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PFASs and PFAS free alternatives in the Electronics and Energy sector
A summary

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Contents

1. Introduction

Per- and polyfluoroalkyl substances (PFASs) are a group of thousands of synthetic chemicals that are used widely in the EU as well as in the rest of the world. PFASs are, or ultimately transform into, persistent substances, leading to irreversible environmental exposure and accumulation.
The authorities of five EU countries, The Netherlands, Denmark, Germany, Sweden and Norway jointly prepared a proposal for the restriction of PFASs under the Registration, evaluation, authorisation and restriction of chemicals (REACH) regulation (REACH Regulation (EC 1907/2006)) which became publicly available on the 7th of February 2023[1]. The proposal was based on available data in literature and data collected from stakeholders in a call for evidence, a targeted consultation and a second consultation. For several sectors, data was collected on, amongst others, the manufacturing, import and export, uses, types, properties, and emissions of PFASs. Also, the emissions to the environment as well as alternatives that are available on the market and socio-economic impacts were assessed.
In this summary report, data that was collected for the electronics, semiconductor, and energy sectors from literature, the call for evidence and the targeted consultation is presented. Data from the second consultation is included on alternatives and where specifically mentioned in the present report.

2. Data collection

Preparation of main report based on call for evidence, literature search and survey

In the summer of 2020, a call for evidence was launched in which stakeholders were invited to provide data. The call for evidence was followed by data collection specifically targeted at the electronics (including semiconductors) and energy sectors between March and May of 2021. Data was collected from literature, websites, databases, a survey using a questionnaire tailored to the sectors, and via in depth interviews with several stakeholders. Questions included in the survey and interview focussed on uses, tonnages, applied substances, alternatives, and socio-economic impact. Stakeholders were consulted directly or through sector organisations including:

SEMI	Global industry association representing the electronics manufacturing and design supply chain
ESIA	European semiconductor industry association
IPC	Global organisation that supports the quality and reliability of electronics manufacturing
Plastics Europe	Trade association representing plastic manufactures
Digital Europe	Representing the digital technology industry in Europe
JBCE	Japanese Business Council Europe
Hydrogen Europe	Association representing the European hydrogen and fuel cell sector

The information was used to draft a main report: Annex XV Restriction Report, PFASs in the electronics and energy industry, September 2021 (confidential).

Update of main report based on second stakeholder consultation

A first summary report, based on the main report, was drafted, and made available to stakeholders in the summer / autumn of 2021. Based on the summary report, stakeholders were

[1] *All news - ECHA (europa.eu)*

asked to clarify remaining questions on tonnages, emissions, use conditions, socio-economic information, and alternatives. The main report was updated to include data on alternatives from the second consultation.

Second summary report (this report)

This second summary report includes data for the electronics and semiconductor sectors combined, and for the energy sector separately. Data on alternatives are presented separately for the electronics, semiconductors and energy sectors (Appendix 3, Table A, B, C).
Data presented in this report may slightly differ from the data in the restriction proposal due to rounding and differences in starting points. As an example, in this report, volumes of PFASs identified as sidechain fluorinated polymers (SCFP) were grouped under polymers, whereas, for impact assessment in the restriction proposal, they were included in the group of non-polymers.

3. Results

3.1 Manufacturing, import and export

3.1.1 Electronics and semiconductor sectors – PFAS volumes and trends

Table 1 provides the estimated volumes of PFASs used in the electronics and semiconductor sectors in the EEA, based on the stakeholder information for the year 2020. The provided volumes reflect estimates based on responses of 27 out of the 30 companies active in the sectors that reacted to the 2020 call for evidence, survey, and the second consultation.

TABLE 1. Estimated PFAS volumes used in the electronics and semiconductor sectors in the EEA

PFASs	Number of PFASs	Number of companies	Volume (t/y)
Non-polymers	61	10	830 – 1 500
Fluorinated gases	12	*	140
Polymers	54	22	1 600 – 4 600
Total	127	27	2 400 – 6 200

** number of companies unknown*

The non-polymers listed by stakeholders in Table 1 consist of 79% non-ionic and 18% ionic PFASs, with 3 % not further specified. The subdivision in non-ionic and ionic is relevant for the prediction of the behaviour of the PFASs in the environment. The main non-polymer ionic PFAS used in the electronics and semiconductor sectors is perfluorobutanesulfonate (PFBS), a surfactant. The non-polymer non-ionic PFASs are mainly solvent cleaners and heat transfer fluids. Of the polymers listed by stakeholders, 90% were fluoropolymers (FP), 9% were perfluoropolyethers (PFPE), and less that 1% were sidechain fluorinated polymers. The main polymeric PFASs used in the electronics and semiconductor sectors are polytetrafluoroethylene (PTFE), perfluoroalkoxy polymer (PFA), polyvinylidene fluoride (PVDF), polyethylenetetrafluoroethylene (ETFE), and fluorinated ethylene-propylene (FEP).
Based on the SPIN database[2], Glüge et al. (2020)[3] estimated that around 4 000 tonnes of non-polymer PFASs were used in the electronics industry in Sweden, Finland, Norway, and

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[2] *SPIN is a publicly accessible database on the use of Substances in Products in the Nordic Countries. link: http://spin2000.net/*

[3] *Glüge, Juliane & Scheringer, Martin & Cousins, Ian & DeWitt, Jamie & Goldenman, Gretta & Herzke, Dorte & Lohmann, Rainer & Ng, Carla & Trier, Xenia & Wang, Zhanyun, (2020). An overview of the uses of per- and polyfluoroalkyl substances (PFAS). 10.31224/osf.io/2eqac*

Denmark between 2000 and 2017[4]. It is unclear whether this quantity includes PFAS-use in the semiconductor industry.
The SPIN database covers a period of 17 years and the four Nordic countries included in the database account for about 5.2% of the EEA by population[5]. By using the estimated tonnage per year and extrapolating to a population of 100%, it is possible to calculate an EEA quantity of 4 500 tonnes of PFASs per year on average. It is unknown if the PFAS use in the electronics industry in the Nordic countries is similar in other EEA countries.
The Urban Mine Platform indicated that a total weight of 12 500 000 tonnes of electrical and electronic equipment was placed on the EEA-market in 2020.[6] Zhang et al., (2020)[7] measured indoor dust concentrations of PFAS in urban, industrial, and e-waste dismantling areas. Using a concentration of PFASs in dust from e-waste dismantling areas of maximal 358 ng/g the following volume of PFASs can be estimated:

$$\text{Max: } 12.5*10^6 \text{ (tonnes)} * 358 \text{ ng/g} = 4\,475 \text{ tonnes PFAS}^{8}$$

This PFAS-volume is in line with the volume found by Wood (2022)[9] and Glüge et al., (2020)[3] for the electronics sector: respectively 3 500 and 4 000 tonnes PFASs.
Stakeholders did not provide specific information on volume trends of PFASs used in the sectors. However, growth in use of PFASs is expected because of their increasing application in electronics, electrical engineering, and electroactive (ferro-, pyro-, and piezoelectric) devices. Stakeholders expect sales of PFAS containing mixtures and articles in the electronics and semiconductor industry in the EEA to annually increase by more than 3% and in some cases up to 100%. However, there is no one-to-one relation between sales and the volumes or quantities of PFASs. No information was provided by stakeholders on relative market share of fluorinated electronics to the total electronics market in the EEA.

3.1.2 Energy sector – PFAS-volumes and trends

Table 2 provides the estimated volumes of PFASs used in the energy sector in the EEA based on stakeholder information for the year 2020. The provided volumes reflect estimates based on responses of 26 out of the 29 companies active in the energy sector that reacted to the 2020 call for evidence and the survey. In the second consultation, a PFAS-volume of 1 600 t/y was reported in batteries, which is also included in Table 2.

TABLE 2. Estimated PFAS volume used in the energy sector in the EEA

PFASs	Number of PFASs	Number of companies	Volume (t/y)
Polymers	20	24	2 600 – 3 000*
Non-polymers	10	5	250
Total	30	26	2 850 – 3 250

[4] *Note that the definition of PFASs used in Glüge et al. (2020) is largely consistent but not identical to the definition used in the restriction proposal (All news - ECHA (europa.eu)) This may lead to differences in tonnages of PFASs identified in the uses.*

[5] *https://countryeconomy.com/countries/groups/european-economic-area*

[6] *http://www.urbanmineplatform.eu/homepage*

[7] *Zhang Bo & Yuan He, Y., & Yingyan Huang, & Danhong Hong & Yiming Yao & Lei Wang & Wenwen Sun & Baoqin Yang, & Xiongfei Huang, & Shiming Song, & Xueyuan Bai, & Yuankai Guo , & Tao Zhang,& Hongwen Sun, (2020). Novel and legacy poly- and perfluoroalkyl substances (PFASs) in indoor dust from urban, industrial, and e-waste dismantling areas. https://doi.org/10.1016/j.envpol.2020.114461*

[8] *It should be noted that this number is probably an underestimation of the actual concentration in electronics since the concentration was measured in dust*

[9] *Wood, 2022: Fluoropolymer Product Group of PlasticsEurope. Update of market data for the socioeconomic analysis (SEA) of the European fluoropolymer industry. Final report. https://fluoropolymers.plasticseurope.org/application/files/1216/5485/3500/Fluoropolymers_Market_Data_Update_-_Final_report_-_May_2022.pdf*

including volumes in batteries reported in the second consultation

The non-polymers listed by stakeholders in Table 2 consist of 92% non-ionic and 8% ionic PFASs. Of the polymers, 96% were fluoropolymers, less than 1% were PFPE, and 3% were sidechain fluorinated polymers. According to stakeholders, the main polymeric PFASs used in the energy sector are PTFE, PFA and perfluoroalkane sulfonic acid ionomers (PFSA), which account for 65%, 14% and 5% of the total fluorinated polymer use, respectively.
The current rapid growth of population, technology, and global warming caused by fossil fuel sources has encouraged development of alternative clean energy sources. Fluoropolymers play a major role in this transition. For the energy sector, stakeholders expect an increase in annual sales of PFAS containing mixtures and articles in and outside the EEA of more than 15%, and in some cases up to 100%. However, there is no one-to-one relation between sales and the volumes or quantities of PFASs. Details on trends in the energy sector are included in Appendix 1.

3.2. Uses

3.2.1. Introduction

PFASs have multiple properties that make them valuable in several electronics and energy applications. An overview of properties is provided in Table 3.

TABLE 3. Properties of PFASs, information from stakeholders and Glüge (2020)[3]

Sector	Identified properties
Electronics	Non-reactive, stable, low surface tension, non-sticking, high purity, low dielectric constant, low off-gassing, ensuring vacuum environment, low dissipation factor, ultra-thin, resistant to oil, resistant to water, resistant to sulphur, high volume/surface resistivity, high dielectric breakdown strength, piezoelectric and pyroelectric properties, dipoles, hydrophobic, good solubility in polymers, optically clear, low loss insulation, flame resistance, thermal stability, low refractive indices, good heat conductivity, good evaporative cooling, acidic.
Semiconductor	Heat resistance, low dielectric constant, clearness, plasma resistance, high photosensitivity, ability to generate acids, low surface tension, Marangoni effect, low refractive index, acidic, non-reactive, stable, non-corrosive, temperature uniformity, generation for reactive oxygen/fluoride species, chemical resistance, high purity, anti-adhesion, insulation, barrier properties, thermal stability
Energy	Chemical/thermal resistance, ion transportation, high weatherability, high transparency, corrosion resistance, oleophobic, hydrophobic, hydrophilic, low surface tension, stable, non-reactive, acid gas scrubber, heat absorption, conductivity, capacity to dissolve gases, bipolar, resistance to acids, and highly oxidizing species, wettability, heat conductivity, high dielectric strength, low global warming potential, forms no residue, dirt repellence, high vapour barrier, high transparency, particular and chemical filtration.

PFASs are used in both electronic products and components itself to enhance their functionality as well as in the production process of those products or components.

3.2.2. Identified uses in the electronics and semiconductor sectors

Glüge et al (2020)[3] identified uses in the electronics sector. These uses were complemented with information from stakeholders, collected in the call for evidence, the survey and the second consultation.
In Table 4 and 5 an overview of identified uses and subuses of PFASs in the electronics and semiconductor sectors is provided.

TABLE 4. Identified uses of PFASs in the electronics sector

Use category Electronics	Sub-use
Wires and cables (Heating cables, coaxial cable)	Heating cables, coaxial cable
Coating of electronic components	Membranes
Electronic component(s)	Liquid crystal displays, vent filters, air filters, sound permeable membrane, printed circuit board, tactile switch components, antennas, membranes, organic light-emitting diode, optical fibres, rod lenses
Anti-drip agent	
Fire protection fluid	
Heat transfer fluids	
Sealing for electronic components	
Solvent	
Aerosol/ Solvent cleaning of electronics components	
Lubricant	
Lubricating oil	
Lubricant deposition	

TABLE 5. Identified uses of PFASs in the semiconductor sector

Use category Semiconductor manufacturing	Sub-use
Photolithography	Photoacid generators, antireflection coatings, topcoats and embedded barrier layers, surfactants, and filters
Nanoimprint Lithography	
Plasma Etch and Wafer Cleaning	
Wafer	Wet etch
Vapour deposition chamber	Cleaning
Heat Transfer Fluids	
Vacuum pump	Vacuum fluid
Thermal testing of semiconductor devices (in-line and end of line)	
Advanced semiconductor packaging	Encapsulants and thermal Interface materials, flux, temporary adhesives, hydrophobic coating/hermetic seal packages
Semiconductor manufacturing equipment & infrastructure - Enabling uses of fluoropolymer articles (polymer parts embedded within manufacturing equipment, spare parts and infrastructure, piping, tubing, gaskets etc)	
Release sheet for thermocompression bonding process of semiconductor chips	
Data centres	
Use category Semiconductor products and components	
Photoresist	Epoxy, case masking
Plastics such as polycarbonate/Acrylonitrile butadiene styrene	

Fluoroelastomers, polymers including polyimides, polyamides, polyesters, polycarbonate	
Adhesive, coating, lubricant	

3.2.3. Identified uses in the energy sector

Uses of PFASs identified by Glüge et al (2020)[3] were complemented with information from stakeholders, collected in the call for evidence, the survey and the second consultation.
In Table 6 an overview of identified uses and subuses of PFASs in the energy sector is provided.

TABLE 6. Identified uses of PFASs in the energy sector

Use category	Sub-use
Photovoltaic cells	Film/coating
Wind energy	Film/coating, cables, lubricants
Coal based power plant	Heat exchanger tubing
Nuclear power plant	Infrastructure: Gasket material
Proton-exchange membrane (PEM) fuel cells	Membrane electrode assemblies in gas diffusion layer, membrane, and microporous layer
	Sealant
PEM electrolyser/ PEM fuel cells	Sealing materials; gaskets
Lithium-ion batteries	Seals, electrode binders, separator films/coatings, electrolyte additives, thermal management pack/module
Batteries	Battery fluid
	Compounds for separator films
	Binder
Electrolysis technologies (not PEM)	Equipment: gaskets, tubes, inliner of pipes/tanks
Oil and gas application	Equipment: gaskets, tubes, inliner of pipes/tanks

3.3. Substance identity

A variety of non-polymeric, polymeric PFASs and fluorinated gases are used in the electronics, semiconductor, and energy sectors. An overview of PFASs listed by Glüge et al (2020)[3] is provided in Appendix 2.
In Table 7, a summary is provided of the number of different PFASs identified by stakeholders and in Glüge et al (2020).[3]

TABLE 7. Number of different PFASs identified by stakeholders and in Glüge et al (2020)[3]

Sector	PFASs	Non-polymers	Non-ionic	Ionic	Polymers	FP	PFPE	SCFP	Fluorinated gases	Unknown
Electronics (including semiconductor)	257	196			39				18	4
Energy	57	35			20				1	1
Total*	286	219	75	103	46	19	19	15	18	5

** Several PFASs were identified in both sector groups*

In Figure 1 and 2, the group distribution of identified PFASs in the electronics (including semiconductor) sector and energy sector are shown.

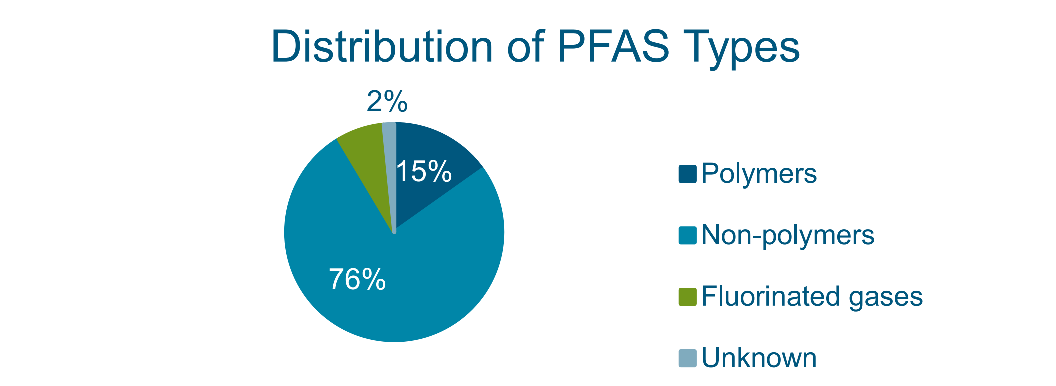

FIGURE 1. Group distribution of identified PFASs in the electronics sector (including semiconductors)

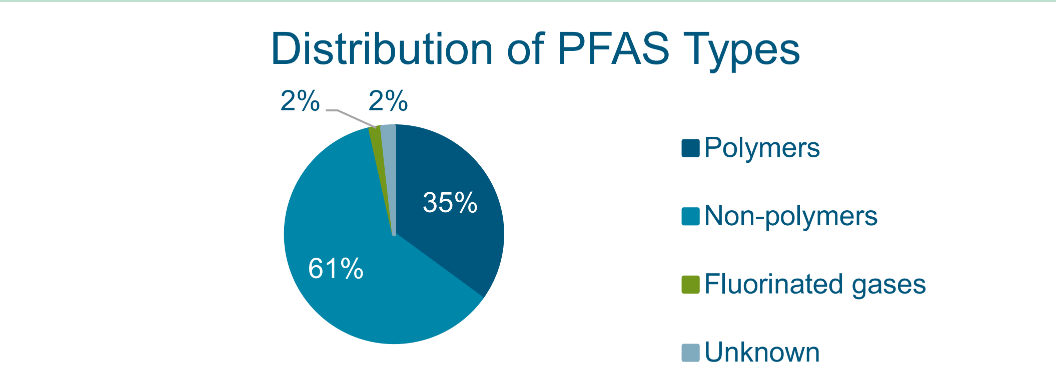

FIGURE 2. Group distribution of identified PFASs in the energy sector

The ratio of different non-polymers and polymers in the electronics (including semiconductors) sector is approximately 1:5. In the energy sector this ratio is approximately 1:3.

3.4. Emission characterisation

3.4.1. Introduction

Emissions of PFASs from the production and use in the electronics, semiconductor, and energy sectors in 2020 were estimated. For the estimation, the REACH methodology[10] was applied, using the volumes of PFASs in tables 1 and 2, default release factors from the REACH environmental release categories[11], and data from a study on emission in the electronics industry by the IPCC[12]

[10] *Guidance on information requirements and Chemical Safety Assessment / Chapter R.16: Environmental exposure assessment. Version 3.0. ECHA (2016)*

[11] *What is Environmental Release Category (ERC) and How It is Used for Environmental Risk Assessment (chemsafetypro.com)*

[12] *Electronics Industry Emissions. In: 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 3: Industrial Processes and Product Use, chapter 6. Intergovernmental Panel on Climate Change (IPCC)*

For the emission characterisation, the different groups of PFASs were slightly modified:

1. Non-polymers, including perfluoroalkyl acids (PFAA), PFAA-precursors and sidechain polymers
2. Fluorinated gases
3. Polymers, including fluorinated polymers and perfluoropolyethers

Although sidechain fluorinated polymers are chemically part of the polymer group, they are grouped under PFAA and PFAA-precursors. The justification for this is that the sidechain of the SCFP easily break off, separating the polymeric backbone from the PFAA sidechain. The SCFP has now become a non-polymer and acts as a non-polymer.

3.4.2. Emissions in the electronics (including semiconductor) and energy sectors

Emissions of PFASs were calculated for different stages in the life cycle. Because of uncertainties in the estimated volumes and many unspecified actual and patented uses the results must be considered as a first tentative estimation with considerable uncertainty because many calculation parameters are based on assumptions with limited underpinning facts. The approach can be used for further refinement when specific and more quantitative data become available. Emissions were calculated for the production and use stages of the life cycle of PFASs. In Table 8 the estimated emission from the electronics (including semiconductor) and energy sectors aggregated for the production and use phases are presented.

TABLE 8. Estimated emission in the electronics (including semiconductor) and energy sectors

Sector	Non-polymers (t/y)	Fluorinated gases (t/y)	Polymers (t/y)	Total PFASs (t/y)
Electronics (including semiconductor)	348 - 677	7	11 – 292	366 - 976
Energy	42		12 - 13	53-56

<u>Estimated growth of PFASs emissions over time in the electronics (including semiconductor) and energy sectors</u>

The growth in emissions of PFASs depends on the growth of the electronics industry (including semiconductors) and the energy sectors. This growth is not exactly known and therefore three scenarios are developed: 5%, 10 % and 20% growth per year. The scenarios provide a preliminary estimation of emissions, assuming that no mitigating measures or alternatives are introduced. The outcome further depends on the reliability of the baseline PFAS use and emission. In Figure 3 and 4 the expected growth in emissions of PFASs per year is given for the electronics (including semiconductors) and energy sectors respectively. For the electronics (including semiconductors) sector, a high estimation of 976 t/y is used as a starting point. For the energy sector, a high estimation of 56 t/y is used.

Based on the highest growth per year (20 %), emissions in 2030 will amount to 6043 tonnes (Figure 3) and 347 tonnes (Figure 4) for the electronics (including semiconductors) and the energy sector respectively.

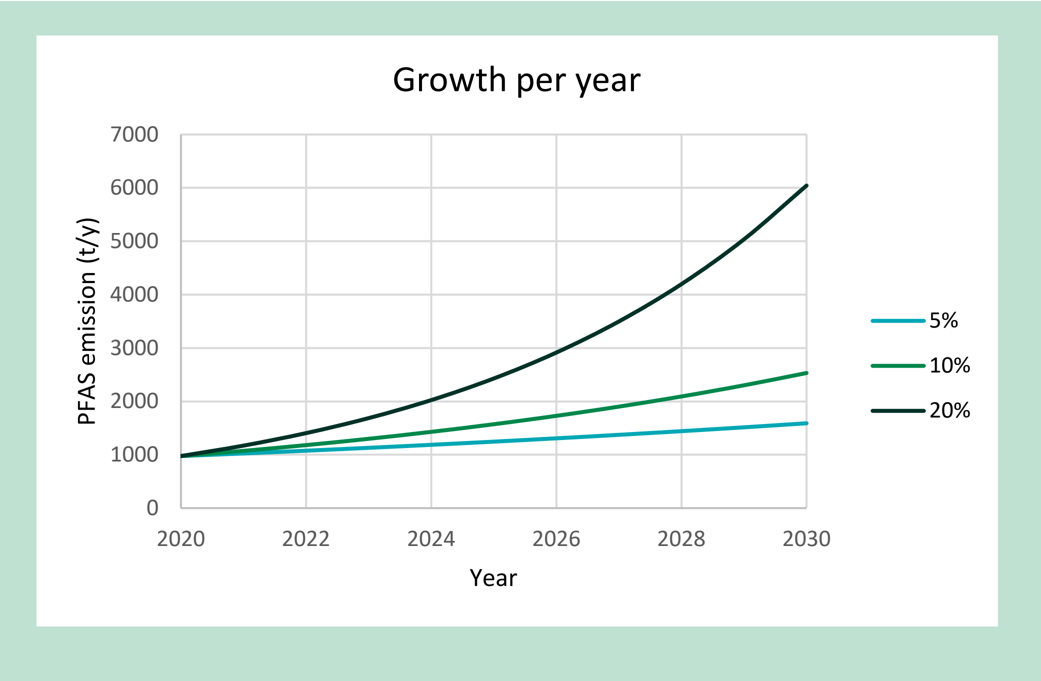

FIGURE 3. Expected growth of emissions of PFAS from the electronics sector (including semiconductors)

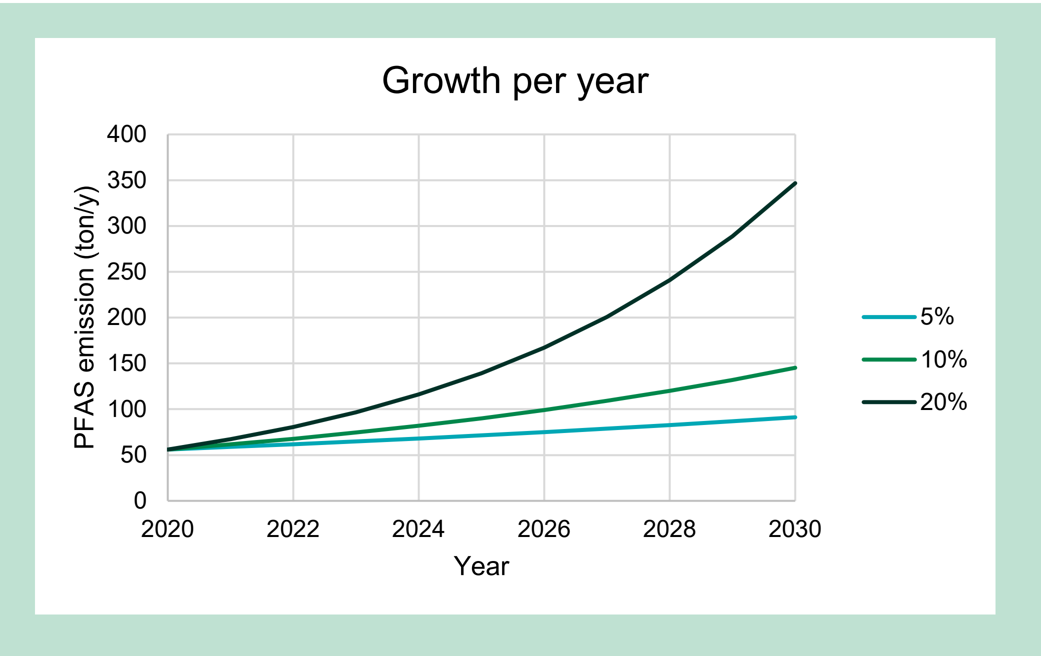

FIGURE 4. Expected growth of emissions of PFASs from the energy sector

3.5. Alternatives

3.5.1. Introduction

The alternatives listed are either commercially available, under development or currently being investigated. In general, information on non-PFAS alternatives and techniques to eliminate PFAS use remains limited. Due to patented and confidential information, the composition of certain alternatives remains unknown. If alternatives become available in due time, considerable cost and time for the transition are expected.

3.5.2. Alternatives in the electronics sector

A list of alternatives mentioned by stakeholders or in literature is included in **Table A in Appendix 3**. The industry stakeholder consensus is that PFAS alternatives are not readily available for the electronics sector.

Wires and cables

For insulation and fire protection, alternatives to PFASs include polyvinylchloride (PVC), polypropylene (PP), polyamide (PA), polyurethane (PUR), low- and high-density polyethylene (PE), nylon, chlorinated polyethylene (CPE), neoprene, and silicone. Other alternatives may not prove as efficient and will show inferior performance, for instance in heat resistance. Mica, ethylene propylene diene monomer (EPDM) and Polyether ether ketone (PEEK) are alternatives that lack flexibility and make the articles they are used in heavier and thus unsuitable for some applications such as in aviation.

Coating

For coating purposes, there are silicon and silica-based alternatives, as well as acrylic resin, epoxy, urethane resin, parallyne and nanocoatings. Silicone alternatives have some drawbacks compared to PFASs, including their stickiness, causing contamination, and blocking of transmission to sensors (e.g., in touchscreens).

Electronic components

PFASs are widely used in electronic components. Several alternatives are available but in general it is unclear if performance of the components remains the same.

Sealing and lubricants

EPDM and silicone are alternatives, but sealing is of inferior quality. Silicon-based alternatives for lubricants are said to cause interaction with the product.

Cleaning

Alcohol-based alternatives are available, but performance compared to PFASs is not clear.

Dielectric fluids and liquid impregnates

Natural and synthetic esters and oils are alternatives to PFASs, but it is unclear if performance is comparable to PFASs.

3.5.3. Alternatives in the semiconductor sector

A list of alternatives mentioned by stakeholders or in literature is included in **Table B in Appendix 3**. The industry stakeholder consensus is that PFAS alternatives are not readily available for the semiconductor sector.

Photoresist

Hydrocarbon-based greases, molybdenum disulphide, graphite are possible alternatives to prevent contamination of the surface of the photomask and to provide uniformity in coating.

Photo acid generators (PAG)

For PAG, aromatic PAG have been proposed. However, it is not clear if it is currently offered on the market.

Immersion cooling

Alternatives include mineral oils, synthetic oils, natural oils, and hydrocarbon fluids. However, their applicability is unclear.

3.5.4. Alternatives in the energy sector

A list of alternatives mentioned by stakeholders or in literature is included in **Table C in Appendix 3**. The industry stakeholder consensus is that PFAS alternatives are not readily available for the energy sector. If alternatives become available in due time, considerable cost and time for the transition are expected.

Solar panels/photovoltaic cells
Alternatives include polyolefin, polyester (PE), polyamides (PA), polyethylene terephthalate (PET), ethylene vinyl acetate and titanium-dioxide nanoparticles, although some stakeholders report inferior performance. In addition, glass and metallisation paste are alternatives in back and front panels.

Windmill blades
Alternatives include coatings based on polyaspartic ester and titanium-dioxide.

Fuel cells and batteries
For seals, hydrocarbon-based seals are an alternative whereas for membranes, hydrocarbon or sulphonated polyether ether ketone (PEEK) may be alternatives, although their durability is questioned. Electrospun polybenzimidazole-type materials are possibly an alternative to reinforce cells.

3.6. Economic impacts

Fluoropolymers play a critical role for many industries. For the scope of this summary report, it is worth to mention some descriptive statistics for the relevant industries in 2020 for the EU. The presented numbers are roughly the same for the EEA with and without the UK.[9]

- Around 40 000 tonnes of fluoropolymers are estimated to be sold in the EEA. Europe is a net exporter of fluoropolymers, with 49 000 tonnes estimated to be produced annually in the EEA, 24 000 tonnes exported outside of the EEA, and around 15 000 tonnes imported), with a relatively high R&D investment rate in fluoropolymers equal to 5.5% of total revenue.
- The electronics industry used 3 500 – 4 000 tonnes of fluoropolymers (for a value of €50 - €80 million) enabling the industry to manufacture several € billion (e.g., EU semiconductor market was valued approximately €25 billion). Fluoropolymers are used, for example, in the manufacture of semiconductors for their resistance to aggressive etching chemicals. They are also used to manufacture millions of electronics products, for enhancing, for example, the reliability and data transmission of cables.
- The renewable energy industry used 500 tonnes of fluoropolymers (for a value of around €20 million). Fluoropolymers are used in this industry for their properties (e.g., optical transparency and electrical insulation strongly reducing the failure rate).

No detailed information on impact of a PFAS restriction on the European industry is available from industry stakeholders nor literature, although one stakeholder claims:
“Impacts on semiconductor yield can be as high as millions of Euros per day, per factory.”
The industry stakeholder consensus is that PFAS alternatives are not available for the electronics (including semiconductor) and energy sectors. Main challenges that the sectors phase, are the cost ranging from €11 - 100+ million and the time needed for the transition ranging from 3 – 15+ years. Industry stakeholders.
Industry stakeholders expected a loss of competitiveness and innovation in the EEA. They highlight that competitors outside the EEA will immediately gain market share because non-EEA competitors (mostly located in Asia) can continue to use a technology (using PFASs) that would be restricted to EEA companies.
Five stakeholders, two of which are based in the EEA, reported a precise estimate of the loss in Earnings before interest, taxes (EBIT) for the electronics sector (including semiconductors):

- €150 million (not clear over which time).
- €1 400 million (over 20 years).
- €20 000 million (over 20 years).
- €50-100 million (over 20 years).
- €1 000 million (over 1 year).

After comparing EBIT losses with annual sales, EBIT sales ratios of 20% and 50% are derived for the two companies in the EEA.

Three stakeholders report some estimates of the loss in EBIT for the energy sector (these are the same stakeholders for the electronics sectors reporting the same expected EBIT losses):

- €50 -100 million (over 20 years); this company is based outside the EEA.
- €1 500 million (over 20 year); this company is based in the EEA.

No conclusions on the EBIT-sales ratio can be derived from these two replies.

3.7. Social impact

Stakeholders reported expected adverse reactions of suppliers and customers following a restriction of PFASs (e.g., redirecting demand towards outside non-EEA markets).

- Manufacturers of PFASs: The main economic impact of a PFAS ban is expected to be downstream the supply chain. The employment effects are expected to be of a larger magnitude for the electronics (including semiconductor) and energy sectors. This is more relevant for companies in these sectors that face stronger competition from producers of similar products with better performances.
- Electronics and semiconductor sectors: The FluoroCouncil report that the use of the fluoro-technology supports more than 72 000 jobs in Europe, though it is not clear how many of these jobs are directly connected to PFAS uses in car-electronics, because fluoro-technology is also used in other automotive solutions (e.g., engines, fuel systems, interiors, transmissions). The FluoroCouncil report that the industry of electronic applications supports more than 53 000 jobs in Europe. The automotive industry also uses PFAS-based electronic components. The FluoroCouncil report that the semiconductor sector involves more than 91 000 jobs in Europe.[13]
- Energy sector: The FluoroCouncil report that the industry of alternative energy applications (e.g., Li-batteries, fuel cells, photovoltaic solar panels) supports more than 2 000 jobs in Europe.[13]

Based on the available stakeholder information, no reasonable estimate can be made of the impact of a PFAS restriction on employment for downstream users.
According to one stakeholder, the impact on employment along the EEA supply chain is anticipated to be huge. An exact number of workers that might face layoff due to the restriction of PFASs without a proper transitional period, also considering the lack of alternatives, was however not provided.
The number of people along the supply chain in the EEA that will be affected. According to the other stakeholders, a PFAS restriction is expected to have impact on between 500 to several thousands of employees in the electronics sector and between 500-2500 in the semiconductor and the energy sectors.
Overall, the restriction of PFASs is likely to affect the workforce in the whole EEA.

[13] *FluoroCouncil, 2019. Societal Benefits of FluoroTechnology [Brochure]. FluoroCouncil Scientific Letter Datasheet REV4.pdf (ct.gov)*

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Footnote	References
1	ECHA publishes PFAS restriction proposal - All news - ECHA (europa.eu)
2	SPIN is a publicly accessible database on the use of Substances in Products in the Nordic Countries. link: http://spin2000.net/
3	Glüge, Juliane & Scheringer, Martin & Cousins, Ian & DeWitt, Jamie & Goldenman, Gretta & Herzke, Dorte & Lohmann, Rainer & Ng, Carla & Trier, Xenia & Wang, Zhanyun, (2020). An overview of the uses of per- and polyfluoroalkyl substances (PFAS). 10.31224/osf.io/2eqac
4	Note that the definition of PFASs used in Glüge et al. (2020) is largely consistent but not identical to the definition used *in the restriction proposal (All news - ECHA (europa.eu))* This may lead to differences in tonnages of PFASs identified in the uses.
5	https://countryeconomy.com/countries/groups/european-economic-area
6	http://www.urbanmineplatform.eu/homepage
7	Zhang Bo & Yuan He, Y., & Yingyan Huang, & Danhong Hong & Yiming Yao & Lei Wang & Wenwen Sun & Baoqin Yang, & Xiongfei Huang, & Shiming Song, & Xueyuan Bai, & Yuankai Guo , & Tao Zhang,& Hongwen Sun, (2020). Novel and legacy poly- and perfluoroalkyl substances (PFASs) in indoor dust from urban, industrial, and e-waste dismantling areas. https://doi.org/10.1016/j.envpol.2020.114461
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21	https://fuelcelltrucks.eu/project/hyundai-1-600-h2-xcient-trucks-in-switzerland/
22	Net Zero By 2050 – A Roadmap for the Global Energy Sector – page 75 https://iea.blob.core.windows.net/assets/deebef5d-0c34-4539-9d0c-10b13d840027/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf
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44	Tek Tip - Light Management & Diffusing Films Selector Guide A Guide to All Three Types of Light Management Films - Light Transmission, Light Diffusion, and Light Reflection. https://www.tekra.com/resources/tek-tip-white-paper/tek-tip-light-management-films-selector-guide
45	Moisture Barrier Bags. https://www.protectivepackaging.net/moisture-barrier-bags
46	PFAS Are The Next PCBs. https://www.engineeredfluids.com/post/are-pfas-the-next-pcbs
47	Dielectric fluids for safer, cooler, greener high performance data centres. https://www.mivolt.com/wp-content/uploads/2021/10/MIVOLT-Data-Centres-Brochure-Mar23.pdf https://www.mivolt.com/
48	GreenScreen Certified™ Products > Cleaners & Degreasers in Manufacturing - https://www.greenscreenchemicals.org/certified/products/category/cleaners-degreasers-in-manufacturing
49	3M™ Fluorinert™ Electronic Liquids. https://www.3m.com/3M/en_US/data-center-us/applications/immersion-cooling/fluorinert-electronic-liquids/
50	Envirotemp 360 fluid. https://www.cargill.com/bioindustrial/dielectric-fluids/envirotemp
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64	https://patentimages.storage.googleapis.com/85/46/dd/6561168dd0eb70/EP3588535A1.pdf
65	Information Requirements under the Essential-Use Concept: PFAS Case Studies. Juliane Glüge, Rachel London, Ian T. Cousins, Jamie DeWitt, Gretta Goldenman, Dorte Herzke, Rainer Lohmann, Mark Miller, Carla A. Ng, Sharyle Patton, Xenia Trier, Zhanyun Wang, and Martin Scheringer. Environmental Science & Technology 2022 56 (10), 6232-6242 DOI: 10.1021/acs.est.1c03732
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Glossary

ALK	Alkaline water electrolysis
CAGR	Compound Annual Growth Rate
CPE	Chlorinated polyethylene
EBIT	Earnings before interest, taxes
ECHA	European chemicals agency
EEA	European Economic Area
EPDM	Ethylene propylene diene monomer
ESIA	European semiconductor industry association
ETFE	Ethylenetetrafluoroethylene
FEP	Fluorinated ethylene-propylene
FP	Fluoropolymer
IPC	Global organisation that supports the quality and reliability of electronics manufacturing
IPCC	Intergovernmental Panel on Climate Change
JBCE	Japanese Business Council Europe
PA	Polyamide
PAG	Photo acid generators
PE	Polyethylene
PEEK	Polyether ether ketone
PEM	Proton-exchange membrane
PET	polyethylene terephthalate
PFA	Perfluoroalkoxy polymer
PFAA	Perfluoroalkyl acids
PFAS	Polyfluoroalkyl substances
PFBS	Perfluorobutanesulfonate
PFPE	Perfluoropolyethers
PFSA	perfluoroalkane sulfonic acid ionomer
PP	Polypropylene
PTFE	Polytetrafluoroethylene
PUR	Polyurethane
PVC	Polyvinylchloride
PVDF	Polyvinylidene fluoride
REACH	Registration, evaluation, authorisation and restriction of chemicals
SCFP	Sidechain fluorinated polymer
SEMI	Global industry association representing the electronics manufacturing and design supply chain
USD	United States Dollar

1. Appendix - Trends in the energy sector

Wood (2022)[9] researched trends in volumes and concluded that the fluoropolymer producers in Europe anticipate strong growth in the fluoropolymer market in the medium term (e.g., by 2025) due to the recovery from the COVID-19 pandemic which compressed the market in 2020. Growth is expected to continue in the long term (e.g., until 2050), partly driven by increasing demand in several key sectors impacted by global mega-trends such as the energy transition and digitalisation.
The current rapid growth of population, technology, and global warming caused by fossil fuel sources has encouraged development of alternative clean sources of energy. According to stakeholders, fluoropolymers play a major role in this, with the use in Solar power, Batteries, Fuel cells and more.

Solar power:
The solar power market in the EU is expected to grow significantly over the next years, and with it the use of PFASs, assuming there is no change in technology. According to a report by Solar Power Europe the growth will be higher than the targets formulated by EU member states in their National Energy and Climate Change plans. The growth is not only driven by the various EU policy initiatives in the context of the EU Green Deal but also by an ongoing cost reduction and Solar's versatility[14].

A trend from 2016 to 2021 The member states of the EU saw an increase of new solar photovoltaic (PV) capacity connected to their grids from 5 GW on 2016 to 25.9 GW in 2021 with a cumulative solar PV of 164.9 GW. It is projected that these numbers will increase to 38.5 in 2023 and 44.6 GW in 2024 with a cumulative GW of >240 GW based on EU market outlook in 2021[15].

Batteries:
Asia (China, South Korea, and Japan) remains the worldwide leader in the production of Lithium-ion batteries, with many manufacturers able to produce several GWh per year. The European production capacity is expected to grow over time[16]. In 2020, the EU share in global production of Lithium-ion batteries was 6.8% (50.44 GWh) of the total of 741.8 GWh, with an expected increase to approximately 17.6% (554.88 GWh) of a total of 3152.7 GWh in 2030[17].
In 2015 approximately 85 000 tonnes of rechargeable lithium-based batteries (lithium-ion batteries) were placed on the EEA market[18]. A stakeholder indicated that this number had increased to 150 000 tonnes in 2020 and estimated a use of 1 500 tonnes of PVDF in lithium-ion batteries in the EEA.
With 50.44 KWh generated by 150 000 lithium-ion batteries placed on the market in 2020, it can be extrapolated that generating 554.88 GWh in 2030 will require approximately 1 650 000

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[14] EU market Outlook for Solar Power, 2021 – 2025 https://api.solarpowereurope.org/uploads/EU_Market_Outlook_for_Solar_Power_2021_2025_Solar_Power_Europe_d485a0bd2c.pdf

[15] Ibid

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[17] European Battery Alliance Fostering a Strategic Value Chain (Presentation) – Numbers from Benchmark Mineral Intelligence 2020. NewsEvents_5_SLIDES_20210122_141131.pdf (project-albatts.eu)

[18] Urban Mine Platform http://www.urbanmineplatform.eu/urbanmine/batteries/weight

lithium-ion batteries. Thus, the volume of PVDF can be expected to increase from 1 500 tonnes in 2020 to 16 500 tonnes in 2030.

PEM fuel cells and water electrolysers[19]

The core of both proton exchange membrane (PEM) water electrolysers and PEM fuel cells is an electro-chemical reaction through a membrane in which certain types of fluoropolymers are used. A very large proportion of planned projects involving electrolysers and fuel cells (and in some applications 100%) are based on this PEM technology.

The total use of fluoropolymers as well as other PFASs are estimated to increase significantly in the coming years as a result of increased production of PEM fuel cells for vehicles and industry.

To produce a 60 kW PEM fuel cell, Hydrogen Europe indicates a total use of:

- 2.5 kg sealing material (typically, ETFE, PTFE, FEPM and FFKM; seal-on- Membrane electrode assemblies (MEA) assumed)
- 0.2 kg ionomer carrying sulfonic acid groups (in the ionomer membrane, reinforced with PTFE)
- 0.15 kg PTFE in the gas diffusion layer

Assuming no changes in use of PFASs, producing 1 GW would require around 44.25 tonnes of PTFE and 3.25 tonnes of ionomer.

Switzerland aims to deploy 1 600 fuel cell trucks by 2025[20] with a fuel cell capacity of 190 kW[21]. Using abovementioned numbers and estimating that a threefold increase in kW (60 kW to 190 kW) will require double the amount of PFASs, around 26.9 tonnes of PTFE and 2 tonnes of ionomer would be required. Looking at the global use, Net Zero by 2050 aims for an increase in fuel cell vehicles to 15 million by 2030.[22] Assuming a fuel cell capacity of 60 kW per vehicle, a total required capacity of 900 GW can be calculated, requiring around 39 825 tonnes of PTFE and 2 925 tonnes of ionomer.

Of the electrolysis projects to be completed by 2030 in the EU, 57% will be based on PEM fuel cell electrolysis technology, with a capacity share of 33% of total generated hydrogen. The membrane used in alkaline water electrolysis (ALK) does not contain PFAS. However, fluoropolymers are used in the product, e.g., as sealing materials and gaskets. Of the water electrolysis projects to be completed by 2030 in the EU, 35% will be based on ALK electrolysis technology, providing a capacity share of 59% of the total generated hydrogen.

Hydrogen Europe calculated that for reaching the objective of 10 million tonnes of renewable hydrogen (ca. 140 GW) in the REPowerEU plan with PEM technology alone, a maximum of 1 750 tonnes of ionomers (e.g., Nafion) is required. Additionally, this would amount require 8 750 tonnes of sealing material (primarily PTFE).[19]

In 2019 the JRC estimated a CAGR (Compound Annual Growth Rate) of 18 % within a few years[23]. General market prediction in 2023 indicate a CAGR of around or above 20% for the fuel cell market towards 2030[24].

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[19] *Hydrogen Europe Position Paper on PFAS, The importance of fluoropolymers across the hydrogen value chain, and impacts of the proposed PFAS restriction for the hydrogen sector, 01 January 2023* Hydrogen-Europe-position-paper-on-PFAS-ban_v12_FINAL.pdf (hydrogeneurope.eu)

[20] *FCHO – Chapter 1, Technology and Market, March 2022 – page 12* https://wayback.archive-it.org/12090/20230417134116/https://www.fchobservatory.eu/sites/default/files/reports/Chapter%201%20-%20Technology%20and%20Market%20-%202022%20Final%20Revised%2007.2022.pdf

[21] *https://fuelcelltrucks.eu/project/hyundai-1-600-h2-xcient-trucks-in-switzerland/*

[22] *Net Zero By 2050 – A Roadmap for the Global Energy Sector – page 75 https://iea.blob.core.windows.net/assets/deebef5d-0c34-4539-9d0c-10b13d840027/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf*

[23] JRC, 2019, page 28. Materials dependencies for dual-use technologies relevant to Europe's defence sector. https://publications.jrc.ec.europa.eu/repository/handle/JRC117729

[24] *https://www.grandviewresearch.com/industry-analysis/fuel-cell-market, https://www.marketsandmarkets.com/Market-Reports/fuel-cell-market-348.html, https://www.globenewswire.com/en/news-release/2023/05/31/2679372/0/en/Global-Fuel-Cell-Technology-Market-Size-on-a-Steady-Rise-Projected-to-Surpass-USD-26-55-Billion-by-2028-with-a-Remarkable-CAGR-of-23.html*

According to The Fuel Cell and Hydrogen Joint Undertaking (FCH JU)[25] the assessment of potential development scenarios by 2024 for the European FCH value chain and manufacturing competitiveness has estimated that the European production of all fuel cells systems combined is expected to amount between €500 million (scenario characterised by low deployment, low EU production share) and €4 200 million (scenario characterised by high deployment, high EU production share). The same estimates range between €1 500 million and €10 600 million by 2030, corresponding to a value added of €500 million and €3 500 million, respectively.[26]
A combination of high European demand and strong European production capacity, especially in the extremities of the value chain, is expected to lead to strong export performance, up to €1 000 million and €2 000 million, by 2024 and 2030, respectively[27] while in the more conservative scenario, in which the European production focuses mostly on components, the annual trade balance is expected to remain neutral.
The market for hydrogen-related machinery, equipment, and components could rise to an annual 200 billion USD by 2050.[28] Fuel cells and electrolysers offer the largest opportunities for machinery makers. Only fuel cells add up to potential revenue for machinery makers of USD 21-25 billion annually by 2050.[29]

Data centres:
Two-phase liquid immersion cooling showed promising results in the energy saving of datacentres. It is more energy-efficient, however, the potential for emissions is deemed higher[30]. In 2016 the cost of the fluids alone was found to be higher than the cost reduction because of a higher energy efficiency[31].
The data centre market is characterized by a strong market concentration with 10 major players controlling more than half (52%) of the market revenues in 2016. The rest of the market is divided among nearly 1 500 vendors[32]. According to the KPMG report for the Icelandic Data Centre industry, the EMEA area, there were 620 data centre operators in 2016. Globally, the data centre market is expected to grow by 10% in the coming years.[33] As of 2020, data centres are consuming 1-3 % of the world power, and according to research from Swedish researcher Anders Andrae, by 2025, data centres will use 20% of the world's energy[34].

Several factors are driving this growth, including the datafication and the increased needs for computational power and storage drove up by technological trends such as Internet of Things,

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[25] Fuel Cells and Hydrogen Joint undertaking. Study on Value Chain and Manufacturing Competitiveness Analysis for Hydrogen and Fuel Cells Technologies FCH contract 192 Findings Report. *https://wayback.archive it.org/12090/20220602163936/https://www.fch.europa.eu/page/FCH-value-chain - Taken from https://wayback.archive-it.org/12090/20220602163936/https://www.fch.europa.eu/page/FCH-value-chain*

[26] *Fuel Cells and Hydrogen Joint undertaking. Study on Value Chain and Manufacturing Competitiveness Analysis for Hydrogen and Fuel Cells Technologies FCH contract 192 Findings Report – page 12. https://wayback.archive-it.org/12090/20220602163936/https://www.fch.europa.eu/page/FCH-value-chain - Taken from https://wayback.archive-it.org/12090/20220602163936/https://www.fch.europa.eu/page/FCH-value-chain*

[27] *Ibid.*

[28] *BCG, 2021, p. 2. - The Green Tech Opportunity in Hydrogen, APRIL 12, 2021, By Max Ludwig, Martin Lüers, Markus Lorenz, Esben Hegnsholt, Minjee Kim, Cornelius Pieper, and Katharina Meidert.*
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[31] *Ernest Orlando Lawrence Berkeley National Laboratory 2016. Immersion Cooling of Electronics in DoD Installations. Henry Coles and Magnus Herrlin Energy Technologies Area.*
[32] *KPMG Report for DCI, 2018, p. 34. The Icelandic Data Center Industry*

[33] *KPMG Report for DCI, 2018, p. 10. The Icelandic Data Center Industry*

[34] *European data Centre, 2020, p. 4. "2020: a tipping point for the industry" https://research.euro.savills.co.uk/netherlands-pdfs/spotlight-eu-data-centre---2020.pdf*

Data & Analytics, Artificial Intelligence (AI) and – particularly – blockchain and video streaming. In 2019, data centres immersion cooling market was valued at USD 177 million, but the market is expected to grow at a CAGR of 23.2% in the reference period 2019-2024 and reach an estimated market size of USD 500 million by 2024[35].

[35] *Immersion Cooling Market by Type (Single-Phase and Two-Phase), Application (High-Performance Computing, Edge Computing, Cryptocurrency Mining), Cooling Fluid, Components (Solutions, Services), and Geography – Global Forecast to 2030.* Markets and Markets report Immersion Cooling Market, 2019

2. Appendix - list of identified PFAS

TABLE 9. Overview of PFASs (Glüge et al., 2020)[3]

CAS. No.	PFAS	Type	Chemical Name	Patented(P) Used(U) Detected(D)
115-25-3	Non-polymeric	Fluorinated gas	Perfluorocyclobutane	U
138495-42-8	Non-polymeric	Fluorinated gas	Pentane, 1,1,1,2,2,3,4,5,5,5-decafluoro-	U
163702-05-4	Non-polymeric	Fluorinated gas	Ethyl perfluorobutyl ether	U
163702-06-5	Non-polymeric	Fluorinated gas	Ethyl perfluoroisobutyl ether	U
163702-07-6	Non-polymeric	Fluorinated gas	Methyl perfluorobutyl ether	U
163702-08-7	Non-polymeric	Fluorinated gas	Methyl perfluoroisobutyl ether	U
22410-44-2	Non-polymeric	Fluorinated gas	Methyl pentafluoroethyl ether	P
2356-62-9	Non-polymeric	Fluorinated gas	1,1,1,2-Tetrafluoro-2-(trifluoromethoxy)ethane	U
354-33-6	Non-polymeric	Fluorinated gas	1H-Pentafluoroethane	U
355-25-9	Non-polymeric	Fluorinated gas	Perfluorobutane	U
355-42-0	Non-polymeric	Fluorinated gas	Perfluorohexane	U
375-03-1	Non-polymeric	Fluorinated gas	Methyl perfluoropropyl ether	U
406-78-0	Non-polymeric	Fluorinated gas	Ethane, 1,1,2,2-tetrafluoro-1-(2,2,2-trifluoroethoxy)-	U
678-26-2	Non-polymeric	Fluorinated gas	Perfluorpentane	U
692-49-9	Non-polymeric	Fluorinated gas	(Z)-1,1,1,4,4,4-Hexafluoro-2-butene	
75-73-0	Non-polymeric	Fluorinated gas	Carbon Tetrafluoride	
76-16-4	Non-polymeric	Fluorinated gas	Perfluoroethane	U
76-19-7	Non-polymeric	Fluorinated gas	Perfluoropropane	U

1064698-37-8	Non-polymeric	Ionic	Reaction mass of 1,1,2,2,3,3,4,4,4-nonafluoro-N,Nbis(nonafluorobutyl)butan-1-amine and 1,1,2,2,3,3,4,4,4-nonafluoro-N-[1,1,2,3,3-hexafluoro-2-(trifluoromethyl)propyl]-N-(1,1,2,2,3,3,4,4,4-nonafluorobutyl)butan-1-amine	
1093615-61-2	Non-polymeric	Ionic	Reaction mass of 2,2,3,3,5,5,6,6-heptafluoropropan-2-yl)morpholine and 2,2,3,3,5,5,6,6-octafluoro-4-(heptafluoropropyl)morpholine	
1107-00-2	Non-polymeric	Ionic	4,4'-(Perfluoro (propaneisopropylidene) diphthalic anhydride	
1186620-71-2	Non-polymeric	Ionic	Diphenyl(p-tolyl)sulfonium 2-[(1-adamantylcarbonyl)oxy]-1,1-difluoroethane-1-sulfonate	
1311401-25-8	Non-polymeric	Ionic	2-(2,2,3,3-Tetrafluoro-1-oxopropoxy)-1-[(2,2,3,3- tetrafluoro-1-oxopropoxy)methyl]ethyl 2-methyl-2- propenoate	
133710-62-0	Non-polymeric	Ionic	5-Norbornene-2,3-dicarboximidyltrifluoromethanesulfonate	
1414956-62-9	Non-polymeric	Ionic	n.a	
144317-44-2	Non-polymeric	Ionic	Triphenylsulfonium perfluoro-1-butanesufonate	
153968-00-4	Non-polymeric	Ionic	Ethanaminium, 2-[[(1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-heptadecafluorooctyl) sulfonyl]amino]-N,N,N-trimethyl-sulfate (1:1)	P
153968-01-5	Non-polymeric	Ionic	1-Propanaminium, 3-[[(1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-heptadecafluorooctyl)sulfonyl]amino]-N,N,N-trimethyl-, sulfate (1:1)	P
153968-03-7	Non-polymeric	Ionic	1-Propanaminium, N,N,N-triethyl-3-[[(1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-heptadecafluorooctyl)sulfonyl]amino]-, sulfate (1:1)	P
153968-05-9	Non-polymeric	Ionic	1-Propanaminium, 3-[[(1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-heptadecafluorooctyl) sulfonyl]methylamino]-N,N,N-trimethyl-, sulfate (1:1)	P
1546-95-8	Non-polymeric	Ionic	7H-Perfluoroheptanoic acid	P
1652-63-7	Non-polymeric	Ionic	1-Propanaminium, 3-[[(1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-heptadecafluorooctyl)sulfonyl]amino]-N,N,N-trimethyl-, iodide (1:1)	P
171417-91-7	Non-polymeric	Ionic	1-Butanesulfonic acid, 1,1,2,2,3,3,4,4,4-nonafluoro-, 1,3-dioxo-1H-benz[de]isoquinolin-2(3H)-yl ester	U
1763-23-1	Non-polymeric	Ionic	Perfluorooctane sulfonic acid (PFOS)	U
178094-76-3	Non-polymeric	Ionic	Perfluorobutane sulfonamido amine oxide	P
194999-85-4	Non-polymeric	Ionic	Bis(4-tert-butylphenyl)iodonium perfluoro-1-butanesulfonate	
19742-57-5	Non-polymeric	Ionic	Heptanoic acid, 2,2,3,3,4,4,5,5,6,7,7,7-dodecafluoro-6-(trifluoromethyl)-, ammonium salt (1:1)	P
2144-53-8	Non-polymeric	Ionic	6:2 Fluorotelomer methacrylate	P
220689-12-3	Non-polymeric	Ionic	Tetrabutylphosphonium perfluorobutane sulfonate	P
2227101-44-0	Non-polymeric	Ionic	n.a	
2252315-46-9	Non-polymeric	Ionic	n.a	
229325-98-8	Non-polymeric	Ionic	di(4-t-butyl)phenyliodonium 2-trifluoromethylbenzenesulfonate	

2412106-51-3	Non-polymeric	Ionic	Benzoic acid, 2,3,5-triiodo-, 2-[(1,1-dimethylethyl)[2-[(2,3,6-triiodobenzoyl)oxy]ethyl]amino]ethyl ester, compd. with 1,1,2,2,3,3,4,4,4-nonafluoro-1-butanesulfonamide (1:1)	P
2412106-69-3	Non-polymeric	Ionic	Benzoic acid, 2,3,6-triiodo-, (1-methyl-3-piperidinyl)methyl ester, compd. with 2,3,3,3-tetrafluoro-2-(1,1,2,2,3,3,3-heptafluoro propoxy)propanoate (1:1)	P
2412106-73-9	Non-polymeric	Ionic	Butanedioic acid, 2,2,3,3-tetrafluoro-, compd. with 2-(diethylamino)ethyl 2,3,5-triiodobenzoate (1:2)	P
259863-01-9	Non-polymeric	Ionic	5-Fluoro-2,4,6-tris(trifluoromethyl)-pyrimidine	
2706-90-3	Non-polymeric	Ionic	Perfluoropentanoic acid (PFPeA)	P
27619-97-2	Non-polymeric	Ionic	6:2 Fluorotelomer sulfonic acid (6:2 FTS)	U
2795-39-3	Non-polymeric	Ionic	Potassium perfluorooctane sulfonate	U
289042-19-9	Non-polymeric	Ionic	Potassium perfluorobutane sulfonamide	P
29420-49-3	Non-polymeric	Ionic	Potassium 1,1,2,2,3,3,4,4,4-nonafluorobutane-1-sulphonate	
2991-51-7	Non-polymeric	Ionic	Potassium N-ethyl perfluorooctane sulfonamidoacetate	U
30334-69-1	Non-polymeric	Ionic	Perfluorobutane sulfonamide	P
307531-76-6	Non-polymeric	Ionic	N-Hydroxy-5-norbornene-2,3-dicarboximide perfluoro-1-butanesulfonate	
3107-18-4	Non-polymeric	Ionic	Cyclohexanesulfonic acid, 1,2,2,3,3,4,4,5,5,6,6-undecafluoro-, potassium salt (1:1)	P
311-89-7	Non-polymeric	Ionic	Perfluorotributyl amine	U
314057-01-7	Non-polymeric	Ionic	Ammonium 6:2 fluorotelomer sulfonate	P
335-67-1	Non-polymeric	Ionic	Perfluorooctanoic acid (PFOA)	U
336-08-3	Non-polymeric	Ionic	Hexanedioic acid, 2,2,3,3,4,4,5,5-octafluoro-	P
34454-99-4	Non-polymeric	Ionic	Perfluorobutane sulfonamidoethanol	P
36913-91-4	Non-polymeric	Ionic	Perfluorobutane sulfonic anhydride	U
375-22-4	Non-polymeric	Ionic	Perfluorobutanoic acid (PFBA)	D
375-73-5	Non-polymeric	Ionic	Perfluorobutane sulfonic acid (PFBS)	U
376-34-1	Non-polymeric	Ionic	Heptanoic acid, 2,2,3,3,4,4,5,5,6,6,7,7-dodecafluoro-, ammonium salt (1:1)	P
38006-74-5	Non-polymeric	Ionic	1-Propanaminium, 3-[[(1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,9,9,9-heptadecafluoro octyl)sulfonyl]amino]-N,N,N-trimethyl-, chloride (1:1)	P
382-28-5	Non-polymeric	Ionic	Morpholine, 2,2,3,3,5,5,6,6-octafluoro-4-(trifluoromethyl)-	U

3825-26-1	Non-polymeric	Ionic	Ammonium perfluorooctanoate	P
39108-34-4	Non-polymeric	Ionic	8:2 Fluorotelomer sulfonic acid (8:2 FTS)	P
39234-86-1	Non-polymeric	Ionic	3,5-Bis(trifluoromethyl)benzenesulfonyl chloride	
39847-39-7	Non-polymeric	Ionic	Bis(1,1,2,2,3,3,4,4,4-nonafluoro-1-butanesulfonyl)imide	
40630-67-9	Non-polymeric	Ionic	N-Ethyl perfluorobutane sulfonamide	P
40630-68-0	Non-polymeric	Ionic	1-Butanesulfonamide, 1,1,2,2,3,3,4,4,4-nonafluoro-N-(2-methoxyethyl)-	P
423-92-7	Non-polymeric	Ionic	Perfluorooctane sulfonic anhydride	U
425670-97-9	Non-polymeric	Ionic	Triphenylsulfonium, 2-(trifluoromethyl)benzenesulfonate(1:1)	
484024-67-1	Non-polymeric	Ionic	Ammonium perfluorobutane sulfonamidoethanol	U
510774-77-3	Non-polymeric	Ionic	Propanoic acid, 2,3,3,3-tetrafluoro-2-[1,1,2,3,3,3-hexafluoro-2-(trifluoromethoxy)propoxy]-, ammonium salt (1:1)	P
524067-97-8	Non-polymeric	Ionic	Iodonium, bis[4-(1,1-dimethylethyl)phenyl]-, salt with 1,1,2,2,3,3,4,4,4-nonafluoro-N-[(nonafluorobutyl)sulfonyl]-1- butanesulfonamide	
577705-90-9	Non-polymeric	Ionic	benzyl(diethylamino)diphenylphosphonium 4-[1,1,1,3,3,3-hexafluoro-2-(4-hydroxyphenyl)propan-2-yl]phenolate	
606967-06-0	Non-polymeric	Ionic	1-Propanesulfonic acid, 3-[hexyl[(1,1,2,2,3,3,4,4,4-nonafluorobutyl)sulfonyl]amino]-2-hydroxy-, ammonium salt (1:1)	P
639827-02-4	Non-polymeric	Ionic	1H-Benz[de]isoquinoline-1,3(2H)-dione, 2-[[(heptadecafluorooctyl)sulfonyl]oxy]-	U
639827-04-6	Non-polymeric	Ionic	1-Butanesulfonic acid, 1,1,2,2,3,3,4,4,4-nonafluoro-, 3,6-dihydro-1,3,6-trioxo[1]benzothiopyrano[2,3-e]isoindol-2-yl ester	U
639827-06-8	Non-polymeric	Ionic	1-Butanesulfonic acid, 1,1,2,2,3,3,4,4,4-nonafluoro-, 3,6-dihydro-8-(1-methylethyl)-1,3,6-trioxo[1]benzothiopyrano[2,3-e]isoindol-2-yl ester	U
66003-78-9	Non-polymeric	Ionic	Triphenylsulfonium triflate	
68298-12-4	Non-polymeric	Ionic	N-Methyl perfluorobutane sulfonamide	P
68555-68-0	Non-polymeric	Ionic	Sodium N-ethyl perfluorobutane sulfonamidoacetate	P
688361-68-4	Non-polymeric	Ionic	Sodium potassium perfluorobutane sulfonamidoacetic acid	P
688738-73-0	Non-polymeric	Ionic	Potassium perfluorobutane sulfonamidoethanol	P
688738-74-1	Non-polymeric	Ionic	Sodium perfluorobutane sulfonamidoacetic acid	P
691358-66-4	Non-polymeric	Ionic	1-Heptanone, 1-(9H-fluoren-2-yl)-2,2,3,3,4,4,5,5,6,6,7,7-dodecafluoro-, O-[(1,1,2,2,3,3,4,4,4-nonafluorobutyl)sulfonyl]oxime	U
70225-14-8	Non-polymeric	Ionic	Diethanolammonium perfluorooctane sulfonate	U
749924-57-0	Non-polymeric	Ionic	1-Butanone, 1-(9H-fluoren-2-yl)-2,2,3,3,4,4,4-heptafluoro-, O-[(1,1,2,2,3,3,4,4,4-nonafluorobutyl)sulfonyl]oxime	U

754-91-6	Non-polymeric	Ionic	Perfluorooctane sulfonamide	D
848352-66-9	Non-polymeric	Ionic	1-Pentanone, 1-(9H-fluoren-2-yl)-2,2,3,3,4,4,5,5-octafluoro-, O-[(1,1,2,2,3,3,4,4,4-nonafluorobutyl)sulfonyl]oxime	P
85342-62-7	Non-polymeric	Ionic	N-Hydroxynaphthalimide trifluoromethanesulfonate	U
857285-80-4	Non-polymeric	Ionic	tert-Butyl 2-[4-(diphenylsulphonium)phenoxy]acetate, nonaflate salt	
864069-32-9	Non-polymeric	Ionic	Butanoic acid, 4-[[(1,1,2,2,3,3,4,4,4-nonafluorobutyl)sulfonyl]propylamino]-, potassium salt (1:1)	P
864069-33-0	Non-polymeric	Ionic	1-Butanesulfonamide, N-butyl-1,1,2,2,3,3,4,4,4-nonafluoro-	P
864069-34-1	Non-polymeric	Ionic	Hexanoic acid, 6-[[(1,1,2,2,3,3,4,4,4-nonafluorobutyl)sulfonyl]propylamino]-, potassium salt (1:1)	P
864069-35-2	Non-polymeric	Ionic	Glycine, N-[(nonafluorobutyl)sulfonyl]-N-propyl-, sodium salt (1:1)	P
864069-36-3	Non-polymeric	Ionic	Glycine, N-(2-methoxyethyl)-N-[(nonafluorobutyl)sulfonyl]-, sodium salt	P
864069-37-4	Non-polymeric	Ionic	Sodium N-methyl perfluorobutane sulfonamidoacetate	P
864069-38-5	Non-polymeric	Ionic	1-Propanesulfonic acid, 2-hydroxy-3-[methyl[(1,1,2,2,3,3,4,4,4-nonafluorobutyl)sulfonyl]amino]-, sodium salt (1:1)	P
864069-39-6	Non-polymeric	Ionic	1-Propanesulfonic acid, 3-[ethyl[(1,1,2,2,3,3,4,4,4-nonafluorobutyl)sulfonyl]amino]-2-hydroxy-, sodium salt (1:1)	P
864069-40-9	Non-polymeric	Ionic	1-Propanesulfonic acid, 2-hydroxy-3-[[(1,1,2,2,3,3,4,4,4-nonafluorobutyl)sulfonyl]propylamino]-, sodium salt (1:1)	P
864069-41-0	Non-polymeric	Ionic	1-Propanesulfonic acid, 3-[ethyl[(1,1,2,2,3,3,4,4,4-nonafluorobutyl)sulfonyl]amino]-, lithium salt (1:1)	P
864069-42-1	Non-polymeric	Ionic	1-Propanesulfonic acid, 3-[[(1,1,2,2,3,3,4,4,4-nonafluorobutyl)sulfonyl]propylamino]-, lithium salt (1:1)	P
864069-43-2	Non-polymeric	Ionic	1-Propanesulfonic acid, 3-[butyl[(1,1,2,2,3,3,4,4,4-nonafluorobutyl)sulfonyl]amino]-, lithium salt (1:1)	P
864069-44-3	Non-polymeric	Ionic	1-Propanesulfonic acid, 3-[methyl[(1,1,2,2,3,3,4,4,4-nonafluorobutyl)sulfonyl]amino]-, lithium salt (1:1)	P
864069-45-4	Non-polymeric	Ionic	Glycine, N-butyl-N-[(nonafluorobutyl)sulfonyl]-	P
864069-46-5	Non-polymeric	Ionic	Glycine, N-[(nonafluorobutyl)sulfonyl]-N-propyl-	P
864069-48-7	Non-polymeric	Ionic	1-Propanesulfonic acid, 3-[butyl[(1,1,2,2,3,3,4,4,4-nonafluorobutyl)sulfonyl]amino]-2-hydroxy-, ammonium salt (1:1)	P
864069-49-8	Non-polymeric	Ionic	1-Propanesulfonic acid, 2-hydroxy-3-[[(1,1,2,2,3,3,4,4,4-nonafluorobutyl)sulfonyl]propylamino]-, ammonium salt (1:1)	P
864069-50-1	Non-polymeric	Ionic	1-Propanesulfonic acid, 3-[(2-hydroxyethyl)[(1,1,2,2,3,3,4,4,4-nonafluorobutyl)sulfonyl]amino]-, lithium salt (1:1)	P
864069-51-2	Non-polymeric	Ionic	1-Butanesulfonic acid, 4-[(2-hydroxyethyl)[(1,1,2,2,3,3,4,4,4-nonafluorobutyl)sulfonyl]amino]-, lithium salt (1:1)	P
864069-52-3	Non-polymeric	Ionic	1-Propanaminium, N,N-dimethyl-N-[3-[[(1,1,2,2,3,3,4,4,4-nonafluorobutyl)sulfonyl]amino]propyl]-3-sulfo-, inner salt	P
864069-53-4	Non-polymeric	Ionic	Glycine, N-hexyl-N-[(nonafluorobutyl)sulfonyl]-, potas-sium salt	P

912290-04-1	Non-polymeric	Ionic	Triphenylsulfonium salt with 1-[(3-hydroxytricyclo[3.3.1.13,7]dec-1-yl)methyl] 2,2-difluoro-2-sulfoacetate (1:1)	
94817-79-5	Non-polymeric	Ionic	2-Undecanol, 3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10,11,11,11-nonadecafluoro-1-[(1-methylpropyl)amino]-	P
94817-80-8	Non-polymeric	Ionic	2-Dodecanol, 4,4,5,5,6,6,7,7,8,8,9,9,10,10,11,11,12,12,12-nonadecafluoro-1-[(1-methylpropyl)amino]-	P
94817-82-0	Non-polymeric	Ionic	1-Pentadecanamine, N,N-dibutyl-3,3,4,4,5,5,6,6,7,7,8,8,9,9, 10,10,11,11,12,12,13,13,14,14,15,15,15-heptacosafluoro-, nitrate (1:1)	P
94817-83-1	Non-polymeric	Ionic	1-Tridecanesulfonamide, 1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10,11,11, 12,12,13,13,13-heptacosafluoro-N-propyl-, hydrochlo-ride (1:1)	P
96513-97-2	Non-polymeric	Ionic	Propanoic acid, 2,3,3,3-tetrafluoro-2-(1,1,2,2,3,3,4,4,4-nonafluorobutoxy)-, ammonium salt (1:1)	P
102116-02-9	Non-polymeric	Non-ionic	9,11,11,12,14,14,15,15,16,16,16-Undecafluoro-3,3-dimethoxy-9,12-bis(trifluoromethyl)-2,7,10,13-tetraoxa-3-silahexadecane	
102488-47-1	Non-polymeric	Non-ionic	Silane, chlorodimethyl(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)-	P
1064697-81-9	Non-polymeric	Non-ionic	Reaction mass of 1,1,1,2,2,3,3,4,4,5,5,6,6,6-tetradecafluorohexane and 1,1,1,2,2,3,3,4,5,5,5-undecafluoro-4-(trifluoromethyl)pentane	
116265-66-8	Non-polymeric	Non-ionic	Perfluoroperhydrobenzyl tetralin	U
1256753-06-6	Non-polymeric	Non-ionic	trans-2-[4'-[difluoro(3,4,5-trifluorophenoxy)methyl]-2,3',5'-trifluoro[1,1'-biphenyl]-4-yl]-5-butyl-1,3-dioxane	
132182-92-4	Non-polymeric	Non-ionic	Pentane, 1,1,1,2,2,3,4,5,5,5-decafluoro-3-methoxy-4-(trifluoromethyl)-	U
133937-72-1	Non-polymeric	Non-ionic	1-(4-trans-Propyl-[1,1-bicyclohexyl]-4-trans-yl)-4-trifluormethoxybenzene	
135734-60-0	Non-polymeric	Non-ionic	1-(trans-4-Butyl[trans-1,1-bicyclohexyl]-4-yl)-4-trifluormethoxybenzene	
1431551-16-4	Non-polymeric	Non-ionic	SUBELYN series®	
15290-77-4	Non-polymeric	Non-ionic	1,1,2,2,3,3,4-heptafluorocyclopentane	
15538-93-9	Non-polymeric	Non-ionic	Silane, trichloro[3-[1,2,2,2-tetrafluoro-1-(trifluoromethyl) ethoxy]propyl]-	P
159148-08-0	Non-polymeric	Non-ionic	1-Hexene, 3,3,4,4,5,5,6,6-octafluoro-	P
173524-60-2	Non-polymeric	Non-ionic	Propanamide, 2,3,3,3-tetrafluoro-2-[1,1,2,3,3,3-hexafluoro-2-(heptafluoropropoxy)propoxy]-N-[3-(,4,6,8-tetramethylcyclotetrasiloxan-2-yl)propyl]- (9CI)	
1805-22-7	Non-polymeric	Non-ionic	Perfluoromethylcyclopentane	U
208338-50-5	Non-polymeric	Non-ionic	(trans,trans)-5-{(4-Propyl[1,1-bicyclohexyl]-4-yl)-difluormethoxy}-1,2,3-trifluorbenzene	
2252-84-8	Non-polymeric	Non-ionic	1H-Heptafluoropropane	P
2416059-53-3	Non-polymeric	Non-ionic	SUBELYN series®	

2570936-33-1	Non-poly-meric	Non-ionic	SUBELYN series®	
297730-93-9	Non-poly-meric	Non-ionic	3-Ethoxy-1,1,1,2,3,4,4,5,5,6,6,6-dodecafluoro-2-(trifluoromethyl)hexane	U
303186-20-1	Non-poly-meric	Non-ionic	4-[Difluor(3,4,5-trifluorphenoxy)methyl]-3,5-difluor-4'-propyl-1,1'-biphenyl	
303186-36-9	Non-poly-meric	Non-ionic	4-[difluoro(3,4,5-trifluorophenoxy)methyl]-2',3,5-trifluoro-4''-propyl-1,1':4',1''-terphenyl	
306-91-2	Non-poly-meric	Non-ionic	Perfluorotetradecahydrophenanthrene	U
306-92-3	Non-poly-meric	Non-ionic	Perfluoromethyldecalin	U
306-94-5	Non-poly-meric	Non-ionic	Perfluorodecalin	U
306-98-9	Non-poly-meric	Non-ionic	Perfluoro-1,2-dimethylcyclohexane	U
307-08-4	Non-poly-meric	Non-ionic	Perfluoroperhydrofluorene	U
319-82-4	Non-poly-meric	Non-ionic	1,2,3,5-Tetrafluoro-4,6-bis(trifluoromethyl)benzene	
335-27-3	Non-poly-meric	Non-ionic	Perfluoro(1,3-dimethylcyclohexane)	U
335-57-9	Non-poly-meric	Non-ionic	Perfluoroheptane	U
338-83-0	Non-poly-meric	Non-ionic	Perfluamine	
338-84-1	Non-poly-meric	Non-ionic	Perfluorotripentyl amine	P
354-97-2	Non-poly-meric	Non-ionic	Perfluoro-2-methyl-3-ethylpentane	U
355-02-2	Non-poly-meric	Non-ionic	Perfluoromethylcyclohexane	U
355-04-4	Non-poly-meric	Non-ionic	Perfluoro-2-methylpentane	U
355-27-3	Non-poly-meric	Non-ionic	Perfluoro-1,3-dimethylcyclohexane	U
374-80-1	Non-poly-meric	Non-ionic	Perfluoroindane	U
375-96-2	Non-poly-meric	Non-ionic	Perfluorononane	P
402-31-3	Non-poly-meric	Non-ionic	α,α,α,β,β,β-hexafluoro-m-xylene	
434-64-0	Non-poly-meric	Non-ionic	1,2,3,4,5-Pentafluoro-6-(trifluoromethyl)benzene	
50285-18-2	Non-poly-meric	Non-ionic	Perfluoro-2,4-dimethyl-3-ethylpentane	U
5121-76-6	Non-poly-meric	Non-ionic	2,2',3,3',4,5,5',6,6'-Nonafluoro-4'-(trifluoromethyl)-1,1'-biphenyl	
514-03-4	Non-poly-meric	Non-ionic	1-Butanamine, 1,1,2,2,3,3,4,4,4-nonafluoro-N-(1,1,2,2,3,3,4,4,4-nonafluorobutyl)-N-(trifluoromethyl)-	P

51851-37-7	Non-poly-meric	Non-ionic	Tridecafluorooctyltriethoxysilane	P
524709-77-1	Non-poly-meric	Non-ionic	2',3,5-Trifluoro-4''-(trans-4-propylcyclohexyl)-4-trifluoromethoxy-[1,1';4',1'']terphenyl	
559-40-0	Non-poly-meric	Non-ionic	Perfluorocyclopentene	P
58432-61-4	Non-poly-meric	Non-ionic	2-(2,3,5,6-Tetrafluoro-4-(trifluoromethyl)phenyl)acetonitrile	
606966-46-5	Non-poly-meric	Non-ionic	1-Butanesulfonamide, 1,1,2,2,3,3,4,4,4-nonafluoro-N-hexyl-	P
639782-56-2	Non-poly-meric	Non-ionic	9H-Fluoren-9-one, O-[(1,1,2,2,3,3,4,4,4-nonafluorobutyl)sulfonyl]ox-ime	U
64028-06-4	Non-poly-meric	Non-ionic	2,5,8,11,14-Pentaoxapentadecane, 1,1,1,3,3,4,4,6,6,7,7,9,9,10,10,12,12,13,13,15,15,15-docosafluoro-	P
647-42-7	Non-poly-meric	Non-ionic	3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctan-1-ol	
662-28-2	Non-poly-meric	Non-ionic	Perfluoroperhydrofluoranthene	U
685-63-2	Non-poly-meric	Non-ionic	C4F6 (Hexafluoro-1,3-butadiene)	
697-11-0	Non-poly-meric	Non-ionic	Perfluorocyclobutene	P
700863-48-5	Non-poly-meric	Non-ionic	Trans-2-[4'-[Difluor(3,4,5-trifluorphenoxy)methyl]-3',5'-difluor[1,1'-biphenyl]-4-yl]-5-propyl-tetrahydro-2H-pyran	
705291-24-3	Non-poly-meric	Non-ionic	Cyclotetrasiloxane, 2,4,6,8-tetramethyl-, Si-mixed 3-(2-oxiranyl-methoxy)propyl and 3-[2,3,3,3-tetrafluoro-2-[1,1,2,3,3,3-hexafluoro-2-(1,1,2,2,3,3,3-heptafluoropropoxy)propoxy]propoxy]propyl and 2-(tri-methoxysilyl)ethyl derivs.	
717825-76-8	Non-poly-meric	Non-ionic	7,7-Dibutyl-13,15,15,16,18,18,19,19,20,20,20-undecafluoro-3-methyl-13,16-bis(trifluoromethyl)-6,11,14,17-tetraoxa-7-silaicos-1-yn-3-ol	
73609-36-6	Non-poly-meric	Non-ionic	Silane, dichloromethyl(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)-	P
74612-30-9	Non-poly-meric	Non-ionic	Silane, chloro-dimethyl(3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10,10-heptade-cafluorodecyl)-	P
756-13-8	Non-poly-meric	Non-ionic	Perfluoro-2-methyl-3-pentanone	U
756819-73-5	Non-poly-meric	Non-ionic	2,4,6,8-Tetramethyl-2-(3-{2,3,3,3-tetrafluoro-2-[hexafluoro-2-(hep-tafluoropropo-xy)propoxy]propoxy}propyl)cyclotetrasiloxane	
78560-44-8	Non-poly-meric	Non-ionic	Silane, trichloro(3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10,10-heptadecafluoro-decyl)-	P
78560-45-9	Non-poly-meric	Non-ionic	Silane, trichloro(3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl)-	P
787582-75-6	Non-poly-meric	Non-ionic	2-[4'-[difluoro(3,4,5-trifluorophenoxy)methyl]-3',5'-difluoro[1,1'-biphe-nyl]-4-yl]-5-ethyltetrahydro-2H-pyran	
798556-07-7	Non-poly-meric	Non-ionic	Trans-2-{4-[difluoro(3,4,5-trifluorophenoxy)methyl]-3,5-difluorophe-nyl}-5-(trans-4-propylcyclohexyl)-1,3-dioxane	
83048-65-1	Non-poly-meric	Non-ionic	Heptadecafluorodecyltrimethoxysilane	P
85643-63-6	Non-poly-meric	Non-ionic	Poly(oxy-1,2-ethanediyl), α-(4,4,5,5,6,6,7,7,8,8,9,9,10,10,11,11,12,12,12-nonadecafluoro-2-hydroxydodecyl)-ω-methoxy-	P

85720-78-1	Non-polymeric	Non-ionic	Pentane, 1,1,1,2,3,4,5,5,5-nonafluoro-2-(trifluoromethyl)-	P
85857-16-5	Non-polymeric	Non-ionic	Tridecafluorooctyltrimethoxysilane	P
86508-42-1	Non-polymeric	Non-ionic	Perfluorotri-n-butylamine; Fluorinert™ FC-40	U
870778-34-0	Non-polymeric	Non-ionic	Pentane, 1,1,1,2,3,3-hexafluoro-4-(1,1,2,3,3,3-hexafluoropropoxy)-	P
90278-32-3	Non-polymeric	Non-ionic	trans-1-[4-(4-Propylcyclohexyl)-1-cyclohexen-1-yl]-4- (trifluoromethyl)-benzene	
914087-74-4	Non-polymeric	Non-ionic	4''-butyl-4-[difluoro(3,4,5-trifluorophenoxy)methyl]-2',3,5-trifluoro-1,1':4',1''-terphenyl	
916156-32-6	Non-polymeric	Non-ionic	4-[difluoro(3,4,5-trifluorophenoxy)methyl]-2',3,5-trifluoro-4''-pentyl-1,1':4',1''-terphenyl	
920-66-1	Non-polymeric	Non-ionic	1,1,1,3,3,3-hexafluoropropan-2-ol	
957209-18-6	Non-polymeric	Non-ionic	2,3,3,4,4-pentafluoro-5-methoxy-2,5-bis[1,2,2,2-tetrafluoro-1-(trifluoromethyl)ethyl]tetrahydrofuran	
n.a.(EC 700-755-2)	Non-polymeric	Non-ionic	Methoxytridecafluoroheptene isomers	
101182-89-2	Polymeric	FP	Poly(1,1,2,4,4,5,5,6,7,7-decafluoro-3-oxa-1,6-heptadiene)	
24937-79-9	Polymeric	FP	Poly(vinylidene fluoride)	U
25038-71-5	Polymeric	FP	Ethylene tetrafluoroethylene copolymer	U
25067-11-2	Polymeric	FP	Fluorinated ethylene propylene	U
25101-45-5	Polymeric	FP	Ethylene chlorotrifluoroethylene	
25190-89-0	Polymeric	FP	1-Propene, 1,1,2,3,3,3-hexafluoro-, polymer with 1,1-difluoroethene and tetrafluoroethene	
26425-79-6	Polymeric	FP	1,1,2,2-tetrafluoroethene;1,1,2-trifluoro-2-(trifluoromethoxy)ethene	
26655-00-5	Polymeric	FP	Perfluoroalkoxy polymer (PFA)	U
27029-05-6	Polymeric	FP	1-Propene, polymer with 1,1,2,2-tetrafluoroethene	
31784-04-0	Polymeric	FP	tetrafluoroethylene/trifluorovinyl pentafluoroethyl ether copolymer	
56357-87-0	Polymeric	FP	Tetrafluoroethene polymer with 1,1-difluoroethene and trifluoro(trifluoromethoxy)ethene	
63654-41-1	Polymeric	FP	1,1,1,2,2,3,3-heptafluoro-3-(1,2,2-trifluoroethenoxy)propane;1,1,2,3,3,3-hexafluoroprop-1-ene;1,1,2,2-tetrafluoroethene	
661476-43-3	Polymeric	FP	Butanoic acid, 2,2,3,3,4,4-hexafluoro-4-[(trifluoroethenyl)oxy]-, methyl ester, homopolymer, hydrolyzed	
68258-85-5	Polymeric	FP	Ethene;3,3,4,4,5,5,6,6,6-nonafluorohex-1-ene;1,1,2,2-tetrafluoroethene	

9002-83-9	Polymeric	FP	Polychlorotrifluoroethylene	U
9002-84-0	Polymeric	FP	Polytetrafluoroethylene (PTFE)	U
9011-17-0	Polymeric	FP	1,1-Difluoretylen-hexafluorpropenpolymer	
n.a.	Polymeric	FP	EFEP: Copolymer of ethylene, tetrafluoroethylene, and hexafluoro-propylene	
	Polymeric	FP	Ethene, 1,1,2,2-tetrafluoro-, polymer with 1,1′-oxybis[ethene]	P
105060-59-1	Polymeric	PFPE	Poly[oxy(1,1,2,2,3,3-hexafluoro-1,3-propanediyl)], α-(1,1,2,2,3,3,3-heptafluoropropyl)-ω-(1,1,2,2,2-pentafluoroethoxy)-ethyl ether	U
113114-19-5	Polymeric	PFPE	Fluorinated polymer of 2,2,3,3-tetrafluorooxetane	
1214752-87-0	Polymeric	PFPE	Borate(1-), tetrahydro-, sodium (1:1), reaction products with reduced polymd. oxidized tetrafluoroethylene, hydrolyzed, diallyl ethers, polymers with 2,4,6,8-tetramethylcyclotetrasiloxane, Si-(8,13-dioxo-4,7,12-trioxa-9-azapentadec-14-en-1-yl) derivs.	
1378309-01-3	Polymeric	PFPE	3-{2,4,6,8-Tetramethyl-4,6,8-tris[3-(trimethoxysilyl)propyl]cyclotetrasiloxan-2-yl}propyl ether of reduced fluorinated reduced polymerized oxidized 1,1,2,2-tetrafluoroethene	
1381840-48-7	Polymeric	PFPE	SIFEL2000®	
161075-02-1	Polymeric	PFPE	Ethene, 1,1,2,2-tetrafluoro-, oxidized, polymd., reduced, decarboxylated	U
215805-19-9	Polymeric	PFPE	SIFEL8000®	
264142-24-7	Polymeric	PFPE	Poly[oxy[trifluoro(trifluoromethyl)-1,2-ethanediyl]], α-[1-[[bis[3-(trimethoxysilyl)propyl]amino]carbonyl]-1,2,2,2-tetrafluoroethyl]-ω-(1,1,2,2,3,3,3-heptafluoropropoxy)-	
26684-76-8	Polymeric	PFPE	Poly[tetrafluoroethylene-co-perfluoro (alkyl vinyl ether)]	
467233-25-6	Polymeric	PFPE	Bis[3-(trimethoxysilyl)propyl] ether of hydrolyzed [reaction product of (reduced polymerized oxidized tetrafluoroethene) and sodium tetrahydroboranuide]	
60164-51-4	Polymeric	PFPE	Poly[Oxy[Trifluoro(Trifluoromethyl)-1,2-Ethanediyl]], .Alpha.-(Pentafluoroethyl)-.Omega.-[	
69991-61-3	Polymeric	PFPE	Polymerised oxidized 1,1,2,2-tetrafluoroethene	
69991-67-9	Polymeric	PFPE	1-Propene, 1,1,2,3,3,3-hexafluoro-, oxidized, polymd.	
753501-40-5	Polymeric	PFPE	Boron, trifluoro(tetrahydrofuran)-, (T-4)-, polymer with 3-methyl-3-[(2,2,3,3,3-pentafluoropropoxy)methyl]oxetane, ether with 2,2-dimethyl-1,3-propanediol (2:1)	
802935-59-7	Polymeric	PFPE	Reaction product of (polymer of 2,3,3,3-tetrafluoro-2-[1,1,2,3,3,3-hexafluoro-2-(heptafluoropropoxy)propoxy]propanoyl fluoride / 2,2,3-trifluoro-3-(trifluoromethyl)oxirane), 3-[dimethyl(vinyl)silyl]-N-methylaniline and 2,4,6,8-tetramethylcyclotetrasiloxane	
851389-08-7	Polymeric	PFPE	2-Propenoic acid, 1,1-dimethylethyl ester, polymer with 4,5-difluoro-2,2-bis(trifluoromethyl)-1,3-dioxole and tetrafluoroethene	P
852533-63-2	Polymeric	PFPE	Propanoic acid, 2,3,3,3-tetrafluoro-2-[(1,1,2-trifluoro-2-propen-1-yl)oxy]-, homopolymer	

86179-28-4	Polymeric	PFPE	Propanoic acid, 3-[1-[difluoro[(1,2,2-trifluoro ethenyl)oxy]methyl]-1,2,2,2-tetrafluoroethoxy]-2,2,3,3-tetrafluoro-, methyl ester, polymer with 4,5-difluoro-2,2-bis(trifluoromethyl)-1,3-dioxole and 1,1,2,2-tetrafluoroethene	P
910114-98-6	Polymeric	PFPE	2-Propenoic acid, 4,4,5,5,6,6,7,7,7-nonafluoro-2-hydroxyheptyl ester, polymer with 2-methyl-2-[(1-oxo-2-propen-1-yl)amino]-1-propanesulfonic acid	P
934505-67-6	Polymeric	PFPE	2-Propenoic acid, polymer with 2-ethenylnaphthalene and 4,4,5,5,6,6,7,7,8,8,9,9,10,10,11,11,11-heptadecafluoro-2-hydroxyundecyl 2-propenoate	P
1005771-59-4	Polymeric	SCFP	Si-[3-(Oxiran-2-ylmethoxy)propyl] derivative of 2,4,6,8-tetramethyl-2-(3-{2,3,3,3-tetrafluoro-2-[1,1,2,3,3,3-hexafluoro-2-(1,1,2,2,3,3,3-heptafluoropropoxy)propoxy]propoxy}propyl)cyclotetrasiloxane	
1010423-83-2	Polymeric	SCFP	Siloxanes and Silicones, Me hydrogen, [[7,9,9,10,12,12,13,13,14,14,14-undecafluoro-1,1-dimethyl-7,10-bis(trifluoromethyl)-5,8,11-trioxa-1-silatetradec-1-yl]oxy]-terminated	
1108730-36-4	Polymeric	SCFP	tert-Butyl 2-ethylperoxyhexanoate initiated polymer of alpha-methacryloyl-omega-hydroxypoly[oxy(methylethylene)] / 3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctyl acrylate	
1538576-70-3	Polymeric	SCFP	Reaction products of allyl(chloro)magnesium, (methyl esters of fluorinated reduced polymerized oxidized tetrafluoroethene) and trimethoxysilane	
1644456-24-5	Polymeric	SCFP	Magnesium, chloro-2-propen-1-yl-, reaction products with 3-bromo-1-propene, Me esters of fluorinated reduced polymd. oxidized tetrafluoroethylene and trimethoxysilane	
166242-54-2	Polymeric	SCFP	Propanoyl fluoride, 2,2'-[(1,1,2,2-tetrafluoro-1,2-ethanediyl)bis(oxy)]bis[2,3,3,3-tetrafluoro-, polymer with trifluoro(trifluoromethyl)oxirane, reaction products with 3-(ethenyldimethylsilyl)-n-methylbenzenamine	
172083-53-3	Polymeric	SCFP	2-Propenoic acid, 3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10,10-heptadecafluorodecyl ester, polymer with 2-methyl-2-[(1-oxo-2-propen-1-yl)amino]-1-propane sulfonic acid and 2,2,2-trifluoroethyl 2-propenoate	P
176894-23-8	Polymeric	SCFP	Methyl 2-methyl-2-propenoate polymer with 3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10,10-heptadecafluorodecyl 2-propenoate, methyloxirane polymer with oxirane mono-2-propenoate, α-(2-methyl-1-oxo-2-propenyl)-ω-[(2-methyl-1-oxo-2-propenyl)oxy]poly(oxy-1,2-ethanediyl	
185701-88-6	Polymeric	SCFP	Propanoyl fluoride, 2,3,3,3-tetrafluoro-2-(1,1,2,3,3,3-hexafluoro-2-(heptafluoropropoxy)propoxy)-, polymer with trifluoro(trifluoromethyl)oxirane, reaction products with 3-(ethenyldimethylsilyl)-n-methylbenzenamine;	
241148-23-2	Polymeric	SCFP	Reaction product of {polymer of 2,3,3,3-tetrafluoro-2-[1,1,2,3,3,3-hexafluoro-2-(heptafluoropropoxy)propoxy]propanoyl fluoride / 2,2,3-trifluoro-3-(trifluoromethyl)oxirane}, 3-[dimethyl(vinyl)silyl]-N-methylaniline and 3,3'-(3,3,4,4,5,5,6,6,7,7,8,8-dodecafluorodecane-1,10-diyl)bis{3-[(dimethylsilyl)oxy]-1,1,5,5-tetramethyltrisiloxane}	
910114-99-7	Polymeric	SCFP	2-Propenoic acid, 4,4,5,5,6,6,7,7,7-nonafluoro-2-hydroxyheptyl ester, polymer with 2-propene-1-sulfonic acid	P
94797-81-6	Polymeric	SCFP	Poly(oxy-1,2-ethanediyl), α-(2,2,3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10,10-nonadecafluoro-1-oxodecyl)-ω-methoxy-	P
94797-96-3	Polymeric	SCFP	Poly(oxy-1,2-ethanediyl), α-[2-(acetyloxy)-4,4,5,5,6,6,7,7,8,8,9,9,10,10,11,11,12,12,13,13,14,14,15,15,16,16,16-heptacosafluorohexadecyl]-ω-(4-nonylphenoxy)-	P

94817-10-4	Polymeric	SCFP	Poly(oxy-1,2-ethanediyl), α-(4,4,5,5,6,6,7,7,8,8,9,9,10, 10,11,11,12,12,12-nonadecafluoro-2-hydroxydodecyl)-ω-(3-hydroxypropoxy)-	P
949573-37-9	Polymeric	SCFP	1,1,1-Trifluoro-2-hydroxy-6-methyl-2-(trifluoromethyl)-heptane-4-yl methacrylate	
n.a.	Polymeric	SCFP	Methylmethacrylate-fluoroakylmethacrylate-methacrylic acid copolymer	
1233945-78-2	Polymeric	Unknown	n.a	
1375105-65-9	Polymeric	Unknown	n.a	
1446241-82-2	Polymeric	Unknown	n.a	
497061-37-7	Unknown	Unknown	n.a.	

3. Appendix - Non-PFAS alternatives

Tabel A, B & C in this appendix included information from stakeholders and publicly available information. If no reference is provided, the information is from stakeholders.

Table 10. Non-PFAS alternatives identified in the electronics sector

Use category	Function performed / sub use	Non-PFAS alternatives identified	Comments by stakeholders / Additional information
Wires and cables: Heating cables, coaxial cable	Insulation/Fire prevention	• Plastics (PVC), polyethylene (PE), polypropylene (PP), etc.) • Rubbers (neoprene, silicone, etc.)[36] [37] [38] • Polyether ether ketone (PEEK), Mica, Ethylene propylene diene monomer (EPDM) • Ceramic based • For coating: Low- and high-density PE, PVC, Polyamide (PA), nylon[39] • Polyurethane (PUR), nylon, and chlorinated polyethylene (CPE)[Fejl! Bogmærke er ikke defineret.]	PVC and silicone are considered good alternatives for wire insulation. However, their environmental impact may be significant. PVC and PE are less flexible and lack performance at extreme temperature variations. Mica and EPDM have drawbacks – heavier, lower chemical resistance, lack of insulation and flame retardance, low dielectric constant. Inferior electrical properties resulting in lower data transmission speed. PEEK performs well at high temperature, but lack of flexibility makes use in aerospace difficult. Ceramic based alternatives have an overall worse combination of properties, the main issue would be an increase in weight. Alternatives for coating have a higher dielectric constant, dielectric voltage breakdown, low DC resistance, low melting point and service temp low water absorption. PVC, PP, PA, PUR, low- and high-density PE, nylon and CPE were tested for oxidation, heat, oil, sun, ozone, abrasion, flame, nuclear

[36] *High-Temperature Wire: Silicone vs Teflon. https://www.sycor.com/blog/post/silicone-vs-teflon*

[37] *Wire Insulation Types and Purposes Explained (jemelectronics.com) https://blog.jemelectronics.com/wire-insulation-types-explained*

[38] *PVC vs Teflon Insulated Wire. https://www.electroprep.com/blog/pvc-vs-teflon-insulated-wire/*

[39] *OECD, 2022. Per- and Polyfluoroalkyl Substances and Alternatives in Coatings, Paints and Varnishes (CPVs). Series on Risk Management No.70. OECD, 2022 CPVs. https://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/per-and-polyfluoroalkyl-substances-alternatives-in-coatings-paints-varnishes.pdf*

Use category	Function performed / sub use	Non-PFAS alternatives identified	Comments by stakeholders / Additional information
			radiation, water, acid, alkali, aliphatic hydrocarbons, halogenated hydrocarbons, alcohol resistance, low temperature flexibility, electrical properties, and underground burial. Most alternatives scored well on some or all properties.Fejl! Bogmærke er ikke defineret.
	Insulation/heat resistance also in combination with specific sensors	• Rubbers (neoprene, silicone, etc.)	Rubbers have less mechanical strength and less abrasion resistance. Thicker insulation might be needed or additional mechanical support. Silicone insulation will lead to chemical deposition on the sensors, making them malfunction.
Coatings of electronic components	Coating of smart phone and screens: Dirt, scratch, smudge resistance	• Silica-based, polymethylmethacrylate powderFejl! Bogmærke er ikke defineret.	
	Coating of touchscreen displays, camera glass, mousepads, back glass	• Silicone-based	Silicone alternatives would create dysfunction in haptics - blocking transmission to sensors in touchscreens
	Coating of ICT equipment with imaging sensors	• Silicone-based	Silicone absorbs oil, is sticky, and causes cross contamination which leads to adhesion loss of other components.
	Coating of PCB	• Acrylic resin, epoxy, urethane resin, silicone resin[40]	
	Pulsed plasma nano-coating	• Epoxy, urethane, acrylic, silicone, parallyne[41] • PFAS free nano-coatings[42]	
Etching agent	Etching of piezoelectric filters	• Alternative substance(s) not available or unknown	One fluorine alternative identified: fluoroboric acid
Liquid crystal displays (LCD)	Surface protection (for displays)	• Cyano group instead of CF3	Decreased performance.
Capacitors	Dielectric films	• Various other polymers such as: PP, PE, polystyrene, polycarbonate, polyethylene naphthalate, polyphenyl sulfide, polyester imides, polyethyle-	

[40] *Types of Conformal Coating: Exploring materials for enhanced PCP protection. https://blog.matric.com/types-of-conformal-coating-pcb-protection*

[41] *Nanocoatings: The Solution to All of Our Environmental Protection Problems? 2015 NREL Photovoltaic Module Reliability Workshop. https://www.nrel.gov/pv/assets/pdfs/2015_pvmrw_133_caswell.pdf*

[42] *Ultra Thin Plasma Coating. P2i. https://www.p2i.com/solutions/*

Use category	Function performed / sub use	Non-PFAS alternatives identified	Comments by stakeholders / Additional information
		neterephthalate, polybutyleneterephthalate, polyetheretherketone, polyvinylchoride, polyimides, polyamides, polymethylmethacrylate3	
Acoustic equipment	Electrical signal; Piezoelectrical material	• Ceramic piezoelectric materials, piezoelectric crystals[43]	
Flat panel display, light management film	Electrical insulation / dust repellency	• Various other polymers such as: polyester polycarbonate[44]	
Adaptors, power supply units, wires	V0 flame retardancy plastics	• (Unspecified) brominated flame retardants, (unspecified) chlorinated flame retardants	
Electronics manufacturing equipment & infrastructure - Enabling uses of fluoropolymer articles (polymer parts embedded within manufacturing equipment, spare parts and infrastructure, piping, tubing, gaskets, seals etc.)	Packaging, air moisture resistance	• Other moisture and vapor-barrier packaging, such as mylar[45]	
Heat transfer fluids	General heat transfer, immersion cooling, evaporative cooling, brine cooling, direct contact cooling	• Various proprietary blends based on "ester chemistry" and others, and generally said to be biodegradable and often halogen free[46 47]	
Sealing for electronic components	Sealing for LCD, home appliance production equipment, sealing for reducer of industrial robot for automation, sealing	• EPDM • Silicone rubbers	Lack of heat resistance, chemical resistance, water vapour barrier and flame-retardant properties. Failure of the seal material to maintain a tight seal due to deterioration (leakage of solution from inside the component or, conversely, penetration of liquid from outside the component).

[43] *Precision Acoustics – PVdF.* https://www.acoustics.co.uk/product/pvdf/

[44] *Tek Tip - Light Management & Diffusing Films Selector Guide. A Guide to All Three Types of Light Management Films - Light Transmission, Light Diffusion, and Light Reflection.* https://www.tekra.com/resources/tek-tip-white-paper/tek-tip-light-management-films-selector-guide

[45] *Moisture Barrier Bags.* https://www.protectivepackaging.net/moisture-barrier-bags

[46] *PFAS are the next PCBs.* https://www.engineeredfluids.com/post/are-pfas-the-next-pcbs

[47] *Dielectric fluids for safer, cooler, greener high performance data centres.* https://www.mivolt.com/wp-content/uploads/2021/10/MIVOLT-Data-Centres-Brochure-Mar23.pdf
https://www.mivolt.com/

Use category	Function performed / sub use	Non-PFAS alternatives identified	Comments by stakeholders / Additional information
	for hard disk of servers		
Aerosol / Solvent cleaning of electronics components		• Products listed on GreenScreen website[48]	It is unknown if the products on the GreenScreen website are effective.
Lubricant / lubricant oil		• Silicone lubricants[Fejl! Bogmærke er ikke defineret.]	Chemical interactions between alternative and product.
Dielectric fluids	Separation of high voltage components	• Natural and synthetic esters[49] [50] [51]	
	Immersion cooling	• Mivolt[52]	No details on chemical structure nor effectiveness
Liquid impregnates	Impregnating capacitator	• Mineral oils, vegetable oils, silicone oils, biodegradable synthetic oils[53]	Not clear if PFASs are actively used in liquid impregnates.

Table 11. Non-PFAS alternatives in the semiconductor sector

Use category	Function performed / sub use	Non-PFAS alternatives identified	Comments by stakeholders / Additional information
Photo mask (optical pellicles)[54]	Transparent membrane attached to photomask surface to prevent contaminating particles falling onto the surface of the photomask.	• Hydrocarbon-based greases, molybdenum disulphide, graphite (for photolithography) [Fejl! Bogmærke er ikke defineret.] [55]	
Photoresist	Photoresist matrix, changes solubility when exposed to light	• KrF (248nm) (active ingredient not disclosed)[56] [57] • DOWTM photoresist (non-PFOS) composed of solvents, acrylic, other polymer resins,	

[48] GreenScreen Certified™ Products > Cleaners & Degreasers in Manufacturing - https://www.greenscreenchemicals.org/certified/products/category/cleaners-degreasers-in-manufacturing

[49] 3M™ Fluorinert™ Electronic Liquids. https://www.3m.com/3M/en_US/data-center-us/applications/immersion-cooling/fluorinert-electronic-liquids/

[50] Envirotemp 360 fluid. https://www.cargill.com/bioindustrial/dielectric-fluids/envirotemp

[51] The MIDEL Range, https://www.midel.com/midel-range/

[52] Dielectric fluids for safer, cooler, greener high performance data centres. https://www.mivolt.com/

[53] Gnonhoue, Olatoundji & Velazquez-Salazar, Amanda & David, Éric & Preda, Ioana. (2021). Review of Technologies and Materials Used in High-Voltage Film Capacitors. Polymers. 13. 766. 10.3390/polym13050766

[54] US Patent Application for Fluoropolymer-coated photomasks for photolithography Patent Application (Application #20030022073 issued January 30, 2003) - Justia Patents Search

[55] RIVM (2021): Report Summary Electronics and Energy for the Second Stakeholder Consultation on a Restriction for PFAS

[56] KrF (248nm) | Fujifilm [United States]. https://www.fujifilm.com/us/en/business/semiconductor-materials/photoresists/krf

[57] UNEP (2018) Draft report on the assessment of alternatives to perfluorooctane sulfonic acid, its salts and perfluorooctane sulfonyl fluoride (UNEP/POPS/POPRC.14/INF/8)

Use category	Function performed / sub use	Non-PFAS alternatives identified	Comments by stakeholders / Additional information
		cross-linking agents, stabilizers and/or surfactants Fejl! Bogmærke er ikke defineret.	
Photoacid generators (PAG)	As components of a photoresist formulation, it should be able to generate strong acids by light irradiation	• Aromatic PAG identified in patents (WO2009091704)[58] • Heteroaromatic PAG identified in patents (WO200909170259, US2011018325960) include the PAG triphenylsulfonium benzo[b]thiophene-2-sulfonic acid, 4(or 7)-nitro-ion(1-) (TPS TBNO) which is currently active and was also identified by Glodde et al.[61] • Alternatives unconfirmed in the market[62]	Patents filed/fluorine free alternatives have been proposed. However, it is not clear if it is currently offered on the market.
Antireflection coatings	Top antireflective coating for photoresist. Controls the reflectivity via the destructive interference.	• DOW™ anti-reflect (non-PFOS), composed of solvents, acrylic, other polymer resins, cross-linking agents, stabilizers and/or surfactants Fejl! Bogmærke er ikke defineret.	
Developer	Facilitates the control of the development process	• Patent US20080299487 for non-fluorinated surfactant, vaguely described[63].	
Surfactants	Uniformity in coating with minimal effect on properties provided by other critical resist/chemical ingredients	• Hydrocarbon-based greases Molybdenum disulphide • Graphite Fejl! Bogmærke er ikke defineret. Fejl! Bogmærke er ikke defineret.	The alternatives do not allow the photosensitive liquid to be applied evenly on the silicon substrate, making accurate patterning difficult and the quality of the product unattainable. To date, there is no information about the technology to use the presented alternatives as a general mass production technique.
Etching cleaning	Etch Cleaning of Silicon Wafers	• Patent EP 3 588 535 A1 details several surfactants including PFAS and non-fluor	Use would require strong acids.

[58] Li, W.; Huang, Wu-Song S. Varanasi, P. R.; Liu, S.; Popova, I. Y. Aromatic Fluorine-Free Photoacid Generators and Photoresist Compositions Containing the Same. WO2009091704, 2009

[59] Liu, S.; Varanasi, P. R. Fluorine-Free Heteroaromatic Photoacid Generators and Photoresist Compositions Containing the Same. WO2009091702, 2009

[60] Liu, S.; Varanasi, P. R. Fluorine-Free Fused Ring Heteroaromatic Photoacid Generators and Photoresist Compositions Containing the Same. US20110183259, 2011

*[61] Chemsec: Glodde, M.; Liu, S.; Varanasi, P. R. Fluorine-Free Photoacid Generators for 193-nm Lithography Based on Non-Sulfonate Organic Superacids. J. Photopolym. Sci. Technol. **2010**, 23, 173– 184, DOI: 10.2494/photopolymer.23.173*

[62] Proposed alternatives referenced in literature. Not clear whether it's actively being used: The isomers of nitrobenzenesulfonate (NBS), PAG based on acceptor-substituted thiosulfonate anions: 2-thiophenesulfonic acid, 5-chloro-4- nitro-, ion(1-) (TN), PAG based on acceptor-substituted aromatic anions: pentacyanocyclopentiadienide (CN5), methoxycarbonyl-tetracyanocyclopentadienide (CN4-C1)

[63]Perfluorooctane sulfonic acid, its salts and perfluorooctane sulfonyl fluoride – Stockholm Convention. http://chm.pops.int/Implementation/Alternatives/AlternativestoPOPs/ChemicalslistedinAnnexB/Perfluorooctanesulfonicacidandperfluorooctane/tabid/5869/Default.aspx

Use category	Function performed / sub use	Non-PFAS alternatives identified	Comments by stakeholders / Additional information
		surfactants which may be alternatives [3] [64]	
Immersion cooling of electronics in data centres - heat transfer fluids		• Mineral oils, synthetic oils, natural oils, Hydrocarbon fluids. • Patent: WO2012127342 [65]	Materials less suitable because they are less likely to be compatible with adhesives, elastomers, and thermal interface materials. Also, hydrocarbons are combustible and/or flammable. Hydrocarbon fluids with sufficiently high boiling points and flash points can be used in some single-phase applications, but they have the disadvantage of being relatively viscous (especially at low temperature) and do not evaporate readily from hardware when it is removed for service creating maintenance issues.
Plastics such as PC/ABS	Flame retardancy	• Brominated and chlorinated flame retardants	

Table 12. Non-PFAS alternatives in the energy sector

Use category	Functioned performed/ sub use	Non-PFAS alternatives identified	Stakeholder comment / Additional information
Solar collector	Solar panel Protective coating	• Polyester (PS), polyamides (PA), polyethylene terephthalate (PET), • titanium dioxide nanoparticles[Fejl! Bogmærke er ikke defineret.]	Unsure if actively used.
Photovoltaic cells	Coating, film, tape, back sheet, front sheet	• Polyolefin, PET, ethylene vinyl acetate (EVA), titanium dioxide nanoparticles	Polyolefin, PET, and EVA lack weather resistance and water vapor barrier properties., leading to defects and/or deterioration of the cell (decrease in service life).
	Back and front sheet	• Backsheet: PET, Glass, PS, PA, Metallization pastes (MP), Frontsheet: Glass, MP[Fejl! Bogmærke er ikke defineret.]	PET: fails over 10 years. PET is flexible and light weight but lacks other properties such as UV resistance. Glass: has UV resist, salt spray resist, fire safety, but is not flexible nor light weight. PS: has UV resist, is flexible and light weight. Lacks information on other properties. PA: fails over 10 years. MP: No data.[Fejl! Bogmærke er ikke defineret.]

[64] *https://patentimages.storage.googleapis.com/85/46/dd/6561168dd0eb70/EP3588535A1.pdf*

[65] *Information Requirements under the Essential-Use Concept: PFAS Case Studies. Juliane Glüge, Rachel London, Ian T. Cousins, Jamie DeWitt, Gretta Goldenman, Dorte Herzke, Rainer Lohmann, Mark Miller, Carla A. Ng, Sharyle Patton, Xenia Trier, Zhanyun Wang, and Martin Scheringer. Environmental Science & Technology 2022 56 (10), 6232-6242*
DOI: 10.1021/acs.est.1c03732

Use category	Functioned performed/ sub use	Non-PFAS alternatives identified	Stakeholder comment / Additional information
Wind energy	Coating of windmill blades	• Polyaspartic ester and titanium dioxide called Hempablade Edge 171.	Coating has exceptional rain erosion protection performance and strong UV resistance.[66] No data have been identified that compares the efficacy of Hempablade Edge 171 with fluoropolymer-based coating for wind turbine blades.
PEM fuel cells	Membrane electrode assemblies (MEA); Gas Diffusion Layer (GDL), microporous layer, gaskets, sealant.	• Fluorine free elastomers, hydrocarbon elastomers (seals), hydrocarbon membrane, sulphonated polyether ether ketone (PEEK)	Fluorine-free-elastomers: but contamination of the MEA, as well as oxidative deterioration of the material itself are issues. The elastomers could be cheaper but are not as chemically stable. They are superior with regards to gas-permeability and cost. Hydrocarbon elastomers: Lack of heat resistance, chemical resistance, water vapor barrier and flame-retardant properties. Failure of the seal material to maintain a tight seal due to deterioration (leakage of solution from inside the component or, conversely, penetration of liquid from outside the component). Lack of durability against load fluctuations during power generation. There is also the possibility of short-circuiting and ignition, which does not guarantee safety.
Membrane		• Hydrocarbon multi-block copolymer electrolyte membranes [multiblock copolymer poly(sulphonate phenylene)-b-poly(arylene ether ketone)] - under development[67] • Hydrocarbon membrane, sulphonated polyetheretherketone (PEEK), polysulfone (Under development, performance may be comparable, durability is very questionable).	Alternatives not suitable in the harsh environment of a fuel cell.[68] Usually, properties and performance of hydrocarbon membrane and sulphonated polyether ether ketone (PEEK) membrane can be reasonably good whereas the durability is often poor, as oxidation by oxygen radicals, which are inevitably generated at the cathode electrode, occurs.

[66] Hempel launches its first leading edge protection coating for wind blades. hempel-launches-its-first-leading-edge-protection-coating-for-wind-blades - Hempel

[67] *Y. Zhao, M. Yoshida, T. Oshima , S. Koizumi , M. Rikukawa , N. Szekely , A. Radulescu and D. Richter , Elucidation of the morphology of the hydrocarbon multi-block copolymer electrolyte membranes for proton exchange fuel cells, Polymer, 2016, 86 , 157 —167, in https://pubs.rsc.org/en/content/articlelanding/2019/EM/C9EM00163H*

[68] PFAS in Automotive Technologies of the Future. https://www.vda.de/vda/de/aktuelles/publikationen/publication/pfas-in-automotive-technologies-of-the-future

Use category	Functioned performed/ sub use	Non-PFAS alternatives identified	Stakeholder comment / Additional information
			It is expected that it will take ten years or more until a validated alternative material is available in volume, meaning that for at least ten years, the existing perfluorinated materials are required to be able to scale up electrolysis and fuel cell technologies and enable the fulfilment of their decarbonisation potential.
PEM electrolyser, PEM fuel cells	Gaskets, sealants	• Hydrocarbon membrane, sulphonated polyetheretherketone (PEEK), polysulfone (Under development, performance may be comparable, durability is very questionable). • Ionomers/sulfonated polymers (Lower ionic conductivity, unstable vs. chemical degradation) • Reinforcement material alternatives: electrospun polybenzimidazole-type materials • Hydrocarbon elastomers (seals)	Electrospun polybenzimidazole-type materials: commercial use is expected to begin not before five to ten years, also motivated by superior mechanical properties compared to those of PTFE. Hydrocarbon elastomers lack heat resistance, chemical resistance, water vapour barrier and flame-retardant properties. Failure of the seal material to maintain a tight seal due to deterioration (leakage of solution from inside the component or, conversely, penetration of liquid from outside the component). Chemical stability, creep resistance, sliding properties, cryogenic properties. It is not clear in which application the "reinforcement" is intended to be used, but if it is intended to be used as a core material in fuel cells. The proposed alternative cannot guarantee the stability, safety and long-term use of the reinforced object.
Li-ion batteries	Electrode binders, separator, films/coatings, electrolyte additives, thermal management pack/module	• Hydrocarbon elastomers (seals). • Solid state batteries. Lead-acid batteries	Hydrocarbon elastomers lack heat resistance, chemical resistance, water vapour barrier and flame-retardant properties. Failure of the seal material to maintain a tight seal due to deterioration (leakage of solution from inside the component or, conversely, penetration of liquid from outside the component). Other types of batteries: reduced energy efficiency, unrealistic that this option would cover expected growth of electric vehicles
Batteries	Binder for anode	• Carboxymethyl cellulose lithium, gelatin (Li-CMC), sodium alginate, xanthan gum, chitosan and derivate, agar-agar, carrageenan, guar gam, and many other polymers as PAA, PMA, PVA, AMAC, AMMA, polyimide, carboxymethyl	Possibly better performing and more environmentally friendly alternatives, but largely at research stage.

Use category	Functioned performed/ sub use	Non-PFAS alternatives identified	Stakeholder comment / Additional information
		cellulose (CMC), and styrene-butadiene rubber (SBR)[69] [70] (Research phase)	
Flow batteries	Ionomer membranes, ion exchange membranes	• Solid-state batteries (research phase)	Research phase
Other	Switch gears, high voltage DC converter valves	• Sulfur hexafluoride (SF6)	High global warming potential.

[69] *Versaci, D., Nasi, R., Zubair, U. et al. New eco-friendly low-cost binders for Li-ion anodes. J Solid State Electrochem 21, 3429–3435 (2017). https://doi.org/10.1007/s10008-017-3665-5*

[70] *Bresser, D., Buchholz, D., Moretti, A., Varzi, A., & Passerini, S. (2018). Alternative binders for sustainable electrochemical energy storage–the transition to aqueous electrode processing and bio-derived polymers. Energy & Environmental Science, 11(11), 3096-3127. https://doi.org/10.1039/C8EE00640G*

PFASs and PFAS free alternatives in the Electronics and Energy sector
Preceding the Universal PFAS restriction proposal (Annex XV report), the use of PFASs in the electronics and energy sectors was assessed and PFAS-free alternatives were identified. Additionally, data on emissions, economics and social impacts in these sectors, were evaluated and summarized.

This report contains publicly available information and information received from stakeholders.
The content may be different from the information provided in the Annex XV dossier.

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