



Check Your Tech

**A guide to PFAS
in electronics**

Content

3	Executive summary
4	How this information was compiled
5	The PFAS issue
6	Use of PFAS and fluoro-polymers in electronics
7	PFAS in electronic devices
11	PFAS in the manufacturing process
14	Semiconductors
17	Summary of identified uses, functions and alternatives
21	Data Gaps and Uncertainties
22	References

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Executive summary

The growing awareness of the global PFAS pollution crisis has triggered both increased customer requirements as well as regulatory proposals to restrict the use of PFAS in products and processes. Most notably, the EU has presented a proposal for a universal ban, with a limited number of derogations, on all PFAS in all products.

The electronics industry is one key sector where PFAS are used. According to the information provided in the restriction dossier, the electronics and semiconductor industry uses 4,400 tonnes of PFAS per year in the EU.

PFAS are used in a variety of applications within the industry and one challenge for many companies operating in the sector is to understand where and why PFAS are being used in their own processes and products.

This report aims to present a guide for individuals within the electronics industry to understand where per- and polyfluoroalkyl substances (PFAS) are used throughout the manufacturing process, what function they perform, which final products they end up in and what can be done to replace them.

The information in this report has been compiled from publicly available literature on PFAS uses within the electronics industry and potential alternatives as well as discussions with experts in the field, from both the academic and industry sectors.

The report is structured into three main categories where PFAS are intentionally used in the electronics industry:

- Electronic devices
- The manufacturing process of electronic devices
- Semiconductors and their manufacturing

For each of these, a number of specific products and/or processes that use PFAS are described, what function they perform and which potential alternatives exist. This guide is not meant to be an exhaustive list of PFAS uses or potential alternatives, and the viability assessment of the presented alternatives is outside of the scope of this document. All substitutions must be evaluated on a case-by-case basis.

It can be concluded that there are a number of “low-hanging fruit” for PFAS substitution in the electronics industry. These are the ones where PFAS are still heavily used even though alternatives are available. This includes printed circuit boards, capacitors, wiring and cables, heat transfer fluids and dielectric fluids.

There are also uses where no alternatives provide the specific properties that PFAS offer with the exact same performance, but where there are alternatives to PFAS that could be considered “good enough”. PFAS may be used because they were easier to identify due to the broad range of functions they can perform, or because they have been heavily marketed. However, they often exceed the necessary requirements and could be replaced by something else that will still perform the necessary functions while being more environmentally and health-friendly.

There are, according to industry, still also several specialized uses of PFAS that currently do not have viable alternatives at the time of the drafting of this guide. These include printed circuit boards for high-speed telecommunication network infrastructure, wiring and cable insulation for high voltage, lubrication and coatings in information and communication technology (ICT) equipment, acoustic equipment for challenging environments, touchscreen displays with haptic feedback as well as several uses in the production of semiconductors. This is where innovation and product development will need extra resources to speed up the development of alternatives.

How this information was compiled

The information compiled in this guide is the result of a review of publicly available literature on PFAS uses within the electronics industry and potential alternatives, as well as discussions with experts in the field, from both the academic and industry sectors.

Targeted internet searches and a review of available literature were conducted to gather information on the uses of PFAS within the electronics industry, and their potential alternatives. Technical brochures, Safety Data Sheets (SDS), and patents were reviewed when available. Alternatives were selected based on either claims to be PFAS or fluorocarbon free, or when detailed information about product composition was available and it was determined by professional judgement that there were no PFAS compounds present.

This guide focuses on where PFAS have been intentionally added to products to perform a specific function, and therefore that is where the literature review was targeted. The topic of unintentional PFAS as contaminants in products is a more complicated issue with less information available and is not a topic of this document.³

Following the initial data gathering through the review of available literature, further consultation with experts was conducted, through email and/or telephone interviews. During this consultation, the Wood/WSP team received input from academic/research experts,² European-level industry associations,² national-level industry associations,¹ and individual companies manufacturing and/or retailing electronic products.

Discussions centred around the issue of PFAS substitution within the industry, the issues that are currently being faced, and promising alternatives that are being researched. Preliminary findings of the literature review were shared with each group; feedback was granted on where information was missing or could be improved, and additional literature sources were provided.

The PFAS issue

PFAS are a family of man-made chemicals that have been extensively used in a wide number of different industrial and consumer applications since the 1950s due to their unique physical and chemical properties (such as water-, oil- and grease-repellence and high chemical and thermal stability). The OECD¹ estimates that there are approximately 4,700 known individual chemical substances in the PFAS family, while there are estimates of several million substances belonging to this group.^{2,63}

Many industries use PFAS, including textiles and leather, cosmetics, transportation, and more.³ Within each industry, PFAS may be intentionally added to products to perform certain functions or may be present as impurities in raw materials and processing; this guide focuses on the former. Uses in the electronics industry are explained in detail in this report and include functions such as protective coatings on electronic devices, specialty fluids used in manufacturing of products, and compounds used in the production of semiconductors.

Some of the unique physicochemical properties of PFAS that have made them so useful and popular in these uses could also result in negative impacts on the environmental and human health.⁴ Some PFAS either are, or degrade to, very persistent chemicals that accumulate in humans, animals and the environment.⁵ Their resistance to degradation, and high mobility in the environment mean that PFAS are now found everywhere, including remote environments such as the Arctic. PFAS have been observed to contaminate water and soil, including in most European Union (EU) countries, and it is extremely difficult and costly to clean up such contamination.⁶

A number of PFAS are known to display toxic and/or bioaccumulative effects. Possible health effects in humans associated with exposure to certain PFAS include increased cholesterol levels, impact on infant birth weights, effects on the immune system, increased risk for cancer, and thyroid hormone disruption.⁷ Some PFAS are classified in the EU as toxic for reproduction, the liver and as suspected carcinogens.⁸

While, within the past decade, several 'longer chain' PFAS compounds (e.g. PFOS, PFOA) have been restricted or banned under the Stockholm Convention and in many jurisdictions, including in the EU, more recently, there have been mounting concerns and evidence that 'short chain' PFAS are also very persistent and very mobile in the environment, potentially leading to contamination of the environment in the future. This is a serious concern, particularly where manufacturers and industry may have switched from longer chain to shorter chain PFAS following the previous regulatory actions.

The European Commission has recommended that actions on the EU level to phase out PFAS should be taken to ensure that the use of PFAS is phased out in the EU, unless it is proven essential for society.⁹ In February 2023, five EU member states submitted a proposal to restrict the use of all PFAS in all products, with some time-limited derogations.

Use of PFAS and fluoropolymers in electronics

PFAS, including both polymeric and non-polymeric compounds, are used all throughout the electronics industry, at different points within the supply chain. PFAS offer a number of key properties, such as flame retardancy, chemical inertness, hydrophobicity, and dielectric strength, which make them desirable for applications in electronic products because these typically involve high temperatures and voltages.

In some cases, they are only used in the manufacturing process of a given product, which is an issue primarily for potential environmental contamination. However, in many cases they are purposefully added to a final product that is delivered to consumers, which then also creates human health concerns.

This section of the guide describes products and processes which use PFAS and offers potential alternatives when available.

The listed alternatives have only been assessed for their technical feasibility in replacing PFAS compounds at a basic level; typically, they are other compounds or products that have been demonstrated to be used for the same function and may not be feasible based on the specific needs of the product in question. Additionally, any specific products that are listed as alternatives have not been independently verified to be PFAS-free; they are listed based on claims from the manufacturers and/or information presented in safety data sheets and technical documents. No hazard assessment has been performed on the alternatives. For all the above reasons these potential alternatives need further investigation before substitution is initiated.

PFAS in electronic devices

The following is a list of specific electronic consumer product categories that have been shown to commonly contain PFAS chemicals.

→ Printed circuit boards

Printed circuit boards (PCB) are ubiquitous in the electronics industry and serve many functions throughout. PFAS may be included directly in the laminate material of the board itself^{3,10,11,12} for flame retardant and dielectric properties, or applied to a finished product as a protective layer known as a conformal coating^{13,14,15} for protection against temperature, moisture, and dust.

For both of these applications, there are available alternatives with similar properties but without intentionally-added PFAS. Two other common laminate materials are FR4 epoxy and polyimide, and some less common options include liquid crystal polymer, polyester, polyethylene naphthalate (PEN), bismaleimide-triazine (BT) resin, cyanate ester, and ceramics.¹² For the conformal coatings, other options include acrylic resin, urethane resin, silicone resin, and epoxy.¹⁵

It has been noted by industry that for existing designs, PTFE cannot be easily substituted in printed circuit/wiring boards without a complete redesign of the equipment (including the mechanical dimensions of the product) thus it is difficult to substitute PFAS for spare parts.

→ Capacitors

Various fluoropolymers are used in capacitors as dielectric films, and occasionally as liquid impregnates.^{16,3} They are used for their high dielectric strength and heat resistance, as well as the ability to be produced into thin films.

Alternative polymers for use as dielectric films include polypropylene (PP), polyethylene (PE), polystyrene (PS), polycarbonate (PC), PEN, polyphenyl sulfide (PPS), polyester imides (PEI), polyethyleneterephthalate (PET), polybutyleneterephthalate (PBT), polyetheretherketone (PEEK), polyvinylchloride (PVC), polyimides (PI), polyamides (PA), and polymethylmethacrylate (PMMA). Common materials used as liquid impregnates for capacitors include mineral oils, vegetable oils, certain waxes, silicone oils, and biodegradable synthetic oil.¹⁶

→ Acoustical equipment

Equipment used in the audio industry (e.g., microphones, speakers, transducers) often include piezoelectric materials. These are substances which provide electrical signals in response to mechanical or thermal signals, or provide mechanical or thermal signals in response to an electric field.

One commonly used material for this purpose in acoustical equipment is PVDF film.^{3,17} It can be made into very thin and flexible sheets, and therefore wrapped/molded into a variety of spaces, including those of very small size.

To replace PFAS one can use the more traditional piezoelectric materials made from ceramic and certain crystals. These work in many applications, but are rigid and often brittle, and may not work in specialty applications. Depending on the function of the product, another technology may be substituted for piezoelectric materials, such using electrodynamic speakers or dynamic microphones.

Expanded polytetrafluoroethylene (ePTFE) is often used in acoustic vent membranes in front of the acoustic diaphragm. The ePTFE acts as a differentially permeable membrane which allows for the passage of air, and thereby sound, while simultaneously keeping liquid and particles out. At present it seems to be difficult to find an alternative that provides the same protection from liquids, which is particularly important for outdoor applications.

→ Liquid crystal displays (LCD)

It has been reported that many liquid crystal displays (LCDs) contain fluorinated compounds as part of the actual crystal structure, to provide a dipole moment and stabilize the conformation,¹⁹ and occasionally use a fluoropolymer as a final coating to protect the panels from moisture.³

Depending on the application, the most suitable alternative would be to use a different display technology, rather than an LCD, such as light emitting diode (LED) or plasma screens.

→ Flat panel displays

Flat panel displays contain a light management film in order to control the brightness of the display. These films contain a thermoplastic base layer and a microstructure prismatic layer. There are various types of light management films on the market, made of different polymers such as polyester and polycarbonate.²¹

There is a patent indicating the use of PFAS compounds to repel dust and resist static electricity in such films.^{3,20}

→ Wiring and cables

Another ubiquitous electronic product category is wiring and cables. The insulating layer around the outside of each wire or cable can be made from a variety of plastic or rubber materials, and are often made from fluoropolymers due to their resistance to heat and fire, corrosion, moisture, and cracking.^{3,22,23,24} Teflon and other fluoropolymer cables and wires are widely available, and used in many applications across industries.

The best alternative will depend on the specific function needed, but there are many options available, including PVC, PP, PE, neoprene, silicone, and others.^{22,23,24}

→ Solar panels

Solar panels need resistance to dust, corrosion, ultraviolet light, and other weather-related effects, while also allowing light to reach the photovoltaic cells. Several fluoropolymers are commercially used for this purpose based on their ability to provide these protections.²⁵

Three non-fluorinated coatings that are commercially available are polyethylene terephthalate, polycarbonate, and polyamide. Less common alternatives include polyester, glass, metallization pastes, and silicon-based coatings.²⁵

→ Fuel cells

High-efficiency fuel cells contain proton-exchange membranes to separate charged particles into different chambers. The most commonly used product for this application is Nafion™, a perfluorosulfonic acid-based polymer sold by Chemours.²⁶ The membrane needs to be conductive and resistant to water and corrosion, and Nafion™ was specifically manufactured for this purpose. Other fluoropolymers are used in the gas diffusion layer as hydrophobic agents and to seal the chambers within the fuel cell.²⁷

The automobile industry notes that there are no replacements available,²⁸ however, there are alternatives under development, but not yet commonly used.²⁶ These include polysulfone, electrospun polybenzimidazole-type materials, hydrocarbon membrane and sulphonated polyetherketone (PEEK).⁶²

→ Lithium-ion batteries

The active materials in lithium-ion batteries are commonly prepared using PVDF as a binder because of its electrochemical stability and adhesion properties.^{29,30} PVDF is also used as a separator material. Additionally, there are several newer battery technologies on the market which use various fluoropolymer compounds as the electrolyte.^{31,32}

More environmentally friendly alternatives to the PVDF binder are still primarily in the research stage.^{29,30} For the electrolyte, the fluoropolymer options are actually the newer technology.

The standard electrolyte for these batteries is lithium hexafluoro phosphate, which is not considered a PFAS compound, but is still persistent.

If looking for alternatives, one could also consider the opportunity to shift to another type of battery.

→ Smartphones and tablets

Fluoropolymers such as PVDF are used in radiation curable coatings added to glass, metal, and plastic parts of many electronic products, including smartphones and tablets.²⁵ These coatings are made to be easy to clean and scratch and corrosion resistant, and PFAS are used in particular because of their hydrophobicity and ability to be applied in a thin layer.

There are other types of coatings used in the industry for the same purpose, which have similar properties to those that contain PFAS. Evaporative curing, moisture curing, and heat curing are all alternatives to radiation curing with similar results. Additionally, two examples listed by OECD for non-fluorinated radiation curable coatings are silica-based coatings, and “TEXTMATTE 6005,” which is a polymethylmethacrylate powder.²⁵

However, an industry group has noted that for touchscreens needing haptics-enabling coatings, good alternatives are currently lacking.

→ Uses in information and communication technology equipment

PFAS are used in Information and Communication Technology (ICT) equipment where their corrosion resistance and physical properties are needed. They are for example applied as lubricants for silicone O-rings and lubricant coatings in other applications requiring low coefficients of friction and where capillary action is needed to adequately fill gaps after jet dispensing.¹⁸ Per communications with an industry association, there are currently not viable alternatives for these specific applications.

→ Other electronic devices

There are many other household products within the electronics industry that have been confirmed or are suspected to contain PFAS chemicals.^{3, 18, 33} These include switches, vacuum cleaners, coffee makers, keyboards, screens, printers, and TVs. PTFE is commonly added to construction plastics as a flame retardant, and Teflon coatings are added to a variety of products for its non-stick properties, so it is likely that PFAS are contained in many more products than are in this list.

PFAS in the manufacturing process

In many cases, while the final product delivered to the consumer may be free of PFAS, the manufacturing process used to produce it was not. The following sections are a list of PFAS-containing products used in the manufacture of various electronic devices, along with their functions and potential alternatives.

→ Heat transfer fluids

During the manufacture of various electronic products there is a need for heat transfer fluids, typically to control temperatures during fabrication of various components. There are several different methods for doing this, each with their own selection of products marketed for the task, including evaporative cooling, brine cooling, direct contact cooling, and total immersion cooling.

In each of these cases, some of the leading products on the market are fluoropolymers and other PFAS-containing compounds. These include the product lines GaldentTM, by Solvay Solexis, FluorinertTM, by 3M, and VertrelTM, by Chemours, among others. Perfluorinated compounds are used for this purpose because of their large liquid temperature range, high dielectric strengths, and chemical inertness.

While these products seem to be marketed as the best performing fluids on the market, there are non-fluorinated alternatives. Eastman Therminol[®] heat transfer fluids are hydrocarbon based, with a variety of temperature ranges and other properties available.³⁴ After use, they are considered nonpetroleum waste oil.

Caldera Heat Transfer Fluids claim to be environmentally friendly, and that they can be disposed of using mineral oil recycling services. The company Engineered Fluids calls out PFAS as harmful to human health and the environment, and makes products based on ester chemistry, with the claim that they are biodegradable.³⁶ MIVOLT[®] products are specifically marketed as dielectric fluids for liquid immersion cooling and are listed as halogen free and readily biodegradable.³⁷

→ Cleaning products

Perfluorocarbons are also present in some solvents and cleaning products on the market that are formulated for the cleaning of sensitive electronic devices. The added PFAS work to control heat-transfer, form a non-flammable vapor blanket, reduce the flash point of the solvent, and rinse off solvent residues.^{3,38}

GreenScreen® For Safer Chemicals has a section on their website for Cleaners & Degreasers in Manufacturing that they have certified to be free of PFAS,³⁹ which means that they have no intentionally added PFAS and have been tested to contain less than 100 ppm total PFAS as impurities. This list includes several products manufactured by Zestron and the KYZEN Corporation, as well as single products by Shenzhen Vital New Material Company Limited, and Kushan Aolin Electronic Company Ltd. Additionally, depending on the specific needs of the cleaning project, simple alcohol cleaners such as isopropyl alcohol may be sufficient.

→ Solvents, carrier fluids, and lubricant deposition

PFAS-containing liquids are often used as solvents and carrier fluids for lubricants, coatings, adhesives, and other materials, in order to apply them in smooth, even coatings on a variety of surfaces.^{3,40} Similar to heat transfer fluids, there are a variety of these products on the market for this purpose, largely manufactured by Solvay Solexis (Galden®), 3M (Novec™), and Chemours (Opteon™). They are generally formulated to be paired with the fluorolubricants and other PFAS-containing products made by these same companies, but are also effective with other products and chemistries.

Perfluorinated liquids are used for these purposes based on their low surface tension, quick-drying properties, and ability to dissolve various lubricants and adhesives. They are also typically marketed as environmentally friendly (no ozone depletion) and lower toxicity alternatives to TCE, methylene chloride, toluene, etc.

Honeywell manufactures products under the label of Solstice® as solvents, cleaners, and carrier fluids, which are comprised of non-PFAS fluorinated compounds, both by themselves and in mixtures with methanol.⁴¹

→ Dielectric fluids

Perfluorocarbons are used in applications requiring the separation of high voltage components, such as in transformers and electric car batteries, largely as replacements for mineral oil. This is due to their high dielectric breakdown strength coupled with their lack of flammability.³ As mentioned above, Novec™ and Fluorinert™ products are marketed for this purpose.

The most promising set of alternatives to these perfluorinated compounds are natural and synthetic ester-based fluids. There are a variety of manufacturers placing these products on the market, such as Cargill, Midel, and NYCO, to name a few.^{43,43,44}

→ Testing compounds

PFAS are purported to be used in the various necessary testing processes for electronics. This includes liquid burn-in testing, reliability testing, dielectric testing, thermal shock testing, gross/fine leak testing, and environmental testing. These test solutions are required to: have a high dielectric breakdown strength, be non-flammable, and be non-reactive so as to not disrupt or damage electronics during testing while fulfilling their role in the test procedure. Manufacturer 3M offers products under the Fluorinert™ Electronic Liquids label marketed for these electronics testing processes.⁴⁵ Additionally, Galden® offers PFPE-based solutions for thermal shock and hermetic seal testing.⁴⁶

No PFAS-free alternatives to these testing solutions were identified; however, SpecialChem, a materials selection platform, has curated a comprehensive list of polymers and their respective dielectric strengths that may meet manufacturing requirements.⁴⁷

→ Piezoelectric ceramic filters

The etching of piezoelectric ceramic filters has been carried out using PFOS in the past.³ It is unclear whether this still occurs, however, it is still approved for use in this application in Japan as an exception to the country's ban on the compound.⁴⁸ For more information on etching, see section 3.2.6 below, in reference to the use of PFAS in etching of semiconductors.

Recent research suggests that etching can be performed on ceramic piezoelectric materials using fluoroboric acid,⁴⁹ which may present a viable alternative to PFOS, but is still persistent.

→ Pulsed plasma nano-coatings

PFAS have been used in pulsed plasma nano-coatings for electronic devices such as smartphones and hearing aids as a barrier to moisture and dust.^{3,50,51} This process is generally regarded as somewhat environmentally friendly, as it typically does not use solvents or produce VOCs. However, the use of perfluorinated compounds as the coating agents still gives room for improvement.

The company P2i provides alternative coatings that they claim are halogen and PFAS-free,⁵² and are still deposited using pulsed plasma technology. Additionally, there are other technologies for depositing hydrophobic coatings onto electronics, which may use different materials such as epoxy, urethane, acrylic, silicone, and paralyne.⁵⁰

→ General electronic equipment packaging

Fluoropolymer films are often used to protect sensitive electronic devices from air and moisture during shipping.^{3,53} They are non-stick, inert, transparent, and resistant to moisture.

There are a variety of other types of moisture and vapor barrier packaging on the market. Many alternatives, such as mylar bags, include a mixture of aluminium foil and various non-fluorine-containing polymers.⁵⁴

Semiconductors

Semiconductors are small electronic components primarily constructed from a semiconductive material, such as silicon, which then have integrated circuits constructed upon the semiconductive substrate (wafer). PFAS chemicals are extensively used through the fabrication process of the semiconductors due to their unique physiochemical properties.

→ Photolithography

Photolithography is the process of creating circuits on the semiconductor wafers. The process involves placing a thin layer of photoresist material on the wafer, and then exposing the wafer to UV light through a mask. The photoresist is then washed off on the exposed or unexposed areas and etching can be done in specific patterns. PFAS chemicals are used in multiple stages of the photolithographic process and their roles are described below.

Photoresist

Photoresist is a light-sensitive polymer that is applied to the semiconductor to facilitate the etching process. Light is used to transfer a pattern from a photomask onto the photoresist of the wafer; the photoresist is removed from the light exposed regions and structures can then be built upon the wafer.

PFAS are found in the photoresist polymer itself and typically require the presence of fluorine. Potential alternatives for PFAS in the photoresist are Fujifilm's KrF (248nm) (active ingredient not disclosed) and DOW™ company's photo-resist products which are marketed as PFOS-free; however, other species of PFAS are potentially used in its place.⁵⁵

The photoresist process also requires the presence of photoacid generators (PAGs) that are typically fluorinated and can include PFAS compounds. Historically, PFOS was largely used as the PAG for this process before being phased out and PFBS, another PFAS chemical, being used as an alternative.

Fluorine-free alternatives required for this process would need to be able to form a strong acid: acceptor-substituted thiosulfonate anions and acceptor-substituted aromatic anions may be suitable substitutes; however, no substitutes in-use have been identified.⁵⁶

There seem to be alternatives for PAGs and photoacid generators⁶² but according to industry experts there is a need for further research and development of these.

→ Antireflective coatings

PFAS can also be used in photoresist itself as an anti-reflective coating to reduce reflections. The photoresist is washed off and etched off during the photolithographic process, so no PFAS from

the photoresist specifically should be on the final chip. Generally, for this use, fluoropolymers with a short fluoroalkyl side chain less than C4 are used and have a low refractive index.²⁵ Non-PFOS alternatives are available, but they seem to contain other PFAS.

→ Developers

PFAS are actively used as additives to developer solutions that facilitate the control of the development process. PFOS has largely been phased out as a developer in favor of shorter-chain PFAS alternatives; however, no fluorine-free alternatives in use were identified. The availability of alternatives is uncertain, but a patent for a non-fluorinated surfactant for this process has been filed.

→ Rinsing Solutions

Rinsing solutions are used to remove the photoresist of the wafer after having undergone a change in solubility. PFAS are reported to be additives in these rinsing solutions as they have low surface tension;⁵⁶ however, their presence in these solutions on the market or potential fluorine-free alternatives have not been determined.

→ Etching

Etching is the step of selectively removing substrate on top of the wafer in order to create a pattern designed by the photolithographical process. There are multiple etching methods including wet and dry etching; both of which are reported to involve PFAS either as an additive in the etching solutions or is captured in the waste of the etching process.

PFOS was the primary PFAS in use for etching applications; however, it has largely been phased out in favour of short-chain PFAS surfactants, which are confirmed to be in use for etching applications and etching agents with ceramic filters.⁵⁸ PFAS are favoured in this process in general due to their reduction of surface tension and reflection in the etching solution. An example of PFAS in etching compounds are Daikin's dry etching agents which reportedly contain perfluorinated carbons.

After the etching process, the silicon wafer needs to be cleaned to remove photo resist and polymer residue left behind; this is done with a strong acid. Chemours' Vertrel™ and Opteon™ specialty fluids are marketed for etching and wafer cleaning/drying processes. Recently, functional alternatives have been identified and successfully implemented to replace semiconductor etchant solutions that use PFAS surfactants including the replacement of Novec 4200 as a surfactant for Buffered Oxide Etchants, FC95 as a surfactant for Chrome Etchants, Novec 4300 as a surfactant for Phosphoric/Acetic/Nitric Acid Etchants, and Novec 4200 for Tetramethyl ammonium hydroxide etchants.⁶⁴

→ Wafer thinning

Wafer thinning is the process by which material is removed from the backside of the wafer in order to meet the required thickness. It is unconfirmed if PFAS are actively in use in the wafer thinning process; however, the use of PFAS as a non-stick coating composition on the carrier wafer for wafer thinning has been patented (patent US20130201635).³ A low surface tension for the chemical is required for this process.

→ Vacuum pumps

Perfluoroalkoxy alkanes (PFA) and fluoropolymers are used in the working fluids of vacuum pumps. Chemours' KrytoxTM line of products are used as vacuum pump oils and contain PFPE. Alternative chemicals for this use would need to be stable and non-reactive;³ however, there do appear to be vacuum pumps for semiconductor applications that are oil-free, indicating that the use of PFAS-containing vacuum pump oil might be engineered out.

→ Vapor phase soldering

PFAS are used in vapor phase soldering and act as a heat transfer medium. This requires the additive compound to have good heat conductivity. PFPEs are primarily used for this process and is in products such as Solvay's Galden[®]LS/HS products line.⁴⁶ No alternatives to PFAS were identified for its use in vapor phase soldering.

→ Components

Certain micromechanical semiconductor components (MEMS) contain PFAS in the final product. Due to their ability to be formed in very thin layers, high temperature stability, and non-stick properties, they are used in MEMS accelerometers and image sensors. These are used in the electronic automotive safety systems of vehicles and some medical equipment, as well as consumer products such as smartphones, tablets, and wearables.²⁷ No alternatives were found for these applications of PFAS.

→ Inert equipment

There are many processes within the semiconductor manufacturing process which require components to be chemically inert and stable, such as moulds, piping, chemical containers, and reaction surfaces.³

Depending on the specific product or process, there are a variety of potentially suitable alternatives. As mentioned in other sections, there are a variety of non-fluorinated polymers with similar properties, such as polypropylene, polyester, polyimide, among others.

Summary of identified uses, functions and alternatives

The table below provides a summary of the uses of PFAS in electronics, the functions that PFAS provide in these products, and the availability of alternatives. Please note that the availability of alternatives will most likely improve over time.

Product Category	PFAS Function	Availability of alternatives
Electronic devices		
Printed Circuit Boards	Structure/Insulation	Common alternative laminate materials are FR4 epoxy and polyimide. Less common options include liquid crystal polymer, polyester, polyethylene naphthalate (PEN), bismaleimide-triazine (BT) resin, cyanate ester, and ceramics.
	Protective coating	For the conformal coatings, options include acrylic resin, urethane resin, silicone resin, and epoxy.
Capacitors	Liquid impregnates	Common materials used include mineral oils, vegetable oils, certain waxes, silicone oils, and biodegradable synthetic oil.
	Dielectric films	Alternative polymers for use as dielectric films include PP, PE, PS, PC, PEN, PPS, PEI PET, PBT and more.
Acoustical Equipment	Piezoelectric effect	Ceramic and certain crystals have traditionally been used, but may not work in specialty applications. Depending on the function of the product, another technology may be used, such as electrodynamic speakers or dynamic microphones.
	Acoustic vent membranes	Alternatives for moisture protection do not seem to be available.
Liquid Crystal Displays	Structure/Dipole moment	Depending on the application, the most suitable alternative would be to use a different display technology, such as light emitting diode (LED) or plasma screens.
	Protective coating	
Flat Panel Displays	Dust and static protection	Light management films made of polyester, polycarbonate, or another alternative polymer.

Product Category	PFAS Function	Availability of alternatives
Electronic devices		
Wiring and Cables	Insulation	The best alternative will depend on the specific function needed, but there are many options available, including PVC, PP, PE, neoprene, silicone, and others.
Solar Panels	Protective coating	Commercially available alternatives are polyethylene terephthalate, polycarbonate, and polyamide coatings.
Fuel Cells	Durable membrane	Alternatives are under development, including polysulfone, electrospun polybenzimidazole-type materials, hydrocarbon membrane and sulphonated polyetherketone (PEEK).
Lithium-Ion Batteries	In general	Consider the possibility to change type of battery.
	Binder	Alternatives are still primarily in the research stage.
	Separator	Alternatives do not seem to be available.
	Electrolyte	The standard electrolyte for these batteries is lithium hexafluoro phosphate, which is not considered a PFAS compound, but is still persistent so not a good substitute.
Smartphones and Tablets	Protective coating	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.
	Haptics enabling coating	It seems that for touchscreens, which need haptics enabling coatings, good alternatives are currently lacking.
ICT Equipment	Lubricants for O-rings	Alternatives do not seem to be available.
	Coatings for specifically low friction	Alternatives do not seem to be available.

Product Category	PFAS Function	Availability of alternatives
Manufacturing		
Heat Transfer Fluids	Heat transfer/cooling	Several commercial alternatives are available.
Cleaning Products	Vapor blanket, cleaning solvents	Several commercial alternatives are available.
Solvents, Carrier Fluids, and Lubricant Deposition	Solvent	Alternatives are available, but may not be suitable for some specific functions, and some alternatives may not be safer than PFAS.
Dielectric Fluids	Separation of high voltage components	Several alternatives available: natural or synthetic ester-based fluids.
Testing Compounds	Protection of electronics	Alternatives seem to be under development.
Piezoelectric Ceramic Filters	Etching	One mentioned alternative is fluoroboric acid, which is not considered a PFAS compound, but is still persistent so not a good substitute.
Pulsed-Plasma Coatings	Protective Coating	There are different alternatives available, including using a different coating technology.
General Electronic Packaging	Protective coating	Several alternative packaging materials are available.

Product Category	PFAS Function	Availability of alternatives
Semiconductors		
Photoresist	Photo-acid generator	There are a few patents on alternatives, but according to some industry experts, there is a need for further research and development.
Antireflective Coatings	Provide low reflectivity	There are “non-PFOS” alternatives, but these are likely containing other PFAS chemicals.
Developers	Facilitate control of development process	There availability of functional alternatives is uncertain.
Rinsing Solutions	Remove developer	Alternatives do not seem to be available.
Etching	Wet and Dry etching agent/ facilitate and clean etch	Alternatives are available for some uses.
Wafer Thinning	Non-stick coating on wafer	Alternatives do not seem to be available.
Vacuum Pumps	Working fluid	Alternatives seem to be under development.
Vapor Phase Soldering	Heat transfer	Alternatives do not seem to be available.
Components	Protective coatings	Alternatives do not seem to be available.
Inert Equipment	Various; non-reacting surfaces	The availability of functional alternatives varies based upon the specific process, and is generally uncertain.

As shown in the table above, there are several product categories for which there are already alternatives available on the market.

The products that are most important to prioritize for replacement are those where PFAS seem to be heavily used throughout the industry, and viable alternatives are available already. In this category are printed circuit boards, capacitors, wiring and cables, heat transfer fluids, and dielectric fluids.

While there may be situations where the specific properties that perfluorinated compounds offer do not have a viable equal yet, in some cases, these products can be replaced with PFAS-free alternatives. In many products and applications, PFAS may be used because they are the easy option, they have been heavily marketed, and/or they have the needed chemical properties for the specific function they are filling. However, they often exceed the necessary requirements, and could be replaced by something else that will still perform the necessary functions while being more environmentally and health friendly.

According to industry input, there are many specialized uses of PFAS within the industry that currently do not have viable alternatives at the time of the drafting of this guide. These include: PCBs for high-speed telecommunication network infrastructure, wiring and cable insulation for high voltage, high frequency, and chemical resistant applications, flame retardant plastics, lubrication and coatings in information and communication technology (ICT) equipment, touch-screen displays with haptic feedback, gaskets in electronic circuits, moving parts and ink tubing in printers, and several uses in the production of semiconductors.

Data Gaps and Uncertainties

There are still many data gaps regarding the use of PFAS in the electronics industry. The specifics of most manufacturing processes and formulations of final products are not disclosed to the public, and therefore the true extent of PFAS use is not fully understood. While PFOS and PFOA have been restricted under the Stockholm Convention since 2009 and 2019, respectively, and therefore have largely been phased out, in many cases they have been replaced by other, shorter chain, PFAS.

Additionally, the various manufacturers in the industry that were spoken to as part of the development of this guide indicated that they were all in early stages of the process to identify PFAS within their supply chain and identify potential alternatives. This suggests that more information on the use of PFAS within the electronics industry is constantly being generated and will hopefully add to the currently available resources as time goes on.

Provided examples of alternatives will not work in all scenarios, based upon the specific physical and chemical properties needed to fulfil the function currently performed by PFAS. Industry has noted that in many cases, finding an exact 'drop in' replacement for PFAS is not always feasible. For example, substituting a new product or compound in place of one that contains PFAS may also require other changes to the product to accommodate any changes in size, resistance, or other differences between the alternative and the PFAS compound. In some cases, suggested alternatives could turn out to contain PFAS themselves (either intentionally added but not disclosed, or as impurities).

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