

Seek and you shall find:

Alternatives to PFAS in electronics



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Executive summary

Escalating concern about the health and environmental impact of per- and polyfluoroalkyl substances (PFAS), widely known as “forever chemicals” on account of their extreme longevity and mobility, has prompted stricter customer requirements and regulatory measures. 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 found. A challenge for many companies is to understand where and why PFAS are used in their products. For regulators, lobbying by legacy industries has obscured the extent to which safer alternatives are both technically feasible and commercially available. The electronic “black box” is also a Pandora’s box of PFAS.

“A universal PFAS restriction has been seen by many companies as an opportunity for innovation”

This guide is therefore intended to support understanding of PFAS uses in electronics by providing illustrative examples of applications, the functions performed by PFAS, and potential alternatives reported by selected suppliers. This is not meant to be an exhaustive list of all PFAS uses, or all available alternatives. But it is broader, deeper and more rigorous than previous research in this area.

The report makes clear that in most applications, the use of PFAS in electronics is far from essential. PFAS are closely linked to niche, high-performance requirements such as thermal stability, low dielectric constant, chemical inertness and low friction. PFAS are also expensive and difficult to work with. Drivers of substitution include cost and avoiding inconvenience associated with fluoropolymers such as PTFE, for example. This is the case, for example, with the development by major suppliers of PFAS-free laminate materials for high-performance printed circuit boards (see Chapter 1).

This report demonstrates that PFAS-free alternatives are widely available. However, product choice is sometimes more constrained in applications that require multiple extreme properties simultaneously. As a result, the feasibility of substitution varies by application and should be assessed on a case-by-case basis. This variability underscores the importance of distinguishing between applications where substitution is straightforward, those requiring performance trade-offs, and those where further development may be needed.

However, the report shows that the likelihood of a universal PFAS restriction in Europe has been seen by many companies as an opportunity for innovation and the development of more sustainable materials and technologies. Companies that proactively address PFAS risks can thereby gain a competitive advantage and enhance their brand reputation.

So we see major multinational manufacturers changing their products in response to customer demands for PFAS-free with respect to component insulation, anti-drip agents and vent filters (Chapters 2, 3 and 7).

In other cases, large manufacturers appear to be changing their marketing of high-performance products, such as coatings and cables, that were already PFAS-free in order to align with changing customer preference (Chapters 4 and 5).

The report's findings with regard to heat transfer fluids (Chapter 8) are particularly timely, given the current boom in data centres and artificial intelligence. Here we find intense technological innovation of PFAS-free alternatives, driven partly by impending regulation but also by the need to increase cooling efficiency as computing power expands. The EU's proposed derogation for PFAS-based heat transfer fluids therefore appears particularly questionable, given that PFAS-based cooling is still such a niche application in this sector.

Why is this report important?

For more than five years, industry has lived with the knowledge that the EU is likely to restrict the use of PFAS “forever chemicals” within the bloc. The ensuing scientific, political and regulatory debate has been intense, at times even febrile.

Central to that debate is the possibility of doing things differently. Can a society that has become so dependent on these substances really manage without them? Precisely where might the obvious benefits flowing from a PFAS ban be outweighed by the damage it could cause to critical aspects of the economy?

When pressure points like this have been identified, the EU member states advocating the restriction proposal have agreed to time-limited “derogations”, or exemptions.

“The electronics industry is not so dependent upon PFAS as is often assumed”

This is an approach with which the authors of this report agree. Where we differ, however, is in our faith that European industry can adapt rapidly to a ban. Indeed, ChemSec is convinced a universal restriction is best for Europe in all respects: both socially and economically. Our long experience in this field has taught us that legacy polluters targeted by regulation routinely exaggerate the difficulties entailed by change.

Electronics is a large and vital sector where claims that industry must have these chemicals are the loudest. The recent boom in Artificial Intelligence has made the centrality of this industry even more obvious. Any threat to its development must be taken very seriously.

We present this report as evidence that the electronics industry is not so critically dependent upon PFAS as is often assumed. This is one of the most innovative sectors on the planet. So perhaps it is not so surprising that we have been able to compile so much information about PFAS-free electronic components that are either commercially available already, or soon to become commercially available.

Never has the Biblical injunction “seek and ye shall find” been so relevant as in the case of PFAS-free alternatives in electronics. In our search, we have been greatly assisted by the Fraunhofer IZM Institute in Berlin, specialists in applied and industrial contract research. ChemSec, however, bears full responsibility for the information contained in this report, its accuracy and interpretation.

Acronyms

■ Fluorinated materials (PFAS)

ECTFE – ethylene chlorotrifluoroethylene

FEP – fluorinated ethylene propylene

PCTFE – polychlorotrifluoroethylene

PFA – perfluoroalkoxy alkane

PFPE – perfluoropolyethers

PTFE – polytetrafluoroethylene

PVDF – polyvinylidene fluoride

PVDF-HFP – polyvinylidene fluoride-co-hexafluoropropylene

■ Non-fluorinated materials

ABS – acrylonitrile butadiene styrene

HDPE – high-density polyethylene

PC – polycarbonate

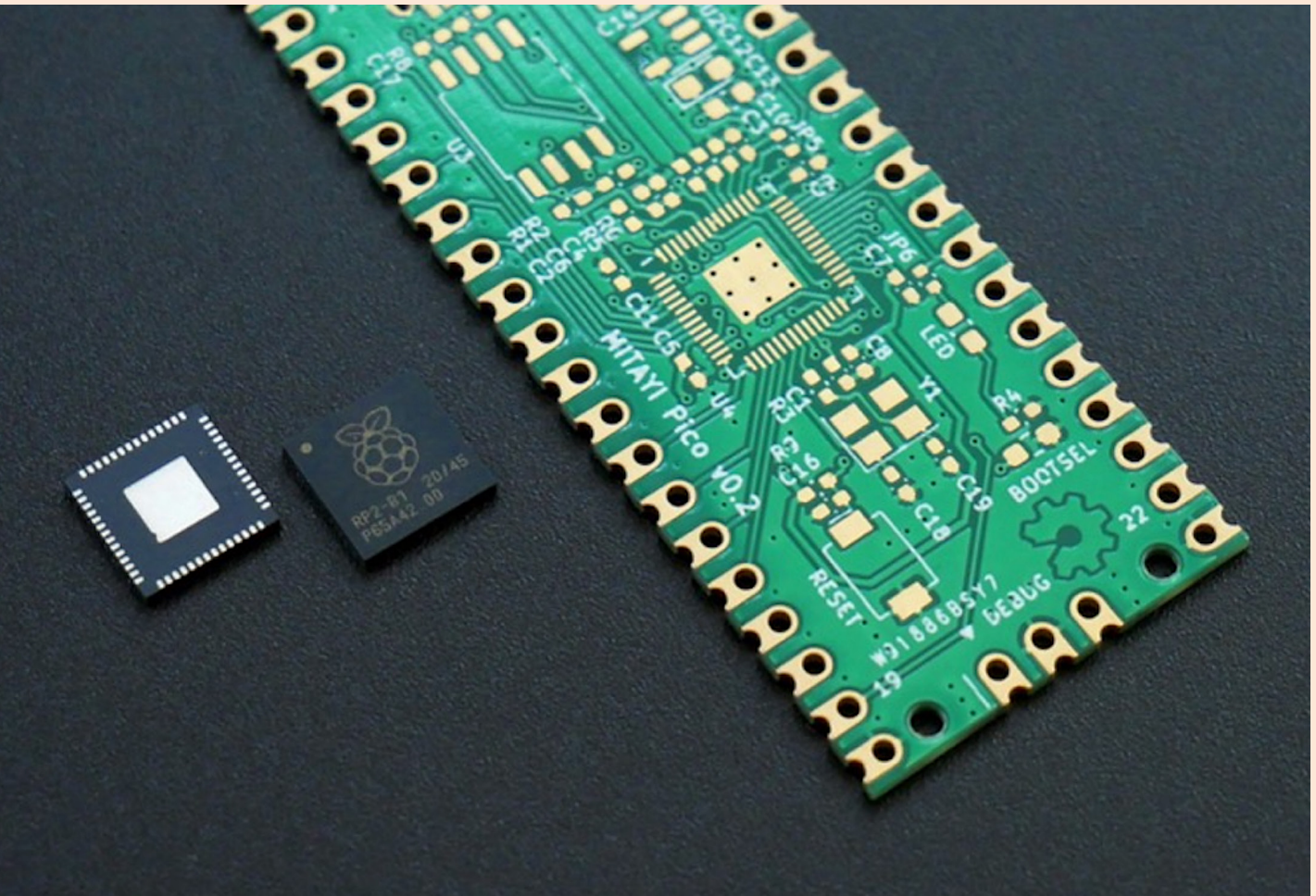
PEEK – polyetheretherketone

PMP – polymethylpentene

TPU – thermoplastic polyurethane

XLPE – cross-linked polyethylene

XLPO – cross-linked polyolefin



1

Printed circuit boards

>> **A typical PCB** is a piece of stiff, green plastic, ranging in size from a fingernail to a newspaper page. PCBs often consist of layers of different materials laminated together.

Copper channels, or traces, are bonded to the surface to conduct electrical current. Electronic components and microchips are then soldered to these channels.

Why are PFAS used to make them?

PCBs are subject to high temperatures and pressures during manufacture, and harsh chemicals are used to etch the copper traces onto the surface. Soldering the components also requires concentrated heat. On top of all that, PCBs need to have low electrical conductivity, withstand the heat caused by high frequency currents, repel moisture and not catch fire.

Laminates commonly used for PCBs include woven fiberglass fabric combined with a hard resin binder (together known as FR-4), lightweight polyimides (high performance polymers), heat resistant ceramics, and a resin called BT epoxy. In terms of manufacturing volume, FR-4 currently dominates by a wide margin.¹

PFAS enter the picture here for the same reasons they are useful in so many other applications – they are tough, stable, chemically inert and have low electrical conductivity. While they can be used on their own with microfibres to make PCBs, they can also be added to the laminate materials listed above to improve their performance.

The kinds of PFAS we are talking about

In PCBs, the most widely used PFAS is a plastic, or fluoropolymer, called PTFE, better known as Teflon.² Also used are ECTFE, PCTFE, and amorphous (non-crystalline) fluoropolymers.

PTFE has a very low dielectric constant, which means electrical signals propagate faster. It also has high thermal and frequency stability, meaning its properties remain constant.

Are there disadvantages to using PFAS in PCBs?

PTFE brings significant problems for PCB manufacture. This is one of the most slippery substances known to science – so slippery, in fact, that insects cannot climb it. It is the only known surface to which geckos cannot stick.³

This makes it difficult for PTFE to bond with other materials, such as copper. So manufacture of PCBs using PTFE demands specialised processes that are complex and expensive.

PTFE and other fluoropolymers therefore occupy a specific niche where their performance justifies the cost and processing complexity. These are premium/specialty materials in PCBs, not mainstream ones. They are used where temperatures, frequencies, and data loads are too high for other materials to withstand.

Here are the PFAS-free alternatives

Because of the cost and complexity of using PFAS in this application, suppliers have developed PFAS-free laminate materials for high-performance PCBs, specifically to replace PTFE.

These are not new technologies – alternatives to PTFE have been sought for many years for purely commercial reasons. The recent regulatory focus on PFAS, however, is now encouraging manufactures to highlight the fact that these products are also PFAS-free.

These non-PTFE materials are compatible with standard PCB fabrication processes traditionally used for FR-4 laminates. Switching to them does not therefore require investment in new machinery and equipment.

■ Rogers Corporation

Alongside products using PTFE, Rogers Corporation⁴ produces a range of PFAS-free hydrocarbon ceramic laminates for PCBs called the RO4000 series, offering high-frequency performance at low cost.⁵

Rogers began the RO4000 series in the 1990s.⁶ Its latest addition, the RO4830 Plus, was launched in March 2025, and is the first to be marketed explicitly as PFAS-free.⁷ Rogers confirmed to Fraunhofer IZM that all the products in this particular range are PFAS-free.

Materials in the RO4000 series can be made into PCBs using the same production techniques for widely-used materials such as FR-4.⁸ This lowers the cost of manufacture while delivering the same performance characteristics.

RO4000 laminates are designed for high-volume commercial RF and microwave applications. Rogers lists cellular base station antennas, RFID tags, and automotive radar and sensors among their typical uses.⁹

■ Isola Group

Isola¹⁰ first announced its Astra range of materials for PCBs in 2013, describing it as an extremely cost-effective alternative to PTFE exhibiting exceptional electrical properties that are constant over a broad frequency and temperature range.¹¹ This made Astra suitable for many applications in cars, such as adaptive cruise control, pre-crash sensors, blind spot detection, lane departure warning and stop-and-go systems.

In 2021, Isola described its Astra MT77 product as “PTFE performance without the hassle!”¹² What was it that made the product a preferred choice for PCB fabricators? “Ease of manufacturing!”, the company said. For example, these laminates are compatible with standard FR-4 fabrication.

Separately, Isola has developed its Tachyon range of high-speed-digital PCB products, aimed at 5G infrastructure, data centres, and other applications operating at speeds of 100 Gb/s and above. The newest product in that line, Tachyon 200JV,¹³ began production in 2025. It is explicitly marketed as PFAS-free.¹⁴

■ **Advanced Chip and Circuit Materials (ACCM)**

In January 2025, ACCM15 announced its Celeritas range of PFAS-free laminates for high-speed PCBs with data rates of up to 224 Gb/s.¹⁶ The materials have comparable electrical properties to PTFE and are compatible with standard FR-4 fabrication processes. The Celeritas range is designed specifically to overcome problems specific to ultra-high-speed PCBs.

The direction of travel

In the high-performance niche occupied by PTFE, two major global producers and one start-up offer market-tested products that are PFAS-free, and a smaller one offers a product for ultra-high-speed PCBs. The main driver for removing PFAS has been to lower manufacturing costs, not to remove these chemicals per se.

How strong is the case for a derogation?

Proposed derogation from the universal PFAS restriction: *PFAS used in printed circuit boards and antennas for 13.5 years after EIF.*¹⁷

Justifying this lengthy derogation, the proposal refers only to industry objections that non-PFAS alternatives cannot operate at high temperatures and frequencies, for high data rates, and low dielectric losses.¹⁸

The existence of the commercial alternatives demonstrated above suggests there is no basis for such an extended derogation.



2

Insulation of components

>> **So you have your PCB.** Now you need to attach many tiny components to it. These could be transistors, resistors, thermistors, capacitors, transducers, or combinations of these etched onto integrated circuits.

With all those electrons flying around, these components need insulation. The higher the frequencies, and the greater the data volume, energy and temperature, the more difficult this is.

Why are PFAS used here?

In most common cases, non-fluorinated materials typically serve as the standard insulation. These can include polyimide, polyester and ceramics.

As we have seen, PFAS are more costly and more difficult to process. But they are used when conventional insulating materials are inadequate. PFAS are therefore best understood as specialty insulation materials selected for niche applications demanding a specific combination of low dielectric loss, high thermal stability, and chemical inertness. They are not general-purpose insulators used broadly across all electronic components.

The kinds of PFAS we are talking about

We are talking specifically about fluoropolymers such as PTFE, and perfluoropolyethers (PFPEs).

Here are the PFAS-free alternatives

We have identified the following substitutes based on publicly available information, but without directly contacting manufacturers or suppliers:

■ onsemi

In January 2023, onsemi¹⁹ published the following statement on its website: “The Company hereby declares that PFAS is not in any onsemi products,” based on information collected from the company’s supply chain, manufacturers and affiliates worldwide.²⁰ When customers approach the company with questions about PFAS, its standard response is to refer them to this statement.²¹

■ Knowles

In November, 2025, Knowles²² issued a PFAS compliance statement using a broad PFAS definition covering all the main international regulatory regimes. It identified three PFAS used in its portfolio: PTFE, PVDF-HFP and a proprietary fluoropolymer. For each manufacturing site and product line, the company specified whether its products are PFAS-free (i.e. no intentionally added PFAS) or intentionally contain PFAS.²³

According to this document, several ranges of Knowles capacitors (single and multilayer, trimmer, radial and ribbon) are PFAS-free.

■ Taiyo Yuden

In the summer of 2023, Taiyo Yuden²⁴ added “organic fluorine compounds” (i.e. PFAS) to its list of restricted substances²⁵ that should not be included in its products. The following year, the reason for this change began to emerge. Taiyo Yuden’s US subsidiary wrote to all its customers²⁶ to inform them of an important change to its products “in response to evolving regulatory requirements and customer requirements” concerning PFAS.

Some customers had already begun to demand PFAS-free products, the company said. In response, it had decided to gradually implement PFAS-free alternatives for product components that currently contain PFAS. This change concerned hundreds of products in its range of inductors (electronic components that store electrical energy). There would be no changes to product specifications, the company said.

In April, 2025, the company announced it was extending this policy, for the same reasons, to change the base resin of its ferrite power inductors to PFAS-free. “The quality level of the changed products is the same as that of the existing ones,” it stated.²⁷

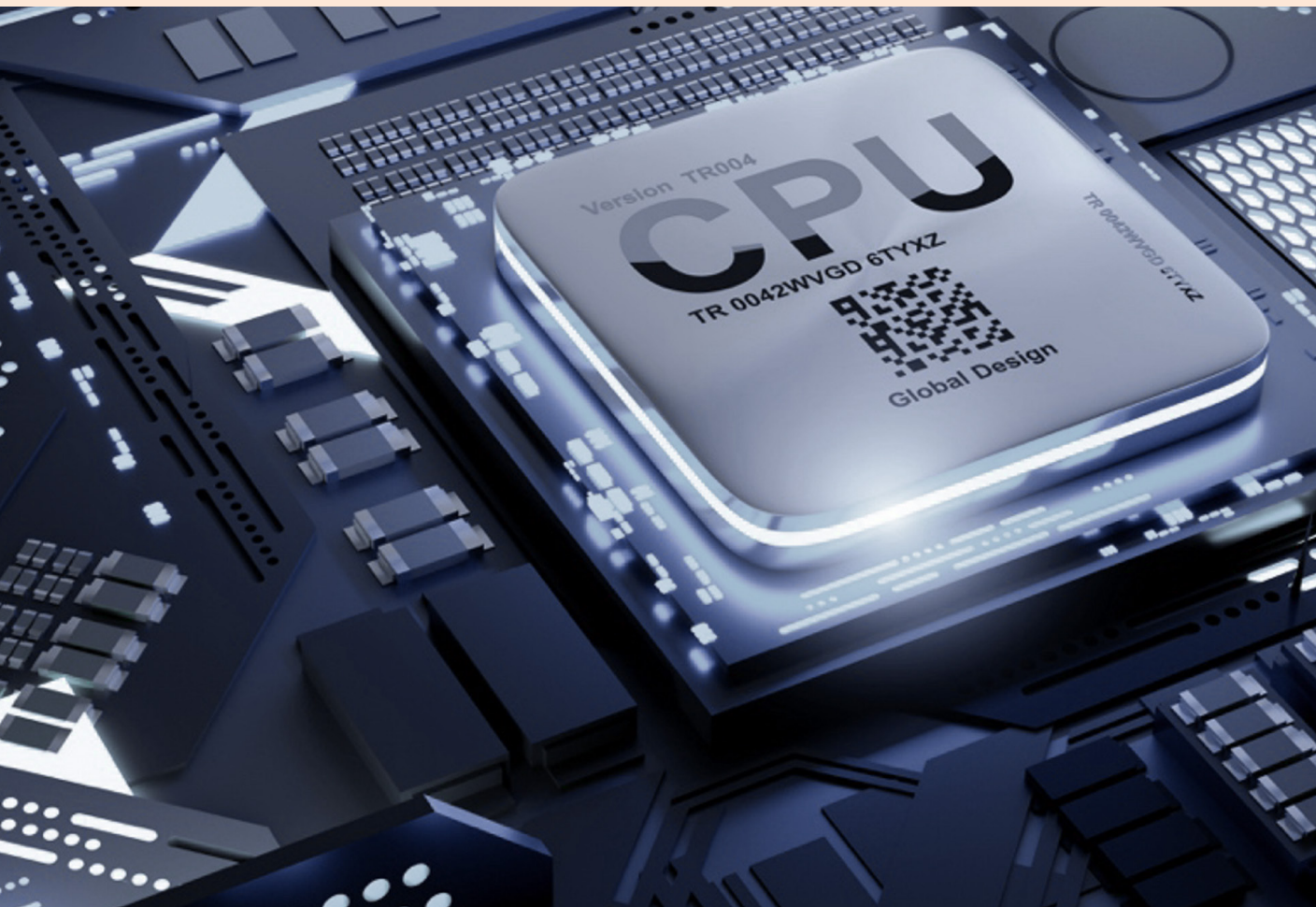
The direction of travel

Large multinational manufacturers are changing their products in response to customer demands for PFAS-free. The companies listed above are clearly aware of regulatory changes with regard to PFAS.

How strong is the case for a derogation?

Proposed derogation from the universal PFAS restriction: *Fluoropolymers and PFPE used for insulation material of electronic components for 13.5 years after EIF (excluding wires, cables and connectors).*

The discussion in the official EU background document that explains the need for this long derogation (delay) is brief and does not mention the producers listed above.²⁸ As we have seen, however, major producers of electronic components are abandoning fluoropolymers for these uses. The existence of commercial alternatives suggests the basis for such a long derogation is open to question.



3

**Anti-drip
agents**

>> **The components on your PCB** are usually contained within tiny protective structures. Plastic enclosures or housings are widely used to protect electronic components from dust, chemicals, heat or electricity. This might be housings for chargers, adapters, laptops and tablets, USB cable overmoulds, or a semiconductor chip or component sealed inside plastic.

Anti-drip agents are added to these plastics to help them achieve the necessary fire safety ratings. These substances prevent molten, burning plastic from dripping and spreading fire when exposed to heat or flames.

The thinner these plastic housings, the lighter the device, the fewer material resources are required, and the less waste is created at end of life. Blends of polycarbonate (PC) and acrylonitrile butadiene styrene (ABS) are habitually used to provide adequate toughness for thin wall (< 1.0 mm) applications in electronic products.

Why are PFAS used as anti-drip agents?

Thin-wall PC / ABS plastics use the fluoropolymer PTFE as an anti-drip agent in electronic components. According to the ECHA background document that is the basis for the proposed PFAS restriction, manufacturers of electronics insist that no alternatives are currently available to replace PTFE in polycarbonate for thin wall applications.²⁹

Here are the PFAS-free alternatives

New grades of polycarbonates have been produced in recent years that achieve the required flame retardancy and anti-drip performance in thin wall electronics applications without using PFAS, while providing the necessary qualities such as impact resistance and ductility.

Several producers of polycarbonates offer PFAS-free solutions:

■ LG Chem

In 2024, LG Chem³⁰ announced a PFAS-free, flame-retardant PC / ABS plastic to be used in electronic devices such as laptops and tablets (for example, chargers, adapters, and power supply covers).^{31 32} The company said a proprietary flame-retardant process had enabled it to enhance the heat resistance of the material without using PFAS.³³

The polycarbonate industry has been using a type of PFAS known as PTFE to gain V-0 flame retardancy (the highest grade) to prevent sparks from dripping when set on fire, the company told a specialist publication. Its new product achieves this 'anti-drip' effect without the use of PTFE.³⁴

Steve Kim, senior vice president of LG Chem's Engineering Materials business unit, said: "The transition to eco-friendly materials, including PFAS-free flame-retardant plastics, will become a global trend."³⁵

In September, 2026, LG Chem announced what it called a next-generation flame-retardant technology platform. Increasing PFAS restrictions and growing demand for recycled-content materials were creating new expectations for flame-retardant plastics, and manufacturers were seeking solutions that maintain performance and reliability while meeting evolving regulatory requirements.³⁶

To address these needs, LG Chem developed No Intentionally Added (NIA) PFAS flame-retardant technology. An example is its LUPOY ER5001PN plastic³⁷ for such electronic applications as smartphone housings, laptop casings, all-in-one PC shells, power adapters, AI speakers, and internet routers.

The platform can be applied across PC and PC/ABS materials, transparent and opaque applications, and multiple flame-retardant performance levels, enabling solutions tailored to customer requirements, the company said.³⁸

The development of PFAS-free plastics requires around three years, Julian Heinisch, an LG Chem Application Engineer, told Fraunhofer IZM. Many customers now consult with producers on PFAS-free solutions if they develop new products, he said.

■ Trinseo

Trinseo³⁹ was approached by a leading global technology company facing a critical challenge in sourcing materials for its laptop and tablet adaptors without using PFAS.⁴⁰ That company required a solution that complied with emerging PFAS restrictions and met stringent standards for toughness, ignition resistance, and aesthetic appeal.

In response, Trinseo developed the PFAS-free formulation EMERGE 8600PR. It launched this product, together with variants, onto Asian markets in April 2024.⁴¹ According to the company, the new products maintain critical performance attributes for consumer electronics and are suitable for applications in a variety of fields such as IT equipment, electronic and electrical products, battery chargers, and voltage stabilisers.

In Europe, the EMERGE 8600 grades are used in overmoulds of AC power cords, the boots and faceplates of USB charging cables, battery chargers and USB data/charging cables. They will also be used in power adaptors and battery packs in Europe from Autumn 2026, Trinseo says.

Trinseo points out that their non-PFAS alternatives cover a limited range of applications, and the company continues to face challenges in achieving non-PFAS solutions for all products. For example, there is still no alternative for lower molecular weight polycarbonate without the use of PTFE to achieve flame-retardant performance, it says.

■ Covestro

Covestro⁴² offers a range of NIA-PFAS (Not Intentionally Added) polycarbonate plastics with the highest grade of flame retardancy, for use in consumer electronics. The company developed new Makrolon and Bayblend flame-retardant grades without intentionally added PFAS to align with the EU's proposed PFAS restrictions.⁴³

"Our solutions enable exceptional thin-wall flame resistance down to low thicknesses and deliver robust mechanical strength to endure drops and impacts," it states.⁴⁴

It is important to note that NIA means PFAS is not intentionally added, which is not the same as a guarantee of zero PFAS. Covestro told Fraunhofer IZM that NIA-PFAS formulations require larger amounts of components to achieve anti-dripping protection, which affects the overall property profile of the materials and leads to greater limitations in their technical performance. For this reason, Covestro continues to use PTFE as an anti-dripping agent.

■ Sabic

Sabic⁴⁵ has developed a PC siloxane copolymer for use in electronics⁴⁶ to which no PFAS are added intentionally. The plastic achieves the highest level of thin-wall flame resistance, the company says, with the same impact resistance and ductility performance compared to traditional flame-retardant polycarbonates using PTFE anti-drip agents. Other Sabic copolymers are advertised as PFAS-free.⁴⁷

■ Mitsubishi

In 2023, Mitsubishi⁴⁸ announced it had developed the XANTAR XF Series of polycarbonate resins for electronics, with high thin-wall flame resistance and without intentionally added PFAS.⁴⁹ The material makes it possible to produce ultra-thin parts down to 0.6mm, contributing to weight reduction and space saving for information electronic equipment, the company said.

■ Marshall

Marshall Group⁵⁰ has been at the forefront of PFAS-free manufacture in recent years. Anna Forsgren, senior product compliance and sustainability manager, confirmed to Fraunhofer IZM that the company uses ABS and PC plastics that do not contain intentionally added PFAS in its headphones and speakers.

At the company's request, suppliers developed ABS and PC plastics with anti-drip agents based on silica and without intentionally added PFAS. These plastics can be used in big and small parts, with thick and thin walls down to 1.0 mm. They are certified with the highest level of flame retardancy, passed all reliability and moulding tests, and met all compliance standards.

Forsgren said it took around three years (i.e. the same as for LG Chem above) from the first step to the first products that were ready for being placed on the market with the newly developed plastics.

The direction of travel

Major global companies are aware of the EU's impending PFAS restriction and have developed commercial plastics for use in electronics that do not require PTFE as an anti-drip agent.

How strong is the case for a derogation?

Proposed derogation from the universal PFAS restriction: *Fluoropolymers and PFPE in anti-drip agents in plastics of electronic components until 13.5 years after EIF.*

Given the range of PFAS-free and NIA-PFAS plastics developed by major corporations without PTFE as an anti-drip agent, the derogation appears open to question.



4

Coatings and films

>> **Once your PCB** is covered with components, it is still not ready to plug in and use. These are delicate assemblies that can easily be damaged by particles of dust, moisture, and other contaminants.

Individual components therefore require the application of a micro-coating called a passivation layer. For a material to be suitable for passivation, it must be an excellent electrical insulator, must adhere well to the substrate, and must provide a barrier to chemicals that could attack the underlying device.

Also, the entire PCB must be “varnished” with a protective film that conforms to its complex shape, called a conformal layer. The conformal coating prevents electrical failures, short circuits and corrosion, thereby increasing product reliability, performance and lifespan by shielding against moisture, blocking out dust and debris, resisting chemicals, and absorbing mechanical and heat stress.

Why are PFAS used for this?

We encounter a similar picture with films and coatings to what we have seen before with PCBs and insulation: Most of the substances commonly used for coatings and films are PFAS-free.

Different formulations of polyimide materials are extensively used as organic passivation layers in the packaging of electronic devices. Other options for PFAS-free conformal coatings include acrylic, silicone, polyurethane, epoxy and parylene.

It is only when we come to specialist applications that we find PFAS being used. These can be niche products for aerospace and defence requiring high-temperature stability, resistance to ultraviolet light, and reliable dielectric properties. Some medical implants also require superior barrier properties for patient safety.

The kinds of PFAS we are talking about

Fluoropolymers such as PTFE and PVDF.

Here are the PFAS-free alternatives

Several major suppliers have developed innovative PFAS-free films and coatings:

■ Nordic Semiconductor

In the summer of 2024, Nordic Semiconductor⁵¹ announced that, in anticipation of the EU's PFAS restriction, it was changing to a PFAS-free polyimide passivation material from Japanese multinational Fujifilm for one of its flagship products. This was to comply with the “global movement to restrict the use of PFAS”.⁵²

This product is a “system-on-chip”, a single microchip that integrates an entire computer onto one piece of silicon. The company describes it as its most advanced, production-ready, multiprotocol wireless IoT solution for use in a broad range of connected products for smart watches and fitness trackers, gaming, virtual and augmented reality, smart homes, and industrial-IoT applications.⁵³

The company described this move to PFAS-free as a major change. Most importantly, it stated that it would impact neither the quality nor reliability of the product.

■ **actnano**

actnano⁵⁴ says it is part of a growing global effort to remove PFAS from supply chains. The company claims that its conformal coating product meets or outperforms numerous, rigorous customer and industry requirements, and is compliant with EU regulations.⁵⁵

actnano offers a portfolio of PFAS-free coatings, with base chemistries ranging from silicone, polyolefin, acrylics and more. Its Advanced nanoGUARD product,⁵⁶ for example, offers fluorine-free, thin-film conformal coatings designed to protect printed circuit board assemblies from humidity, condensation, salt, and other environmental stresses. The coatings provide full three-dimensional coverage, including connectors, antennas, LEDs and heat-generating components, without negatively affecting signal integrity or thermal performance. They are applied without the need for complex masking and integrate easily into existing manufacturing processes, the company says.

actnano states that its products are capable of substituting PFAS coatings in all but a small number of applications in aerospace and medicine.⁵⁷

■ **P2i**

P2i⁵⁸ manufactures a PFAS-free ultra-thin barrier coating designed for high-performance protection of PCB assemblies in doorbells, hearing aids, wireless earphones and other wearable devices.⁵⁹ The company says it can optimise its nanocoatings to meet desired performance requirements, and challenges companies to bring “their hardest protection problem”. However, there are no independent test data comparing the performance of these products with fluoropolymer-based competitors, and P2i uses fluoropolymers in some of its products.

■ **Dow**

This global chemicals company offers a range of silicone-based conformal coatings designed to protect electronic components. While these are mainly manufactured with no added PFAS, they are not marketed as such, and the company makes no effort to compare the performance of these products with fluoropolymer-based competitors.⁶⁰

■ **Plasmalex**

Launched in March, 2025, its PlasmaGuard products are a family of ultra-thin conformal coatings that are 100% PFAS-free.⁶¹ The company⁶² claims these coatings provide strong hydrophobicity, excellent dielectric and barrier properties, and high durability while remaining transparent and highly conformal, even at nanometer or micrometer thicknesses. However, there are no independent test data comparing PlasmaGuard against fluoropolymer-based competitors.

■ **HD Microsystems**

In May, 2025, HD Microsystems⁶³ announced a new, developmental polyimide that is PFAS-free.⁶⁴ However, we could not identify any suppliers that have transitioned to the new material.

The direction of travel

The market for PFAS-free films and coatings in electronics appears to be waking up to public opposition to PFAS and impending regulation in the EU. There is no shortage of products now being marketed as PFAS-free. However, as noted earlier, most of the substances commonly used for coatings and films were PFAS-free to start with.

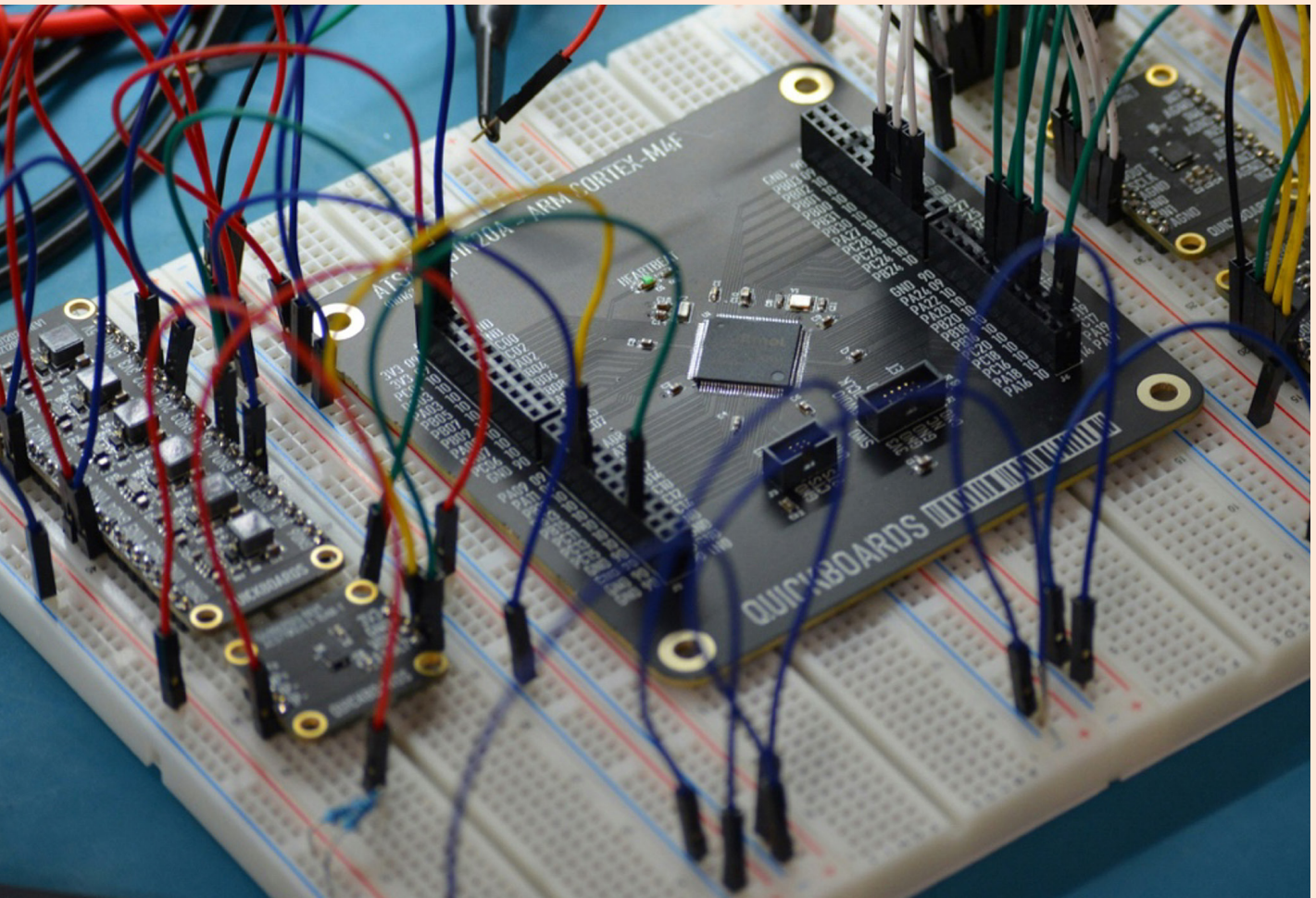
Two substantial companies have recently removed PFAS from some products, but both announcements were made to customers only, not to investors or the media, and it is unclear if they are part of any broader intention.

How strong is the case for a derogation?

Proposed derogation from the universal PFAS restriction: *PFAS used in coating and films of electronic components (excluding displays and lenses) for 13.5 years after EIF.*

Given the large choice of PFAS-free products with varied high-performance characteristics, and the claims of companies such as actnano to be able to substitute PFAS in all but a few applications, the basis for such a long derogation appears open to question.

For ultra-high-temperature, ultra-high-frequency, or specific aerospace and medical applications, there may still be a case for PFAS-containing coatings. But a careful, application-specific assessment often reveals PFAS-free solutions that meet or exceed performance, reliability, and regulatory criteria.



5

Wires, cables and connectors

>> **Now that your PCB** is safely covered in components that are suitably protected, you need to plug them in. Wires, cables and connectors transmit electrical power or electronic data. Each component serves a distinct role:

- A wire consists of a metal conductor, usually a solid piece of copper or aluminium, or multiple strands of the metal twisted together, that is coated with an insulating layer
- A cable is a bundle of two or more individually insulated wires encased in a single protective outer jacket
- A connector is a detachable device to join wires or cables to circuits, equipment, or other cables.

The plastics used in wire insulation, cable protective jackets and connectors serve different purposes and so have different properties and performance requirements.

So why are PFAS used here?

As we have encountered in previous chapters, PFAS plastics can meet the performance requirements demanded by extreme operating conditions. They are expensive and difficult to work with, but that trade-off can be worth it in certain applications.

The kinds of PFAS we are talking about

Perfluoroalkoxy alkane (PFA) insulated wires are designed for high-performance power transmission applications that require high dielectric strength, high thermal stability and chemical resistance and a lifetime of more than 40 years. They are used in applications that are relatively insensitive to cost, such as aerospace and aviation, robotic machinery, cleanroom environments for semiconductor manufacturing, and some medical devices that require frequent sterilisation.

PFA, FEP (fluorinated ethylene propylene), and PTFE are used as wire insulation for high-speed and/or high-frequency data transmission applications. They have very low dielectric constants, low dissipation losses and high frequency stability. The same materials are used for cable protective jackets and connectors with the same performance requirements.

Are there PFAS-free alternatives?

A wide range of PFAS-free insulated wires is available based on polyvinyl chloride (PVC). However, although PVC is PFAS-free, it is viewed as a regrettable substitution. PVC and its additives have been under regulatory scrutiny for the past decade.

Other PFAS-free insulate wires include those based on cross-linked polyethylene (XLPE) and cross-linked polyolefin (XLPO). However, they lack the thermal stability necessary for high operating temperatures.

PFAS-free wires designed for high-frequency and high-speed data transmission can be insulated with polymethylpentene (PMP) and XLPE. However, PMP is brittle at room temperature and XLPE dissipation losses increase progressively above 1 MHz.

For cables, PFAS-free materials such as thermoplastic polyurethane (TPU), XLPE, high-density polyethylene (HDPE) and silicone rubber are widely used. Silicone rubber is very flexible and durable under extreme temperature fluctuations, high resistance to chemicals and fire, biocompatible and chemically inert, making it ideal for medical cables or food-grade environments.

Similarly, PFAS-free materials such as polyetheretherketone (PEEK), silicone, polycarbonate and PA66 (Nylon 66) are in widespread use for connectors that do not need high insulation, extreme thermal stability or chemical inertness.

Polyimide and PEEK offer high-performance, PFAS-free wire insulation for demanding applications,⁶⁵ providing excellent thermal stability and chemical resistance. PEEK is particularly suited to harsh environments due to its durability and resistance to chemicals and radiation. Polyimide insulation, also known by the brand name Kapton⁶⁶ following its invention by DuPont in the 1960s, is used in specialist, high-temperature coatings. (Kapton is now manufactured by Qnity Electronics, which was spun off from DuPont in 2025.)

Specialised thermoplastics such as PMP offer the high performance necessary⁶⁷ for data transmission wire insulation in high-frequency and high-speed environments. Its primary application is in advanced telecommunications and electronics, where it can be used as a PFAS-free alternative to fluoropolymers such as PTFE. PMP has very low dielectric constant and dissipation loss and extremely high level of frequency stability, although it is brittle at room temperature.

The excellent dielectric properties of XLPE, its mechanical robustness and resistance to environmental stress make it suitable for reliable, long-term performance in demanding cable applications.⁶⁸ It has low dielectric constant and dissipation loss, and frequency stability up to 1 MHz, beyond which the dielectric constant remains stable but dissipation losses increase.⁶⁹

In terms of connectors, PEEK provides a lower dielectric field strength than PFA but the same high thermal stability. Its tensile strength is comparable to some metals.

Unlike PEEK, silicone is flexible and moisture resistant across operating temperatures from -60 °C to +230 °C, making it a primary choice⁷⁰ for applications requiring repeated bending, vibration dampening, or high-reliability waterproofing. It is biocompatible and chemically inert, making it suitable for medical or food-grade environments. However, it has lower dielectric field strength than PFA.

In this context, it is obvious that there is no need for PFAS / fluoropolymers to be the default choice for cables, wires and connectors. The choice of material depends on the specific performance requirements of the application in question.

To illustrate this conclusion, there follows a brief discussion of companies that offer PFAS-free, high-performance solutions in this area:

■ BASF

In October, 2026, BASF⁷¹ began marketing its Ultrason range of cable and wire insulation towards AI and electronic applications. The Ultrason range consists of polyarylethersulfone thermoplastics. One of these, polyphenylsulfone (PPSU), can replace PFAS-containing polymers, the company said. With its high chemical resistance, flexibility, and stable electrical insulation under high temperatures, the BASF-PPSU can also replace PFAS containing polymers used for cable jacketing and wire insulation.⁷²

As polyarylethersulfones, these products are by their nature not fluoropolymers, and are therefore PFAS-free. However, one of this range, Ultrason KR 4113 produced for the automotive industry, does contain PTFE.⁷³

■ Igus

Igus⁷⁴ positions its chainflex cables as largely PFAS-free solutions by deliberately avoiding fluorinated materials such as PTFE. The vast majority of its chainflex cables are considered PFAS-free based on testing of 96 PFAS substances, the company states.⁷⁵ This provides customers with a high level of planning security as existing applications are less likely to be affected by upcoming regulations.⁷⁶

Igus PFAS-free cables use PVC, polyurethane or thermoplastic elastomer for insulation and jacketing. While these cables may exhibit slightly lower maximum temperature and chemical resistance compared to fluoropolymer-based alternatives, they already achieve a high level of technical performance suitable for a wide range of industrial applications, the company says.

■ Allectra

Wire insulated with polyimide, widely known in the industry as Kapton (see above), typically requires a PTFE bonding layer to secure the insulation to the metal conductor. Allectra⁷⁷ has developed a proprietary process that eliminates the need for this PTFE layer, enabling the production of a fully PFAS-free polyimide-insulated wire suitable for general and specialist uses.⁷⁸

The product is designed for high-performance environments, offering excellent radiation resistance up to 10⁹ rad and reliable operation up to 300°C, the company says. Additionally, it supports a voltage rating of up to 20kV under vacuum conditions, making it suitable for demanding technical applications.

Allectra is collaborating with customers and partners to replace PTFE in an increasing number of connector types. Through targeted engineering efforts, Allectra has recently introduced PFAS-free, in-vacuum coaxial and triaxial connectors in which all PTFE components have been substituted with PEEK. For in-vacuum signal transport applications, Allectra's PFAS-free products are commercially available and in active use at most synchrotron and particle accelerator research facilities across Europe.

The company notes that PTFE, when exposed to radiation, can release harmful fluorine into the apparatus, a risk mitigated by using Allectra's PFAS-free wires and cables in such settings. The company is planning to release cable variants

in the near future with higher voltage, current, and power ratings. Achieving a higher frequency range represents a more challenging target which remains in an early research and development phase, the company says.

■ Habia

Since the 1990s, Habia⁷⁹ has worked to make its cables “halogen free”,⁸⁰ with the aim of reducing smoke generation and toxicity. The halogen group of substances includes fluorine, but also chlorine, iodine and bromine. Although Habia does not mention PFAS on its website, it says its use of fluoropolymers is not its default choice. The company uses them only where their unique combination of properties is necessary to meet functional and safety requirements.

Over the years, Habia says it has successfully replaced fluoropolymers with a range of alternative materials, including polyesters, PEEK, polyethylene, and various halogen-free flame retarded compounds. These solutions cover a large share of applications.

How strong is the case for a derogation?

Proposed derogation from the universal PFAS restriction: *Fluoropolymers and PFPE used for wires and cables (incl. connectors) for 13.5 years after EIF.*

As we have seen, industry is delivering PFAS-free cables, wires and connectors suitable for demanding environments. In this context, the derogation appears open to question.



6

Coatings for displays and lenses

>> **Your digital gadget** is ready to go. But users need to be able to interact with it, and it may need to admit or emit light. The modern electronics industry therefore relies extensively on advanced surface coatings. The typical smartphone, for example, depends on these invisible protective films which must withstand continuous touching, cleaning, and exposure to the elements while maintaining optical clarity and tactile responsiveness. The same considerations apply for camera lenses, optical sensors and display panels in professional and consumer electronics.

The three most commonly used display coatings are:

- Anti-fingerprint (AF)
- Anti-reflective (AR)
- Anti-glare (AG).

Why are PFAS used for this?

Anti-fingerprint (AF): PFAS are commonly used in AF coatings, particularly for touchscreens, due to their excellent oleophobic and hydrophobic properties that effectively repel fingerprints and smudges.

Anti-reflection (AR): Everyday products such as eyeglasses, smartphone screens, and camera lenses employ AR coatings made of low-refractive-index materials such as magnesium fluoride or silicon dioxide. These layers minimise reflection at a targeted wavelength, but are limited in suppressing reflections over the entire visible spectrum. Also, traditional inorganic AR coatings are often unsuitable for plastics.

In contrast, fluoropolymer AR coatings adhere strongly to a wide range of optical plastics and retain flexibility. PFAS compounds are therefore used in AR coatings for their antireflective characteristics and to enhance durability, although their use is less common compared to AF coatings.

Anti-glare: AG coatings do not contain PFAS, as they are usually based on silica or polymer materials.

The kinds of PFAS we are talking about

Anti Fingerprint (AF): Most manufacturers currently combat fingerprints by applying a transparent PFPE coating to touch-screen glass. This coating lowers surface tension and imparts hydrophobic and oleophobic properties, reducing fingerprint adhesion.

However, even state-of-the-art AF treatments typically achieve only limited repellence and continued susceptibility to fingerprint oils. Therefore, enhancing anti-fingerprint and anti-fouling performance without degrading the optical properties of glass has become an important research focus.⁸¹

Anti-Reflection (AR): The fluoropolymers used can be Teflon (PTFE), PVDF, PFPE and others.

Here are the PFAS-free alternatives

The replacement of PFPE-containing AF coatings with PFAS-free alternatives for touchscreens is a challenge. AF coatings must be applied as extremely thin nanofilms to ensure that touch sensitivity and optical properties are not compromised. Furthermore, achieving sufficient oleophobicity – the critical property for resisting grease and smudges during frequent use – is a key metric. Industrial application and mass production present additional obstacles, particularly due to limited process time for curing.

Alkylsilanes and organosilanes are important building blocks for PFAS-free AF coatings on displays and touch screens. Non-fluorinated silanes can be grafted or co-condensed onto glass or oxide-coated plastic. Layers such as these lower surface energy compared with bare glass and provide reduced fingerprint adhesion and improved cleanability, while preserving high optical transparency.

■ Kriya Materials

Kriya⁸² told Fraunhofer IZM that PFAS functionality has been substituted by an inorganic–organic nanocomposite platform that achieves low refractive index without fluoropolymers, thereby eliminating PFAS entirely. The coatings can be applied with standard industrial processes.

Durability and abrasion resistance are reported as superior to many PFAS-based coatings, and the products are qualified on glass, TAC, PET, and PC plastics. Overall performance is rated equivalent or superior to PFAS solutions.

The technology is already used in electronic equipment on the market, and is being validated by major electronics manufacturers, including qualified use as a waveguide coating in AR/VR glasses. Key benefits are higher wear resistance, comparable or sometimes lower application costs, and improved supply-chain security through EU-sourced raw materials.

■ Anonymous Supplier

This supplier, which asked to remain anonymous, confirms that its coating solutions contain no substances within the PFAS definition used for the EU restriction and does not rely on substances listed on substances listed as hazardous in European legislation.

The supplier told Fraunhofer IZM that it has substituted PFAS with polysiloxane-based chemistry. The PFAS-free coating targets high and durable water/oil contact angles and is intended as a “rip and replace” anti-fingerprint solution. The product demonstrates slightly lower oleophobicity compared to fluoropolymers but meets other performance requirements and is currently in high-volume production.

The supplier rates the PFAS-free option as fully equivalent to PFAS-based solutions such that a derogation is not needed. The solution is qualified by customers for use in their products, with applications including consumer device displays, automotive displays, AR/VR devices and lenses.

Expected benefits, besides PFAS elimination, include cost parity with incumbent solutions and broader functionality (easy-to-clean, reduced fingerprint haziness). Further improvements are planned in durability and suitability for more substrates.

■ CCM

CCM's⁸³ PFAS-free 7675 Duo Glass-Metal coating is designed to replace fluorochemical anti-fingerprint and easy-to-clean coatings on non-absorbent surfaces (glass, plastics and metals).⁸⁴ The product is in commercial use in the EU on architectural glass, appliances, sanitary installations public infrastructure, and also displays and touchscreens.

CCM confirmed to Fraunhofer IZM that 7675 contains no substances within the PFAS definition. Its hydrophobic and oleophobic properties are achieved purely via an organic-inorganic sol-gel network. The formulation contains no substances listed under the REACH Candidate List, REACH Annex XVII, RoHS or POPs.

CCM judges that this PFAS-free solution can cover a substantial share of applications, implying that the derogation scope can be reduced because technically and commercially viable PFAS-free anti-fingerprint coatings are already available for standard applications.

CCM is currently involved in several research activities with partner companies to produce and replace conventional and fluorinated oleophobic AF coatings.

■ Nanize

Nanize⁸⁵ has recently developed patented and patent-pending PFAS-free organic polysilazane coatings that can be ultra-rapidly cured in under 60 seconds at temperatures below 70°C to form fully cross-linked, glass-like networks covalently bonded to a wide range of substrates (metals, glass and plastics such as TPU, acrylic, and polycarbonate).⁸⁶

Nanize confirmed to Fraunhofer IZM that these coatings deliver durable anti-soiling, anti-smudge, anti-scratch, anti-abrasion, non-marking, smooth, and hydrophobic properties and can also increase light transmittance, making them highly suitable for displays and optical lenses.

The technology overcomes a historical barrier to large-scale adoption of polysilazane coatings, namely, the lack of a cost-efficient, high-volume curing process, by enabling full 3D cross-linking at low temperatures compatible with sensitive substrates.

The coatings are already being tested for touch screen applications by industry customers and are in the process of qualification for use. Nanize can further implement multilayer solutions to enhance anti-reflectivity and achieve greater glare reduction. This solution is still in the upscaling phase, and further testing and adjustments regarding touchscreen application are ongoing.

■ Daken Chemicals

Daken⁸⁷ has recently developed a powerful silane coupling agent with a unique molecular architecture which allows it to bond with glass surfaces.⁸⁸ Manufacturers apply it to display glass to create an effective anti-fingerprint coating. There is no information on the extent to which this product is in commercial use.

The direction of travel

Ongoing development and optimisation (formulation, layer architecture, curing processes) are expected to further close any remaining gaps between PFAS-based and PFAS-free coatings and reduce any remaining need for PFAS-based coatings in specialized applications.

How strong is the case for a derogation?

Proposed derogation from the universal PFAS restriction: *PFAS used in coating and films on displays and lenses of electronic complex objects until 6.5 years after EIF.*

Regarding AR coatings, a mature PFAS-free solution exists that meets the optical and durability requirements of current PFAS-based technologies and is already deployed at industrial scale. For AF coatings, multiple PFAS-free chemistries are technically and commercially viable for many applications. In most standard use cases, PFAS-free coatings can replace PFAS-containing AF coatings without significant performance loss. In this context, the proposed derogation appears open to question.



7

Vent filters

>> **Your gadget** will most likely also need to have openings to the air to enable it to transmit or receive sound or measure air temperature or pressure. Vent filters are the microporous membranes that cover the openings in electronic devices. They protect the electronics inside from damage by particles, water, oils and other contamination. A sound-permeable membrane has many of the same functions, but is optimised for sound transmission.

For example, smartphones and digital cameras rely on hydrophobic vents to survive water splashes while allowing air exchange for their sensors. Smart watches, laptops, hard drives, battery packs, hearing aids, electric toothbrushes and washable shavers all rely on vent filters.

The vent membrane needs to be hydrophobic, enabling it to repel water. In some cases it needs to be oleophobic, enabling it to deal with oils, chemicals and other fluids. Filters also need to be thin and lightweight. In some cases, they should vibrate easily in response to sound waves, converting the airborne energy into mechanical vibrations.

Some applications require the vent to be integrated into an individual electrical component, such as a sensor, which may need to survive the very high temperature associated with soldering the component onto a circuit board.

The kinds of PFAS we are talking about

Sound-permeable and vent filters often use PTFE, which strongly repels fluids such as coffee. It also withstands the temperatures associated with soldering.

Here are the PFAS-free alternatives

PFAS-free alternatives are available on the market:

■ SAATI

Over recent years, SAATI⁸⁹ has invested significantly in research and development to expand its portfolio of PFAS-free solutions, demonstrating that it is possible to eliminate intentionally added PFAS while preserving the levels of performance, reliability and consistency required by the market.⁹⁰ The product also withstands the high temperatures used for soldering.

SAATI use electrospinning technology to manufacture their SAATivent series of high performance PFAS-free acoustic vents, which are suitable for a range of consumer electronics and automotive applications.⁹¹ The company says that its venting membrane are PFAS free, which means no PFAS substances are intentionally added to the product or declared in its components. Trace amounts may be present due to unintentional contamination or background environment exposure.

■ SABEU

Growing concern about PFAS has led to increased demand for environmental-friendly alternatives, SABEU⁹² says.⁹³ Its PFAS-free membranes deliver the same properties – without the use of PFAS chemicals. This gives them the right balance between high efficiency and environmental protection, the company claims.

SABEU membranes can be used in electronic components such as sensors, batteries, lighting systems and control units in sectors that require protection from external substances and pressure compensation during heating, the company says.⁹⁴

SABEU manufactures a range of PFAS-free microporous acoustic membranes called TRAKETCH. These, the company says, preserve the application specific sound quality / transparency, including all acoustic properties. At the same time, they protect sensitive electronics, such as loudspeakers and microphones against external impact.⁹⁵

The product range is marketed as suitable for electronic earmuffs or hearing aids, microphones and loudspeaker systems (also for outdoor use), two-way speaker systems and radio devices, mobile and portable devices such as smartphones, tablets, cameras, smartwatches and headphones.

However, PFAS-free solutions do not always have the same properties with respect to chemical resistance. They must therefore be evaluated case by case, considering the specific requirements of each individual application.⁹⁶

How strong is the case for a derogation?

Proposed derogation from the universal PFAS restriction: *PFASs in sound-permeable and vent filters for electrical and electronic equipment for 6.5 years after EoF.*

Well-established manufacturers market PFAS-free alternatives that deliver the same or similar performance. A lengthy derogation is therefore a burden on progressive manufacturers and a disincentive to innovate.



8

Heat transfer fluids

>> **Perhaps the most iconic use** of electronic technology is inside data centres used for generative artificial intelligence. A large data centre can easily contain millions of PCBs

Servers in modern data centres generate considerable heat coming mainly from microchips in their processors. The higher computing power necessary to operate ever larger generative AI models means the energy that must be dissipated is constantly, and rapidly, rising.

Cooling technologies have different levels of performance:

- Air cooling: 350 Watt (W)
- Single phase liquid cooling (direct to chip or immersion): 350 W to 700 W
- 2-phase liquid cooling: >700 W

The latest generation of “superchips” require 1200 W⁹⁷ performance, and 2000W is on the near horizon. This makes air cooling physically impossible at the density of servers that hyperscalers require. By early 2026, around 19% of data centres were using liquid cooling,⁹⁸ with a further 36% planning to adopt these technologies within 12-24 months.

There are two main kinds of two-phase liquid cooling:

2-phase direct-to-chip (2DC) cooling – also referred to “cold-plate” cooling. Cold plates are placed directly on top of the processor. In two-phase direct-to-chip cooling, a low-boiling heat-transfer fluid is used. The heat from the processors boils the fluid, and the latent heat of evaporation keeps the chips cool.

2-phase immersion (2I) cooling. Servers are immersed in tanks filled with a dielectric fluid with a low boiling temperature. The heat boils the fluid, as with 2DC cooling.

It is important to note that two-phase cooling, while more powerful than other cooling methods, is still a small niche within the data centre sector globally.

Estimates of the share of installed data centre computing power by cooling method suggest that air cooling (PFAS-free) still represents more than 80% of the market, single-phase liquid cooling (PFAS-free) has less than 20%, while PFAS-based liquid cooling still represents less than 1% of global data centre cooling.⁹⁹

Why are PFAS used here?

Single-phase liquid cooling techniques – both immersion and direct-to-chip – can be operated without PFAS heat transfer fluids. PFAS are thus only discussed here in the context of 2I-cooling and 2DC-cooling.

PFAS are electrically non-conductive, so that they do not present a risk to the IT equipment in case of any leakage. They can also be engineered to boil at different temperatures.

Table 1 overleaf summarises the advantages and drawbacks of two-phase liquid cooling technologies.

The kinds of PFAS we are talking about

These are fluorinated substances including hydrofluoroethers, perfluorocarbons, perfluoropolyethers and, more recently, hydrofluoroolefins. The latter break down in the atmosphere into trifluoroacetic acid, or TFA, a short-chain PFAS about which there are serious health concerns.

Here are the PFAS-free alternatives

1. Two-phase liquid cooling

For both 2I and 2DC cooling, PFAS-free alternatives are close to being commercially available:

Table 1: Pros and cons of 2-phase liquid cooling

Technique	Advantages	Disadvantages
2I-cooling	Removes most heat from servers due to immersion of servers into fluid; High cooling performance due to rapid evaporation of dielectric fluid; Cools also other components than CPUs and GPUs, no additional cooling required for those components;	Use of large volumes of PFAS; High emissions of PFAS into atmosphere because tanks need to be opened for maintenance or repair; Large, heavy tanks require significant data center infrastructure investment; Components in tank must be compatible with the dielectric fluid to prevent damage; Boiling in tanks erodes material from motherboard, solder material, and other equipment material, detrimental to lifetime of equipment; Continuous filtering needed to remove eroded material, requiring large filters. Regular maintenance required, burdensome since servers and racks are not easily accessible, longer server downtimes.
2DC-cooling	No large, expensive tanks like in immersion cooling, little to no changes in data center infrastructure; Eliminates risk of damage to servers from water used in 1DC cooling; No filtering and replacement of heat transfer fluid: Closed system, no/little PFAS released into atmosphere; Liquid always remains below boiling point, works seamlessly even as chips get hotter in future; Servers and racks remain directly accessible and serviceable.	Complicated piping and hoses to supply coolant to many cold plates; Risk of pipe corrosion; Use of PFAS, even though much lower quantities compared to 2I-cooling (but so far no derogation for use of PFAS) Emissions of fluorinated liquids leading to safety hazards Additional cooling (air) required for other components such as SSDs, power delivery components, etc.

Source: IDTechEx¹⁰⁰

■ ZutaCore

In May, 2023, ZutaCore¹⁰¹ pledged to eliminate PFAS from its cooling products, announcing that it would bring “a PFAS-free direct-on-chip liquid cooling solution to the market in 2026”.¹⁰²

At the time, ZutaCore cooling systems were in tests with data centre giants Equinix and Intel. Intel, a long-term partner of ZutaCore, backed the intention to go PFAS-free, saying it was “thrilled” that ZutaCore is committed to a sustainable data industry.

Since then, ZutaCore has issued no further information on when this PFAS-free solution will become available. Its website states that the company is actively tracking regulatory developments, and can respond to regulatory change with “minimal infrastructure disruption”, suggesting that its PFAS-free solution may not be far off.¹⁰³

■ Blue Wolf Fluids

When the US multinational 3M exited PFAS manufacture at the end of 2025, it discontinued its widely used Fluorinert and Novec heat transfer fluids. With data centres and chip manufacturers looking for replacements, Blue Wolf Fluids¹⁰⁴ engineered novel fluids to match the specifications and functionalities of 3M's discontinued products, aiming to minimise disruption to existing processes.¹⁰⁵

These heat transfer fluids are PFAS-free. The company says it has engineered its fluids to be completely free of, or produced at non detectable levels of, PFAS and other harmful chemicals, deliver expected performance “without compromising the well-being of our planet and those who inhabit it”.¹⁰⁶

These fluids are suitable for two-phase immersion cooling. Apart from anonymous customer testimonials on the company's website, we have no information about the commercial deployment of these products.

2. Direct-to-silicon

This new technology is close to commercialisation and is backed by some of the biggest companies on the planet

■ Microsoft

In 2025, Microsoft revealed a proprietary microfluidic cooling approach which routes fluid directly into microchannels etched onto the back of the silicon itself, guiding the coolant to high-heat regions inside the chip.¹⁰⁷ The coolant is typically a mix of water and propylene glycol, according to one specialist source.¹⁰⁸

The channels are typically micrometers thick, similar to the size of a human hair. Rather than simple straight lines, the layout mimics patterns found in nature, such as leaf veins or butterfly wings, to guide the fluid more efficiently.¹⁰⁹

The technology removes heat three times more efficiently than typical cold plates, Microsoft said last year.¹¹⁰ Microfluidics also reduced the maximum temperature rise of the silicon by 65 percent, though this would vary by the type of chip. Microsoft has been experimenting with the technology for some years and demonstrated the first prototype in 2022.

This approach is called direct-to-silicon liquid cooling. Microsoft is not the only major company to develop methods to produce embedded coolant channels inside a chip or chip package.¹¹¹ IBM pioneered this approach and published a patent in 2022.^{112 113}

■ Taiwan Semiconductor Manufacturing Company

In 2025, TSMC¹¹⁴ unveiled a direct-to-silicon liquid cooling solution integrated into its chip manufacturing platform.¹¹⁵ TSMC tested prototypes of its silicon-integrated micro cooler using de-ionized water as coolant. The technology can dissipate more than 3,000 Watts of power.¹¹⁶

Challenges remain, such as scaling microfluidic fabrication to high volumes and ensuring coolant purity to avoid corrosion. Kevin Zhang, TSMC's Deputy Co-COO and Senior Vice President, described this technology as "transformative". "Direct-to-silicon liquid cooling breaks the thermal wall, unlocking the full potential of [TSMC's manufacturing platform] for exascale AI. This isn't just incremental; it's transformative for sustainable computing."¹¹⁷

TSMC says it is targeting commercial deployment by 2027.¹¹⁸

This technology shifts cooling responsibility toward semiconductor manufacturers and system vendors rather than data centre operators.¹¹⁹ Semiconductor labs at Samsung and Intel are working on similar techniques.¹²⁰

The direction of travel

The complexity, cost and physical limits of existing cooling techniques are driving research into new technologies. Powerful PFAS-free cooling technologies are on the brink of commercialisation. The pace of technological change is rapid.

Optical and quantum computers, which are both experiencing a surge in investment worth billions of dollars, would slash energy and heating requirements for data centres and AI.¹²¹ But these are still at a developmental stage and their commercial future is uncertain.

How strong is the case for a derogation?

Proposed derogation from the universal PFAS restriction: *PFAS used for heat transfer fluid for 2-phase immersion cooling for 13.5 years after EIF.*

As we have seen, ZutaCore and Blue Wolf Fluids appear to be on the cusp of commercial, PFAS-free alternatives for two-phase immersion and direct-to-chip cooling. Moreover, semiconductor behemoths are developing direct-to-silicon cooling as an even more efficient alternative, apparently using non-PFAS cooling fluids. The world's largest chip manufacturer is expected to bring this technology to market next year (2027).

Nevertheless, PFAS used as heat transfer fluids for 2-phase immersion cooling are set to enjoy a lengthy derogation. It appears to be unnecessary to derogate a use when there are other technologies that solve the issue.

Conclusion

Industry is facing the legacy of more than 50 years of product development built around the availability of fluoropolymers and other PFAS chemicals.

These materials have offered an unusually attractive combination of performance, versatility, and cost. PFAS chemicals often come with a safety margin in terms of performance: you can specify a PFAS-based material and be confident it will do the job under a wide range of conditions.

Industry has therefore designed products, processes, and supply chains around them. This is why PFAS are so deeply embedded in products today.

However, as this report demonstrates, there are many cases where substitution is possible and viable alternatives exist.

More than half of companies recently surveyed said they had limited or zero internal knowledge of substituting PFAS with safer chemicals.¹²² So when we hear “there is no alternative”, this often means no alternative has yet been identified, validated, or made visible to the right decision-makers.

This report demonstrates the truth of Biblical saying: “Seek and ye shall find” (Matthew 7:7-8). When you start looking, it is remarkable what is out there already. For many PFAS applications in electronics, the relevant substitution knowledge already exists. And if not, PFAS-free alternatives are being developed or close to implementation.

“For most PFAS uses in electronics, substitution is not primarily a technical problem”

The problem of over-specification is well-documented in industry. Companies choose the PFAS solution because it offers performance beyond that which is specified by the application in question. When you look closer, however, you find that alternative products can provide the necessary performance characteristics.

Substitution rarely happens by simply pulling a ready-made replacement off the shelf. The alternative does not always match PFAS on every parameter. Sometimes we have to accept a somewhat lower performance, or a higher degree of maintenance. But equally, substitution can just as easily lead to a better product.

When companies seriously engage in substitution, they often do not just replicate the old solution. They revisit what the product actually needs to do. And in many cases, that can lead not only to substitution, but to performance improvements and cost savings.

This means that, for most PFAS uses in electronics, substitution is not primarily a technical problem. It is a knowledge problem. Of course, there are cases where substitution remains highly challenging. But these are the exception rather than the rule, in electronics as in other sectors.

This report demonstrates that PFAS-free alternatives are widely available in many electronics applications. Industry needs the incentive provided by a universal PFAS restriction to take the final steps to substitution.

In these circumstances, granting lengthy PFAS holidays to legacy producers will only allow the continued build-up of PFAS in the environment and EU citizens' blood, while punishing forward-thinking companies that are investing in innovative solutions. With specific regard to semiconductor electronics, we believe the evidence presented here requires that the proposed derogations be re-assessed.

This report also shows that proposals for a partial ban on PFAS in consumer products only are deeply problematic. Semiconductors can be found in everything from mobile phones to the vast data centres that drive the AI boom. To make a distinction between consumer and industrial products and processes is artificial.

To most people, semiconductor electronics are a black box. We plug in our devices and expect them to perform. This research demonstrates they are also a Pandora's box of long-lived substances linked to a range of adverse health effects. Through the universal PFAS restriction, the EU has an opportunity to shut the lid tight. This report shows there is no reason to hesitate.

Methodology

ChemSec had prepared a list of selected proposed derogations with relevance for the electrical/electronics industry. An AI-supported investigation conducted by ChemSec suggested potential PFAS-free alternatives for these derogations to be available or foreseeable at least for certain applications in the scope of these derogations.

Fraunhofer IZM received from ChemSec this list with 10 proposed derogations and contact details of producers of potential PFAS-free substitutes for further investigation.

1. Fluoropolymers and perfluoropolyethers used for wires and cables (including connectors)
2. Fluoropolymers and perfluoropolyethers used for insulation material of electronic components (excluding wires, cables and connectors)
3. Fluoropolymers and perfluoropolyethers used as anti-drip agent in plastics of electronic components
4. Fluoropolymers and perfluoropolyethers used in sealing applications in industrial uses (not included in the report)
5. PFAS used in sound-permeable and vent filters for electrical and electronic equipment
6. PFAS used in coatings and films on displays and lenses of electronic complex objects
7. PFAS used in coatings and films of electronic components (excluding displays and lenses)
8. PFAS used in printed circuit boards and antennas
9. PFAS used as lubricants or lubricant additives for industrial and professional uses (not included in the report)
10. PFAS used as heat transfer fluids for 2-phase immersion cooling

Fraunhofer IZM investigated the technical background of these derogations via literature research including the Background Document and supported by in-house expertise, and reached out to contact persons asking for more information via a questionnaires and personal interviews. Fraunhofer IZM also searched new and additional contact persons for a second and third request for information where the first attempts had not yielded the aspired results.

The information was processed and the status of potential PFAS-free alternatives discussed with the respective stakeholders to understand the potentials and limits of PFAS-free alternatives for the applications of PFAS in the scopes of the 10 exemptions. The results are described in the report.

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- 3 <https://www.vitalpolymers.com/reference/etching-how-to-bond-ptfe/>
- 4 Rogers Corporation is a speciality materials engineering company, founded in the US in 1832, with more than 3,000 employees globally. It has manufacturing facilities in the US, Europe and Asia. Rogers holds a leading market position within its specialty area of high-frequency, low energy loss laminates and 5G/AI server materials.
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- 6 <https://www.microwavejournal.com/articles/6618-company-profile-rogers-corporation>
- 7 <https://news.pcim.mesago.com/rogers-corporation-c-270212/news/67e4412f9d550/>
- 8 <https://www.eurocircuits.com/content/uploads/2025/02/RO4000-Laminates-Data-sheet.pdf>
- 9 <https://www.eurocircuits.com/content/uploads/2025/02/RO4000-Laminates-Data-sheet.pdf>
- 10 Founded in 1912, US material science company Isola Group manufactures in the US, Europe and Asia. It has more than 1,300 employees and specialises in producing the core components of PCBs. Like Rogers Corporation, Isola is a major player in this market.
- 11 <https://www.microwavejournal.com/articles/20369-isola-introduces-very-low-loss-materials-for-advanced-automotive-safety-and-driver-assistance-systems>
- 12 <https://www.isola-group.com/news/isolas-astra-mt77-product-ptfe-performance-without-the-hassle/>
- 13 <https://test.isola-group.com/pcb-laminates-prepreg/astra-mt77-laminate-and-prepreg/>
- 14 <https://test.isola-group.com/wp-content/uploads/data-sheets/astra-mt77-laminate-and-prepreg.pdf>
- 15 ACCM is a small company in California that develops and manufactures specialist PCB materials for AI, ultra high-speed digital, and semiconductor applications.
- 16 <https://www.businesswire.com/news/home/20250124033956/en/Advanced-Chip-and-Circuit-Materials-Introduces-CeleritasSF-CeleritasBU-Products-for-Ultra-High-Speed-Buildup-and-UHDI-Printed-Circuit-Boards>
- 17 EIF = “entry into force” of the legislation.
- 18 <https://echa.europa.eu/documents/10162/ce7fec8-d080-656c-079a-7b0b2a1dcd67>
The proposed derogation also mentions antennas, but most antennas inside electronic devices are copper traces etched onto the substrate. PFAS in or on antennas themselves are covered in chapters 2, 3 and 5.

2. Insulation of components

- 19 ON Semiconductor Corporation, known as onsemi, is a global supplier of semiconductor components and modules with manufacturing facilities in Europe, the US and Asia. It has around 23,000 employees. Onsemi estimates its microchips are present in half of China's electric vehicles. <https://www.ft.com/content/72f9418e-e611-4bc5-a11b-705de5a81637?syn-25a6b1a6=1>
- 20 <https://community.onsemi.com/s/article/PFAS-Information>
- 21 <https://www.onsemi.com/search-results#q=pfas&sort=relevancy&f:@languagebysource=%5BEnglish%5D>
- 22 Knowles Corporation is a US-based multinational manufacturer of high-performance semiconductor devices and components with more than 5,000 employees, manufacturing in the US, Europe and Asia. Knowles focuses on products for high performance in harsh environments.
- 23 <https://info.knowlescapacitors.com/hubfs/PD-BPQUL-F29%20PFAS%20Compliance%20Statement-2.pdf>

- 24 Taiyo Yuden is a Japanese multinational manufacturer of semiconductor devices; its multilayer ceramic capacitors are its main product line. The company has more than 20,000 employees and has manufacturing units in six Asian nations.
- 25 https://www.yuden.co.jp/resource/data/sustainability/environment/green_purchase_standard_e.pdf
- 26 <https://www.tti.com/content/dam/ttiinc/products/PCN/taiyo-yuden/TaiyoYuden-PCN-UTY-PCN24-03D.pdf>
- 27 <https://www.tti.com/content/dam/ttiinc/products/PCN/taiyo-yuden/TAIYO%20YUDEN-PCN-UTY-NP25-02.pdf>
- 28 <https://echa.europa.eu/documents/10162/ce7fec8-d080-656c-079a-7b0b2a1dcd67>

■ 3. Anti-drip agents

- 29 <https://echa.europa.eu/documents/10162/ce7fec8-d080-656c-079a-7b0b2a1dcd67>
- 30 LG Chem is South Korea's largest chemical company and a major global manufacturer of advanced materials. It has more than 17,000 employees.
- 31 <https://www.lgcorp.com/media/release/27988>
- 32 https://blog.lgchem.com/en/2025/09/12_focus_on_pfas_free/
- 33 <https://www.lgcorp.com/media/release/27988>
- 34 <https://www.recyclingtoday.com/article/a-notable-achievement-for-lg-chem/>
- 35 <https://www.lgcorp.com/media/release/27988>
- 36 <https://www.fakuma-messe.de/en/Product-Innovations/14787-lg-chem-introduces-a-next-generation-flame-retardant-technology-platform/>
- 37 <https://www.lgchem.com/product-detail/lupoy>
- 38 <https://www.fakuma-messe.de/en/Product-Innovations/14787-lg-chem-introduces-a-next-generation-flame-retardant-technology-platform/>
- 39 Trinseo is a global specialty plastics manufacturer that was spun off from Dow in 2010. It has some 2,800 employees worldwide and manufactures in Europe, North America and Asia.
- 40 https://trinseo.widen.net/s/xhmmmwjcwbc/case-study_emerge-8600pr
- 41 <https://investor.trinseo.com/home/news/news-details/2024/Trinseo-Introduces-Groundbreaking-Flame-retardant-Plastic-Grades-Without-Using-PFAS-Additives-During-Manufacturing-Process/default.aspx>
- 42 Covestro is a major German multinational that produces high-tech polymers and raw plastics, employing 17,500 people across 46 production sites worldwide.
- 43 <https://solutions.covestro.com/en/highlights/articles/stories/2025/flame-retardant-nia-pfas-polycarbonates>
- 44 <https://solutions.covestro.com/en/highlights/articles/stories/2025/flame-retardant-nia-pfas-polycarbonates>
- 45 Sabic is a Saudi chemicals multinational with more than 26,000 employees.
- 46 <https://materialfinder.sabic-specialties.com/material/Inp-elcres-npexl9834>
- 47 <https://www.specialchem.com/plastics/product/sabic-lexan-elcrin-slx2373rcc>
- 48 The Mitsubishi Chemical Group is a Japanese multinational with more than 50,000 employees.
- 49 https://www.mcgc.com/english/news_release/01718.html
- 50 Marshall Group manufactures iconic amplifiers, speakers and headphones.

■ 4. Coatings and films

- 51 Nordic Semiconductor is a Norwegian company that designs microchips but outsources the physical manufacturing to specialised third-party manufacturers. With around 1,500 employees, the company is a major player within its niche of low-power wireless connectivity (such as Bluetooth, where it has 40% of the market) and the Internet of Things.
- 52 https://nrfconnectdocs.nordicsemi.com/pdf/PCN/pcn_205_v1.0.pdf
- 53 <https://www.nordicsemi.com/Nordic-news/2018/03/Volume-production-of-the-Nordic-Semiconductor-nRF52840-SoC>

- 54 Founded in 2012 in Massachusetts, USA, actnano is a startup that has developed PFAS-free specialised protective nanocoatings for printed circuit boards and electronic components. The company has venture backing from companies such as BMW and Porsche.
- 55 <https://actnano.com/pcba/>
- 56 <https://actnano.com/pcba/>
- 57 <https://actnano.com/press-release/>
- 58 P2i is a UK-based nanotechnology company with fewer than 300 employees globally. Its core technologies include plasma-applied nanocoatings created via a patented vapor deposition process that can be integrated into existing manufacturing lines.
- 59 <https://p2i.com/solutions>
- 60 <https://www.dow.com/en-us/product-technology/pt-gels-encapsulants.html>
- 61 <https://www.plasmalex.com/plasmalex-launches-plasmaguard-x-the-new-generation-of-100-pfas-free-conformal-barrier-coatings/>
- 62 Plasmalex is a French industrial group which also manufactures in Belgium.
- 63 Originally formed by DuPont and Hitachi corporations, HD Microsystems is a US-Japanese company making chemicals used in the passivation of semiconductors.
- 64 https://www.hdmicrosystems.com/hubfs/images23/pdf/Product/Experimental_HD4100GT_v1.3_2025_simplified.pdf

■ 5. Wires, cables and connectors

- 65 <https://polyfluorold.com/blog/peek-vs-polyimide-comparing-two-of-the-toughest-polymers>
- 66 https://www.qnityelectronics.com/content/dam/electronics/amer/us/en/electronics/public/documents/en/EI-10142_Kapton-Summary-of-Properties.pdf
- 67 https://www.mitsui.com/de/en/business/plastics/_jcsFiles/afieldfile/2024/12/05/TPX_1.pdf
- 68 <https://www.cablejn.com/ar/a-understanding-the-benefits-of-xlpe-cable-a-comprehensive-guide.html>
- 69 https://www.researchgate.net/publication/3340853_Dependence_of_XLPE_insulated_power_cable_wave_propagation_characteristics_on_design_parameters
- 70 <https://jehbco.com.au/from-material-properties-to-applications/>
- 71 BASF is the largest chemicals manufacture in the world.
- 72 https://plastics-rubber.basf.com/global/en/performance_polymers/products/ultrason
- 73 https://download.basf.com/p1/8a8082e487c2697d0187dac1f10a7e2f/en/PFAS_in_Ultrason%25C2%25AE
- 74 Igus is a German multinational manufacturer of high-performance plastics. It has 4,600 employees worldwide.
- 75 <https://www.igus.com/plastic-bearings/resources/iglide-pfas>
- 76 <https://www.igus.com/news/pfas-free>
- 77 Allectra is a small Anglo-German company that manufactures specialist cables and connectors.
- 78 <https://www.allectra.com/pfas-free-kapton-insulated-wire/>
- 79 Habia is a German-Swedish company with around 1,000 employees, manufacturing in Europe and China. Habia specialises in creating custom cables “for the world’s most demanding applications”.
- 80 <https://www.habia.com/en/knowledge-hub/halogen-free-cables-and-materials/>

■ 6. Coatings for displays and lenses

- 81 <https://pubmed.ncbi.nlm.nih.gov/38112659/>
- 82 Kriya Materials is a specialist Dutch chemical manufacturing company. It offers PFAS-free anti-reflective coatings that contain no fluorinated substances.
- 83 CCM is German chemical manufacturing company specialising in the development and production of advanced PFAS-free liquid glass surface coatings.
- 84 https://www.ccm-liquid-glass.com/en/download/7675_duo_glass_metal_product_sheet_ccm/
- 85 Nanize is a Norwegian materials technology company that develops patented, PFAS-free, polysilazane-based nano-coatings.

- 86 <https://nanize.com/>
- 87 Daken Chemical is a Chinese company specialising in custom synthesis and electronic chemicals. It employs over 40 researchers at its R&D centre and around 80 factory workers, serving clients in North America, Europe and Asia.
- 88 <https://www.dakenchem.com/hydrophobic-and-oleophobic-surface-modifier/>

■ 7. Vent filters

- 89 SAATI is an Italian multinational, founded in 1935, that manufactures advanced technical precision fabrics, filtering membranes, meshes and specialty chemicals. It employs 1,100 people and has manufacturing facilities in Europe, the Americas, and Asia.
- 90 <https://www.saati.com/news/making-a-material-difference/>
- 91 https://www.saati.com/media/a5ebhtxg/saativent_brochure_2026-22_09.pdf
- 92 SABEU is a German manufacturer founded in 1958 that specialises in microporous filter membranes and precision injection moulded plastic components.
- 93 <https://traketch.com/products/pfoa-pfca-pfas-free-membranes/pfas-free-membranes>
- 94 <https://www.sabeu.com/products-and-development/filter-membranes>
- 95 <https://www.sabeu.com/applications/industrial-and-automotive/acoustic-solutions>
- 96 <https://traketch.com/products/pfoa-pfca-pfas-free-membranes/pfas-free-membranes>

■ 8. Heat transfer fluids

- 97 <https://introl.com/blog/physical-infrastructure-1200w-gpus-next-gen-requirements>
- 98 <https://mgrid.org/2026/02/13/data-center-pue-plateau-liquid-cooling-19-percent-adoption/>
- 99 Not derived from audited data, of which there are none. This is ChemSec's estimate with AI assistance (Claude Sonnet 5.5), based on datacentres.com, Axis Intelligence, and other market summaries.
- 100 <https://www.idtechex.com/de/research-article/two-phase-cold-plate-cooling-will-take-off-as-early-as-2026-2027/34068>
- 101 ZutaCore is a well-established California company that provides direct-to-chip liquid cooling solutions for data centres, AI infrastructure and high-performance computing.
- 102 <https://www.datacenterdynamics.com/en/news/zutacores-two-phase-cooling-will-eliminate-pfas-in-2026/>
- 103 <https://zutacore.com/zutacore-technical-faq-two-phase-cooling-explained>
- 104 Based in California, Blue Wolf Fluids is a start-up specialising in the manufacture of PFAS-free dielectric coolants and thermal transfer liquids designed for data centres and cryptocurrency mining operations.
- 105 <https://www.bluewolffluids.com/>
- 106 <https://www.bluewolffluids.com/>
- 107 <https://datacenters.microsoft.com/wp-content/uploads/2025/09/Microfluidic-Cooling-Infographic.pdf>
- 108 <https://hyper.ai/en/stories/183fc11de10fbe0a15605da901059076>
- 109 <https://www.tomshardware.com/pc-components/liquid-cooling/microsoft-develops-breakthrough-chip-cooling-method-microfluidic-channels-can-cut-peak-temps-by-up-to-65-percent-outperform-conventional-cold-plates-by-up-to-3x>
- 110 <https://news.microsoft.com/source/features/innovation/microfluidics-liquid-cooling-ai-chips/>
- 111 <https://www.tomshardware.com/pc-components/liquid-cooling/microsoft-develops-breakthrough-chip-cooling-method-microfluidic-channels-can-cut-peak-temps-by-up-to-65-percent-outperform-conventional-cold-plates-by-up-to-3x>
- 112 <https://www.nextplatform.com/compute/2025/09/26/microsoft-and-corintis-champion-microfluidics-cooling-pioneered-by-ibm/1635362>
- 113 <https://patents.google.com/patent/US11462512/en>
- 114 TSMC manufactures more than 80% of advanced semiconductor chips used by AI giants such as Nvidia, AMD and Google.

- 115 <https://semiwiki.com/semiconductor-manufacturers/362017-breaking-the-thermal-wall-tsmc-demonstrates-direct-to-silicon-liquid-cooling-on-cowos/>
- 116 <https://semiengineering.com/novel-assembly-approaches-for-3d-device-stacks/>
- 117 <https://semiwiki.com/semiconductor-manufacturers/362017-breaking-the-thermal-wall-tsmc-demonstrates-direct-to-silicon-liquid-cooling-on-cowos/>
- 118 <https://medium.com/@yourassignmenteditor/why-your-ai-chatbot-drinks-more-water-than-your-neighborhood-and-the-breakthrough-that-could-31ceec845805>
- 119 <https://introl.com/blog/cowos-advanced-packaging-chip-architecture-data-center-2025>
- 120 <https://medium.com/@yourassignmenteditor/why-your-ai-chatbot-drinks-more-water-than-your-neighborhood-and-the-breakthrough-that-could-31ceec845805>
- 121 <https://www.ft.com/content/ae9eedd2-4530-47e4-be4b-242d0e2a6253?syn-25a6b1a6=1>
- 122 <https://chemsec.org/we-have-the-technology-phasing-out-pfas-must-become-the-profitable-option/>