000-5000 ppm) in PC [62] ; Industry noted that in order for plastics to meet the V0 flame retardancy grade, it is required that there is suppression of dripping of any melted plastic as the plastic is heated. Only alternatives would be brominated or chlorinated flame retardants which are also restricted.	62	Resins used in the housings of devices such as TVs and personal computers, and resins used around power supplies and heating elements in electrical parts may be required to be certified as flame retardant according to UL94 standards by law. In order to satisfy these standards, the addition of flame retardants is unavoidable, but especially for advanced resins of V-0 grade or higher, it is necessary to prevent the generation of burning particles that can ignite, and drip prevention is essential. When halogen flame retardants are regulated by law, and inorganic flame retardants and phosphate ester flame retardants may be used, inorganic flame retardants need to be added in large quantities to obtain a sufficient flame-retardant effect, resulting in impaired physical properties of the resin. On the other hand, phosphate ester flame retardants are limited to resins that are easy to exert effects (resins that are easily carbonized including oxygen) due to the flame-retardant expression mechanism (carbonization layer formation during combustion). Flame retardant resins using phosphate ester flame retardants in polycarbonate and styrene resin alloys (PC/ABS) are widely used in home appliances and OA equipment, but because they are easy to drip due to the plasticizing effect of phosphate ester flame retardants. In order to achieve V-0, it is essential to add PTFE, which is an anti-drip agent (fibrillated fluoropolymer increases the melt tension of low-viscosity resins and has an anti-drip effect) as a flame retardant auxiliary. In addition, the addition of an anti-drip agent makes it possible to reduce flame retardants.

Category of use	Function performed	Product(s)	PFAS identified	Contained in the product?	Actively used?	Alternatives available?	Alternatives Identified	Additional Comments	References	Comments on ChemSec-Electronics-Guide
Electrical Devices	Protective coatings (dirt, scratch, smudge resistance)	Radiation Curable Coatings on Smartphones & other screens	PTFE (9002-84-0) PVDF (24937-79-9) Perfluoropoly-ether and polyurethane blend	Yes[19]	Unconfirmed	Yes	Silica-based coatings, Polymethylmethacrylate powder coating[19]		19	PFAS alternatives for antifouling coatings that satisfy solvent resistance have not been identified.
Electrical Devices	Protective coatings (dirt, water, UV)	Solar Panels	FEP (25067-11-2) ETFE (68258-85-5) FEVE (146915-43-7)	Yes[19]	Unconfirmed	Yes	PET□PC□Polyamides□PS Titanium Dioxide nanoparticles[19]		19	Durability, weather resistance, light resistance (especially UV resistance), and antifouling are important for the protective film of photovoltaic panels, but PET, PC, Polyamide, and PS are easily degraded by the ultraviolet light contained in sunlight, which shortens the life of the panel. TiO2 is added to improve hydrophilicity, not an alternative.
Electrical Devices	Coating	ICT equipment with imaging senors	Not specified	Yes[62]	Confirmed [62]	No[62]	No alternatives identified	Industry association notes that use in coating to fill main ingress path to oleic acid and thus prevent glue failure at imaging sensor. Coating must be able to fill the gap by capillary action after jet dispensing. Only potential alternative is Silicone but Silicone absorbs oil, is sticky, causes cross contamination and leads to adhesion loss of other components. [62]	62	We have no information.
Electrical Devices	Lubricant	ICT equipment	Not specified	Yes[62]	Confirmed [62]	No[62]	No alternatives identified	Lubrication/coating e.g. for Silicone O ring installation – e.g. to provide good corrosion resistance, low Coefficient of Friction <0.15, good adhesion to substrate, low surface roughness Ra < 0.6 um, harder than Polycarbonate to withstand 30K cycles of REL testing. Coating to fill main ingress path to oleic acid and thus prevent glue failure at imaging sensor. Coating must be able to fill the gap by capillary action after jet dispensing. Industry association noted that all alternative dry coatings have been tested and failed for either corrosion or cosmetics. Alternative lubricants have been tested and do not meet performance requirements [62].	62	In ICT equipments, PFAS alternatives for dry coat cannot be used due to corrosion and appearance problems. Also, PFAS alternatives for lubricants do not meet the required properties.
Electrical Devices	Coating	Touchscreen displays, camera glass, mousepads, backglass	Not specified	Yes[62]	Confirmed [62]	Yes [62]	Silicone-based coatings	Low surface energy anti-finger printing and haptics enabling coatings Industry association[62] note that silicone alternatives absorb oil, are sticky, and cross contamination leads to adhesion loss of other components. Silicone alternatives would create dysfunction in haptics - blocking transmission to sensors in touchscreens.	62	When a touch display or camera lens is coated with a silicone base alternatives it is not suitable for high-performance products because silicone base alternatives absorb oil, increase stickiness, which causes dysfunction of haptics (blocking transmission to touchscreen sensors) .
Electrical Devices	Proton exchange membrane	Fuel Cell	Ethanesulfonic acid, 2-[1-[difluoro[(trifluoroethenyl)oxy]methyl]-1,2,2,2,-tetrafluoroethyoxy-1,1,2,2-tetrafluoro-, polymer with tetrafluoroethene (31175-20-9) PTFE (9002-84-0) Other proprietary polymers	Yes[20]	Confirmed	Uncertain	Hydrocarbon multi-block copolymer electrolyte membranes [multiblock copolymer poly(sulphonate phenylene)-b-poly(arylene ether ketone)] - under development. [20] Car industry argues that no replacements are available, since for example only PFSA ionomers have reached technological maturity for use in proton exchange membranes for these functions in the harsh environment of a fuel cell. [21]		20, 21	PTFE is the only material that can withstand redox environments. For details, please refer to the comments of the organizations that handle the equipments.
Electrical Devices	Binder	Lithium Ion Batteries	PVDF (24937-79-9)	Yes[22,23]	Confirmed[24]	Maybe	PI, PAA, CMC, SBR Many suggest that PVDF will soon be replaced with better performing and more environmentally friendly alternatives, but this appears to be largely at research stage.[22,23]		22.23.24	Please refer to the input from the battery industries, such as those from RECHARGE (Ref.No. 3925 in RCOM Part.2) or from Battery Association of Japan (BAJ) (Ref.No.4331 in RCOM part 14), for the concrete details.
Electrical Devices	Electrolyte	Lithium Ion Batteries	LiTFSI (90076-65-6) LiBETI (132843-44-8) LiFAP□LiTFAB LiFSI (171611-11-3) LiTA	Yes[25]	Confirmed[26]	Yes	$LiPF_6$ is the standard electrolyte for lithium ion batteries, but more efficient PFAS compounds are being developed/implemented.		25, 26	Please refer to the input from the battery industries, such as those from RECHARGE (Ref.No. 3925 in RCOM Part.2) or from Battery Association of Japan (BAJ) (Ref.No.4331 in RCOM part 14), for the concrete details.
Electrical Devices	Cathode electrode binder material	Lithium Batteries	PVDF and copolymers	Yes[62]	Confirmed [62]	No	No alternatives identified	Industry association [62] consider that there is no alternative to PVDF for cathode electrode binder material. It is noted [62] that over the years many polymers have been tried and PVDF has consistently been found to be the best option to meet the performance and process requirements for binder material. Originally PVDF was used as the binder material for both anode and cathodes. More recently styrene-butadiene copolymer (SBR) was found to be a good alternative for the anode binder material. CMC is used together with SBR as a thickener to control slurry viscosity. CMC/SBR is now the most popular anode binder material due to its low cost and good cell performance. But SBR is not a good option for the cathode binder material as its double bound structure can be oxidized under cathode potential. Replacing PVDF with other polymers will likely cause cell performance and manufacturability issues.	62	Please refer to the input from the battery industries, such as those from RECHARGE (Ref.No. 3925 in RCOM Part.2) or from Battery Association of Japan (BAJ) (Ref.No.4331 in RCOM part 14), for the concrete details.

Category of use	Function performed	Product(s)	PFAS identified	Contained in the product?	Actively used?	Alternatives available?	Alternatives Identified	Additional Comments	References	Comments on ChemSec-Electronics-Guide
Electrical Devices	Battery separator material	Lithium Batteries	PVDF and copolymers	Yes[62]	Confirmed [62]	No[62]	No alternatives identified	Industry association [62] consider that no alternative would result in similar performance of battery.	62	Please refer to the input from the battery industries, such as those from RECHARGE (Ref.No. 3925 in RCOM Part.2) or from Battery Association of Japan (BAJ) (Ref.No.4331 in RCOM part 14), for the concrete details.
Electrical Devices	Creation of important microporous structures	Speaker modules	Expanded PTFE	Yes[62]	Confirmed [62]	No[62]	No alternatives identified	Expanded PTFE for speaker membrane. Industry association[62] notes that PTFE has a unique ability to create important microporous structures that allow for proper air permeability and good water and dust-proofing. Industry association [62] consider that using an alternative would result in loss of sound transmission quality and durability,	62	We have no information.
Electrical Devices	Gaskets	Electronic circuits	PTFE	Yes[62]	Unconfirmed	No[62]	No alternatives identified	Industry association [62] notes that PTFE has unique quality to allow vapor and gas to pass through while preventing liquds from doing so which is required for applications in which venting is very important. This is important in many elecronic circuits that require venting without water entering an enclosure and building up around circuits. Industry association [62] consider that using an alternative would not allow for water proofing simultaneous with gas permeability.	62	There is no gasket material that is both solvent resistant and heat resistant other than PFAS.
Electrical Devices	Low friction	Moving parts, paper handling in printers	PTFE	Yes[62]	Confirmed [62]	Yes [62]	Several other materials, depending on the specific use case.	Industry association [62] notes that alternatives have to be investigated on case by case basis and there is no drop-in replacement. Often a more comprehensive redesign is required.	62	The low-friction properties of PTFE include not only a low coefficient of dynamic friction but also a low coefficient of static friction, as well as heat resistance, electrical insulation, flame retardancy, and chemical resistance. Replacing it with a substitute product causes an increase in power consumption due to an increase in sliding resistance, a deterioration in quietness, and a shortening of service life due to deterioration in durability. *Please refer to the input from the related industries, such as Japan Business Machine and Information System Industries Association (JBMIA), for the concrete details.
Electrical Devices	Low friction - non-stick (e.g. prevent toner sticking)	Moving parts e.g. in printers	PTFE	Yes[62]	Confirmed [62]	No[62]	No alternatives identified		62	*Please refer to the input from the related industries, such as Japan Business Machine and Information System Industries Association (JBMIA), for the concrete details.
Electrical Devices	Chemical resistance	Printers: ink tubing, sealing, parts in contact with ink	Fluoropolymers and fluoroelastomers	Yes[62]	Confirmed [62]	No[62]	No alternatives identified	Industry association [62] consider that for chemcial resistance, there is no alternative	62	Containers and tubes that can maintain the performance of the things contained inside must have multiple functions such as abrasion resistance, heat resistance, chemical resistance, and cleanliness, and such materials have not been confirmed except for PFAS. *Please refer to the input from the related industries, such as Japan Business Machine and Information System Industries Association (JBMIA), for the concrete details.
Electrical Devices	Lubrication	Lubricant	PTFE, PFHxA related substances	Yes[62]	Confirmed [62]	Yes [62]	Silicone lubricants	Industry association [62] consider that product redesign could be required due to chemical interactions between the alternative and the product. PFAS are very inert and alternatives might have unwanted interactions with the product	62	Silicone may be substituted in some applications, but in applications that are overused in harsh environments, silicone lubricants deteriorate and produce volatile low-molecular siloxanes, resulting in poor electrical contacts and unsafe use.
Manufacture	Chemical resistance, flexibility, sealing	Tubing, valves, sealing	PTFE, PVDF, fluoroelastomers	No (only used in factory, not in electronic product)	Confirmed [62]	No[62]	No alternatives identified	Industry association [62] consider that for chemcial resistance, there is no alternative	62	
Manufacture	Separation of high voltage components	Dielectric Fluids (3M™ Novec™ 7100 Engineered Fluid 3M™ Fluorinert™ Electronic Liquids)	1,1,1,2,2,3,4,5,5,5-decafluoropentane (138495-42-8) PTFE	Yes[1]	Confirmed[27]	Yes	Natural and synthetic esters[28,29,30]		27,28,29,30	-Alternatives tend to have a flash point, and the lower the viscosity, the lower the flash point. Therefore, when designated as a hazardous material, more caution is required in storage, transportation, and handling than before. In addition, the use of these products requires explosion-proof equipment, which entails a huge investment. - Ester-based products deteriorate due to hydrolysis and require caution.
Manufacture	Liquid burn-in testing		Perfluoroperhydrofluorene (307-08-4) PFPEs	Yes[1]	Unconfirmed	Uncertain	N/A		1	
Manufacture	Reliability testing		Perfluoroalkyl methyl ether (375-03-1)	Yes[1]	Unconfirmed	Uncertain	N/A		1	
Manufacture	Dielectric test media	Galden® PFPE Hermetic Seal Testing[36], 3M™ Fluorinert™ Electronic Liquids[40]	Methyl perfluoroalkyl ether (163702-07-6) Methyl perfluoroisoalkyl ether (163702-08-7)	Yes[1]	Confirmed[31]	Uncertain, see reference [32] for a list of compounds and their respective dielectric strengths that may meet manufacturing requirements	Use would need high dielectric breakdown strength, be non-flammable[1]		1,31,32	PFAS is used because it is a low-dielectric and nonflammable material at the same time, but no alternative has been found.
Manufacture	Thermal shock testing	Galden® PFPE Hermetic Seal Testing[36], 3M™ Fluorinert™ Electronic Liquids[40]	Perfluoroisohexane (355-04-4) Perfluoro-1,3-dimethylcycloalkane (355-27-3) Perfluoromethyldecalin (306-92-3) Perfluoroperhydrofluorene (307-08-4) Perfluorotetradecahydrophenanthrene (306-91-2) PFPEs	Yes[1]	Confirmed[33]	Uncertain	Use would need to be non-reactive[1]		1,32,33	PFAS is used because it is a material with low dielectric constant and stability at the same time, but no alternative to it has been found.

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Manufacture	Gross and fine leak testing	Galden® PFPE Hermetic Seal Testing[36], 3M™ Fluorinert™ Electronic Liquids[40]	PFPEs	Yes[1]	Confirmed[33]	Uncertain	Use would need to be non-reactive[1]		1,31,33,34	There is no alternative that is non-flammable, insulating, low-viscosity, inert, low erosive and moderately volatile.
Manufacture	Electrical environmental testing	3M™ Fluorinert™ Electronic Liquids[40]	Perfluorinated fluids	Yes[1]	Confirmed[31]	Uncertain	Use would need to be non-reactive[1]		1,31	It is required to be non-flammable and must contain a certain amount of fluorine. Since alternative products are not nonflammable, using them requires investment in explosion-proof equipment.
Manufacture	Use for testing in general		Perfluoromethylcycloalkane (355-02-2) Perfluoro-1,2-dimethylcycloalkane (306-98-9) Perfluoroperhydrofluoranthene (662-28-2)	Yes[1]	Unconfirmed	Uncertain	N/A		1	Solvents for thermostatic chambers that measure the temperature characteristics of electronic components with ultra-high accuracy must be non-flammable, insulating, low-viscosity, inert, low-erosive, and highly thermally conductive, and have moderate volatility, and there is no alternative.
Manufacture	Heat transfer fluids	General heat transfer	1H-Perfluoroalkane (354-33-6) 1,1,2,2,-Tetrafluoroethane (359-35-3) 1,1,2,2-tetrafluoro-ethene, oxidized, polymd., reduced, decaroxylated (161075-02-1)	Yes[1]	Confirmed[35]	Yes	Various proprietary blends on the market that claim to be environmentally friendly; based on "ester chemistry" and others, and generally said to be biodegradable and often halogen free[36,37,38,39]		1,35,36,37,38,39	It must have high volume resistivity, low viscosity, and prevent moisture content from increasing during use. In addition, it must be nonflammable unless it is used in an explosion-proof facility, which requires a huge investment. Ester-based products require attention because of degradation due to hydrolysis.
Manufacture	Heat transfer fluids	Total Immersion cooling	Methyl perfluoroalkyl ether (375-03-1) Ethyl perfluoroisoalkyl ether (297730-93-9)	Yes[1]	Confirmed	Yes	See row for "General Heat Transfer"		See row for "General Heat Transfer"	See row for "General Heat Transfer"
Manufacture	Heat transfer fluids	Evaporative Cooling	Aliphatic perfluoroalkane (76-19-7) 1,1,1,2,2,3,4,5,5,5-decafluoropentane (138495-42-8)	Yes[1]	Confirmed	Yes	See row for "General Heat Transfer"		See row for "General Heat Transfer"	See row for "General Heat Transfer"
Manufacture	Heat transfer fluids	Brine Cooling	1,1,1,2,2,3,4,5,5,5-decafluoropentane (138495-42-8) Methyl perfluoroalkyl ether (163702-07-6) Methylperfluoroisoalkyl ether (163702-08-7) Ethyl perfluoroalkyl ether (163702-05-4) Perfluoroindane (374-80-1)	Yes[1]	Confirmed	Yes	See row for "General Heat Transfer"		See row for "General Heat Transfer"	See row for "General Heat Transfer"
Manufacture	Heat transfer fluids	Direct contact cooling	Aliphatic perfluoroalkane (335-57-9) 1H-perfluoroalkane (354-33-6) 1,1,2,2,-tetrafluoroethane (359-35-3) Perfluoroisohexane (355-04-4) Perfluoro-2-methyl-3-ethylpentane (354-97-2) Perfluoro-2,4-dimethyl-3-ethylpentane (50285-18-2) Perfluoromethylcycloalkane (1805-22-7) (355-02-2) Perfluoro-1,2-dimethylcycloalkane (306-98-9) Perfluoro-1,3-dimethylcycloalkane (335-27-3) Perfluorodecalin (306-94-5) Perfluoromethyldecalin (306-92-3) Perfluoroperhydrofluorene (307-08-4) Perfluorotetradecahydrophenanthrene (306-91-2) Perfluoroperhydrofluoranthene (662-28-2) Perfluoroperhydrobenzyltetralin (116265-66-8)	Yes[1]	Confirmed	Yes	See row for "General Heat Transfer"		See row for "General Heat Transfer"	See row for "General Heat Transfer"
Manufacture	Cleaning	Solvent Systems and Cleaning Products	3,3,4,4,5,5,6,6,-octafluoro-1-Hexene (159148-08-0) 3,3,4,5,5,5-hexafluoro-1-Pentene (2375-68-0) 1,1,1,2,3,4,5,5,5-nonafluoro-2-(trifluoromethyl)-Pentane (85720-78-1) 1,1,1,2,2,3,4,5,5,5,-decafluoro-Pentane (138495-42-8) Methyl perfluoroalkyl ether (22410-44-2), (375-03-1), (163702-07-6) Methyl perfluoroisoalkyl ether (22052-84-2) Methyl perfluoroisobutyl ether (163702-08-7) Ethyl perfluoroalkyl ether (163702-05-4) Ethyl perfluoroisobutyl ether (163702-06-5) 1,1,2,2-tetrafluoro-1-(2,2,2-trifluoroethoxy)-ethane (406-78-0) Aliphatic non-branched perfluoroalkanes (76-19-7)	Yes[1]	Confirmed[40]	Yes	IPA, Other alcohol cleaners without PFAS added Products listed on Green-Screen website[41]		1,40,41	When cleaning, low surface tension is required, as well as nonflammability unless the equipment is explosion-proof, which entails a huge investment.
Manufacture	Carrier fluid/lubricant deposition	Carrier fluid/lubricant deposition	Perfluoroisohexane (355-04-4) 1,1,1,2,2,3,4,5,5,5-decafluoro-Pentane (138495-42-8)	Yes[1]	Confirmed[42]	Yes	Honeywell fluorinated (but not perfluorinated) Solstice® solvents[43]		1,42,43	It is required to be nonflammable and must contain a certain amount of fluorine. Since the alternatives are not non-flammable, using them requires explosion-proof equipment, which entails a huge investment.
Manufacture	Etching	Piezoelectric ceramic filters	PFOS (1763-23-1)	No[1]	Unconfirmed[44]	Yes	Fluoroboric acid[45]	Industry association [62] note that PFOS and PFOA are banned. Unlikely to be still in use	1,44,45, 62	
Manufacture	Pulsed plasma nano-coating	Smartphones and Tablets	PFOA (335-67-1)	Yes[1,46]	Confirmed[47]	Yes	Epoxy, urethane, acrylic, silicone, paralyne[47] PFAS-free nanocoatings[48]	Industry association [62] note that PFOS and PFOA are banned. Unlikely to be still in use There are other types of coatings used in the industry for the same purpose: evaporative curing, moisture curing and heat curing. Examples of non-fluorinated radiation curable coatings are silica-based coatings and polymethylmethacrylate powder.	1,46,47,48, 62	
Manufacture	Haptics enabling coating	Smartphones and Tablets	-	Yes	Unconfirmed	Uncertain	For touchscreens, which needs haptics enabling coatings, good alternatives are currently lacking.			

Category of use	Function performed	Product(s)	PFAS identified	Contained in the product?	Actively used?	Alternatives available?	Alternatives Identified	Additional Comments	References	Comments on ChemSec-Electronics-Guide
Manufacture	Air/moisture resistance	General electronic equipment packaging	PCTFE (9002-83-9)	Yes[1]	Confirmed[49]	Yes	Other moisture and vapor-barrier packaging, such as mylar and a mixture of aluminium foil and various non-fluorine-containing polymers[50]		1,49,50	Since aluminum foil does not allow the user to see the parts in the package, fluorine film can only be used where moisture-proofing and transparency are required at the same time.
Semiconductors	Photolithography		PFOA (335-67-1) PFOS (1763-23-1) Perfluoropolymers	Yes	Unconfirmed [51]	Potentially	hydrocarbon-based greases, Molybdenum disulfide, graphite (for photolithography) [52]	PFOA and PFOS have been largely phased out	51, 52	PFOS and PFOA have already been eliminated in Japan, and PFOS and PFOA are not used as identified PFAS (we agree with Additional Comments), but they are used as PFAS. Also, 'Contained in the product? (Column E)' is Yes. As with antiflection films, the resist used in the front-end process does not remain in the final semiconductor product. In other applications, current semiconductor technology uses photoresist in many applications to provide properties by leaving a variety of products in the final semiconductor product. In this case, the PFAS remains in the final semiconductor product. The authorities should review the materials of "Semiconductor PFAS Consortium https://www.semiconductors.org/pfas/" in detail. Hydrocarbon greases, molybdenum disulfide, and graphite (for photolithography) already use carbon films as mask materials, but lithography is essential for patterning mask materials, and resist materials are still needed.
Semiconductors	Photoresist matrix, changes solubility when exposed to light	Photoresist	PFOA (335-67-1) PFOS (1763-23-1) PFHxS (alternative to PFOS/PFOA) [28,29,30]	Yes	Confirmed	Yes	KrF (248nm) (active ingredient not disclosed) [53] DOW™ photo-resists (non-PFOS) composed of solvents, acrylic, other polymer resins, cross-linking agents, stabilizers and/or surfactants Alternatives should containt fluorine	PFOS has been largely phased out	53,54,55,56	KrF resists and DOWTM photo-resists (non-PFOS), which are listed as alternative resists, are of limited use and do not cover all resists with different exposure wavelengths. If non-PFOS is used, PFOS is excluded under the Stockholm Convention, and the resists currently used in Japan are already PFOS-free but not PFAS-free. Photoresist requires several actions such as photoacid generation as well as surface activity, and the authorities only mention some of them, so the difficulty of replacing non-PFAS is clearly underestimated. The authorities should review the materials of "Semiconductor PFAS Consortium https://www.semiconductors.org/pfas/" in detail. It is stated that the replacement of photo-oxidants will take more than 25 years.
Semiconductors	Increase the photosensitivity of the photoresist	Photoresist (photosensitizer)	PFOA (335-67-1) PFOS (1763-23-1)	Yes	Unconfirmed	No	N/A	PFOS has been largely phased out	-	
Semiconductors	Generate strong acids by light irradiation	Photoresist (Photo-acid generator, PAG)	PFOA (335-67-1) PFOS (1763-23-1) Shorter-chain PFAS (PFBS) functionalized fluoroethanesulfonates	Yes	Confirmed	None currently (patents filed/fluorine free alternatives have been proposed)	Aromatic PAGs identified in patents (WO2009091704) Heteroaromatic PAGs identifed in patents (WO2009091702, US20110183259).Triphenylsulfoniumbenzo[b]thiophene-2-sulfonic acid, 4(or 7)-nitro-,ion(1-) (TPS TBNO) is identified Glodde et al. have proposed a Fluorine free PAG in their 2010 publication. Functionally need to generate strong acids	PFOS has been largely phased out	57,58	From "SIA PFAS Consortium"page38 https://www.semiconductors.org/pfas/ The authorities need to consider all the material at this URL. "non-PFAS PAGs (CN5 and thiophene sulphonate), which has highlighted the difficulty of developing formulations that meet all performance criteria simultaneously, as shown in Table 4-4. As such, non-PFAS PAGs are for a narrow range of use applications only, as no known non-PFAS PAG/photoacid exhibits the same level of performance for all criteria. While a candidate chemistry might show good acid strength, it will have lower photospeed because of lower acid diffusivity, and at the same time the acid anion might be transparent for a single wavelength only. PFAS PAGs, on the other hand, present simultaneously good to excellent performance for all listed performance criteria with the notable exception of environmental persistence."
Semiconductors	Controlling the diffusion of the acid to unexposed region	Photoresist (Quencher)	PFOA (335-67-1) PFOS (1763-23-1)	Yes	Unconfirmed	Uncertain	N/A	PFOS has been largely phased out	-	
Semiconductors	Provide low reflectivity	Antireflective coating	PFOA (335-67-1) PFOS (1763-23-1) PFHxS (alternative to PFOS/PFOA, 355-46-4)	It is noted the FP coating is not present in the final chip and is spun out and goes to waste/destroyed in the etching process	Confirmed	Yes	-AZ Aquatar 8 (Fluoroalkyl acid ester, homopolymer, hydrolyzed, 67829000004-6092P)[2] -DOW™ anti-reflect (non-PFOS), composed of solvents, acrylic, other polymer resins, cross-linking agents, stabilizers and/or surfactants -FP with a short fluoroalkyl side chain less than C4 -Alternatives should containt fluorine; functionally require low refractive index		19,59	The materials listed in column D has already been published in the Stockholm Convention. Column G is substituted for "present" and column H is substituted for "FP with a short fluoroalkyl side chain less than C4." This indicates that there is no substitute for all applications of semiconductors. The applications are diverse, and it is very dangerous to understand that there is one substitute for all alternatives. The authorities themselves describe FPs whose substitutions eventually have short fluoroalkyl side chains less than C4.
Semiconductors	Facilitate the control of the development process	Developer	PFOA (335-67-1) PFOS (1763-23-1) Shorter-chain PFAS used as alternatives to PFOA/PFOS	Yes	Confirmed	Uncertain	Patent US20080299487 for unfluorinated surfactant, vaguely described.	PFOS has been largely phased out	57	Contained in the product? is Yes,but like an antireflection film, no developer remains in the final semiconductor. But, the opinion that "photoresist used in semiconductor manufacturing does not remain in the product" is decades old, and current semiconductor technology uses photoresist in many applications to provide properties by leaving a variety of products in the final product. In this case, the PFAS remains in the final semiconductor product. In some applications, it should be emphasized that the PFAS remains in the final semiconductor product. Authorities should review the materials of the Semiconductor PFAS Consortium https://www.semiconductors.org/pfas/ in detail.
Semiconductors	Rinsing the photoresist to remove the developer	Rinsing Solution	Unknown	Uncertain	Unconfirmed	Uncertain	Use would require low surface tension		57	
Semiconductors	Etching	3M™ Fluorinert™ Electronic Liquids	PFOA (335-67-1) PFOS (1763-23-1) short-chain perfluoroalkyl sulfonates are alternatives in use today	No (at least there shouldn't be, its reported that PFAS is captured in the waste/it’s a closed system)	Confirmed	Yes	Amyl acetate (628-63-7)□Anisole (100-66-3) n-Butyl acetate (123-86-4)□Ethyl lactate (97-64-3) Propylene glycol methyl ether acetate (108-65-6) Methyl-3-methoxypropionate (3852-09-3) non PFOS-based surfactants are in use for etching application for etching agents with ceramic filters (WSC 2011),		60	It seems that the description of equipment coolant is urged from row C, but since PFOS and PFOA are neither etchant nor coolant, it is strange in a double sense. The authorities do not understand the dry etching process of semiconductors. The authorities should review the materials of "Semiconductor PFAS Consortium https://www.semiconductors.org/pfas/" in detail.
Semiconductors	Etching Wetting agent	See General etching	See General etching	See General etching	See General etching	See General etching	Use would require low surface tension		See row for "General etching"	
Semiconductors	Etching Reduce the reflection of the etching solution	See General etching	See General etching	See General etching	See General etching	See General etching	Use would require low refractive index		See row for "General etching"	
Semiconductors	Etching agent in dry etching	See General etching	See General etching	See General etching	See General etching	See General etching	Use would require Strong acids		See row for "General etching"	The main dry etch is PFC, and those indicated by "PFAS identified" are not used. "Alternatives Identified" are also completely wrong.

Category of use	Function performed	Product(s)	PFAS identified	Contained in the product?	Actively used?	Alternatives available?	Alternatives Identified	Additional Comments	References	Comments on ChemSec-Electronics-Guide
Semiconductors	Etch Cleaning of Silicon Wafers	General etching	PFOA (335-67-1) PFOS (1763-23-1) PFBS (375-73-5) PFNA (375-95-1) PFHxA(307-24-4)	No	Unconfirmed (patented) [1]	Uncertain	Patent EP 3 588 535 A1 details several surfactants including PFAS and non-fluorosurfactants which may be alternatives[1] Use would require Strong acids [35]		1, 61	Perfluoroalkyl acids such as PFOA and PFOS (which are already substances subject to the Stockholm Convention) are not used for "etch cleaning of silicon wafer". This usage information for PFOA and PFOS is incorrect. Therefore, the description of line H is completely wrong. It can be guessed from the document of the authority that the description is about photo-oxidizer, but it seems that the answer is not about wafer etching but about photoresist. In addition, the description of the patent is found on the whole, but for this technology to be established as a substitute, many tests and quality assurance are required for mass production. In the end, there are many patents that are not used because the test and quality assurance cannot be satisfied and cannot be applied to mass production. By listing the patent number, authorities that provide alternative cases underestimate the difficulty of substitution. Authorities should review the Semiconductor PFAS Consortium https://www.semiconductors.org/pfas/ document in detail.
Semiconductors	Remove cured epoxy resins/Cleaning of integrated circuit modules		Unknown	Uncertain	Unconfirmed	Uncertain	N/A			
Semiconductors	Remove dielectric film build up	Cleaning vapour deposition chamber	Unknown	Uncertain	Unconfirmed	Uncertain	Use would require reactive oxygen species (ROS) generation[1]		1	
Semiconductors	Non-stick coating composition on carrier wafer	Wafer thinning	PFOA (335-67-1), PFOS (1763-23-1) likely if used, but unconfirmed	Uncertain	Unconfirmed (patented) [1]	Uncertain	Use would require low surface tension[1]		1	PFOA and PFOS subject to the Stockholm Convention are described in Wafer thinning, but the meaning of this description is not understood.
Semiconductors	working fluid	Vacuum pumps	Perfluoroalkoxy alkanes (PFA) fluoropolymers	Uncertain	Unconfirmed	Uncertain	Use would require alternative be stable, non-reactive[1]		1	
Semiconductors	polymeric PFAS used in inert moulds, pipes, elastomers	Technical equipment in contact with process chemical or reactive plasma	Polymeric PFAS	Uncertain	Unconfirmed	Uncertain	Use would require alternative be stable, non-reactive[1]		1	
Semiconductors	Bonding ply composition	Multilayer circuit board	PFOA (335-67-1), PFOS (1763-23-1) likely if used, but unconfirmed	Uncertain	Unconfirmed (patented) [1]	Uncertain	Use would require low dielectric constant, low dissipation factor[1]		1	PFOA and PFOS subject to the Stockholm Convention are described, but the meaning of this description is not understood. "Authorities should review the Semiconductor PFAS Consortium https://www.semiconductors.org/pfas/ document in detail.
Semiconductors	Vapor Phase Soldering	Galden® LS and HS grades (LS/HS) [36]	PFPEs	Yes	Confirmed	Uncertain			33	Alternative materials that do not affect the substrate by soldering with high temperature reflow need to be developed. Authorities should review the Semiconductor PFAS Consortium https://www.semiconductors.org/pfas/ document in detail.

Alternatives listed in PFAS Annex E and reasor

Note: This sheet was originally provided as Annex 2 to our previous input, "The
EEE", in 13 June 2023. We attach it here again for your convenience.

	Application	PFAS
a)	Sealing	fluoroelastomers
b)	Wire insulation	PTFE, PFA, ETFE, FEP, FEPM, PFPE
c)	Immersion cooling （Heat transfer fluid）	Hydrofluoroethers Fluorinated amines
d)	liquid crystal displays (LCD)	-CF3 group

ıs for non-replacement

unfeasibility of “possible substitutes” in the dossier in the actual

Non-PFAS alternatives
Ethylene propylene diene monomer (EPDM) silicone rubbers
Silicone materials Polyetheretherketone(PEEK) mica EPDM Polyvinyl chloride ceramic based polymer
Mineral oils synthetic oils natural oils Hydrocarbon fluids
Cyano (-CN) group

Reasons why PFAS cannot be replaced by non-PFAS
In sealing material applications (e.g. packing), heat resistance, solvent resistance and low gas permeability are important, and EPDM and silicone rubber provide low or medium durability but not enough property, so they cannot replace all applications and fluorinated materials must be used.
In cable insulation materials, mechanical, thermal, volume resistance and electrical properties are important, and the alternatives listed as alternatives have low resistance to any of these properties and cannot replace them in applications where they need to be met simultaneously, and fluorinated materials need to be used. For example, silicone has low resistance to mechanical properties (susceptible to tearing/abrasion), PEEK has low electrical properties, mica is hard and not suitable as a cable, etc.
Compared to fluorinated materials (liquids), the viscosities of all alternative oils are considerably higher and it is difficult to circulate them and maintain a constant temperature. In addition, the flash point is considerably lower, and significant equipment modifications are required to ensure safety.
For liquid crystal molecules, low viscosity, high resistance, low dielectric anisotropy and low birefringence are important, and replacing a liquid crystal molecule with a CF3 group with a cyano group will result in a deterioration in all of these properties and cause adverse effects such as slow response speed and unsmooth display, and high voltage drive and high energy consumption.