Report summary Electronics and Energy

Contents

1. Uses / Applications 3
2. Main PFAS 4
3. Tonnage band 4
4. Import and Export 6
5. Manufacturing and Market 7
6. Number of production sites 9
7. Emissions 9
8. Alternatives 13
9. Economic impacts in case of a full PFAS ban 13
10. Other impacts in case of a full PFAS ban 14
11. Environmental and social impact 15
12. Methods used 16
13. Uncertainties 17
Appendix I: Examples of PFAS used 18

1. Uses / Applications

PFAS particularly fluoropolymers (PTFE and with a growing share of PVDF and FEP) have multiple properties that make them valuable in several electronics and energy applications. PFAS 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. PFAS (mainly fluoropolymers) in the energy sector are i.e. used in photovoltaic cells, in wind energy systems and is energy storage systems such as fuel cells and (lithium ion) batteries. PFAS could also be applied in immersion cooling applications. PFAS are used as testing fluid, heat transfer fluid, solvent, additive, carrier fluid and as photosynthesizer. PFAS are also used for cleaning, sealing, etching, quenching and rinsing.

In Table 1 and 2 the identified subuses of "electronics and semi-conductor industry" and "energy industry" are listed.

Table 1: Use categories (where PFAS are applied) in electronics and semi-conductor (incl. immersion cooling)

Use category Electronics	**Use category Semi conductor manufacturing**
Wires and cables	Photolithography
Coating of electronic components	Polyimides and polybenzoxazoles
Electronic component(s)	Nanoimprint Lithography
Anti-drip agent	Plasma Etch and Wafer Cleaning
Fire protection fluid	Wafer
Heat transfer fluids	Vapour deposition chamber
Sealing for electronic components	Heat Transfer Fluids
Solvent	Vacuum pump
Aerosol/ Solvent cleaning of electronics components	Thermal Testing of Semiconductor Devices (in-line and end of line)
Lubricant	Advanced Semiconductor Packaging
Lubricating oil	Semiconductor Manufacturing Equipment & Infrastructure - Enabling Uses of Fluoropolymer Articles (polymer parts embedded within manufacturing equipment, spare parts and infrastructure, piping, tubing, gaskets etc)
Lubricant deposition	Release sheet for thermocompression bonding process of semiconductor chips
	Data Centres - Immersion Cooling of Semiconductor Devices/Servers
	Semiconductor products and components
	Photoresist
	Plastics such as PC/ABS
	Fluoroelastomers, polymers including polyimides, polyamides, polyesters, polycarbonate
	Adhesive, coating, lubricant

Table 2. Identified uses of PFAS in the energy industry

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
PEM fuel cells	Membrane electrode assemblies (MEA,); Gas Diffusion Layer (GDL),
	Membrane electrode assemblies (MEA); membrane
	Membrane electrode assemblies (MEA); Microporous layers (MPL)
	Sealant
PEM electrolyser/ PEM fuel cells	Sealing materials; gaskets
Lithium ion batteries	Seals
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

2. Main PFAS

A variety of PFAS (non-polymer PFAS, fluoropolymers and side-chain fluorinated polymers) are used in Electronics and the Energy industry. Based on the stakeholder information around 215 non-polymer PFAS and around 100 fluorinated polymers are reported to be used in this sector. A brief non-exhausting list of PFAS used in these sectors with identified properties is presented in Appendix I. For immersion cooling specific PFAS are used (not listed in Appendix I).

3. Tonnage band

Based on the SPIN database[1], Glüge et al. (2020)[2] estimated that around 4,000 tonnes of non-polymer PFAS were used in the electronics industry in Sweden, Finland, Norway, and Denmark between 2000 and 2017[3]. It is unclear whether this quantity includes PFAS-use in the semiconductor industry. Note: PFAS volume is the tonnage of the PFAS substances, regardless of the level of fluorination.

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[4]. 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 PFAS tonnes 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.

Table 3 provides the estimated volumes of PFAS used in the electronics, semiconductor and energy industry 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 electronics industry who reacted to the 2020 call for evidence. According to information from stakeholders, the ratio non-polymers:polymers is approximately 1:3 in the electronic sector. The proportion of side-chain fluorinated polymers used in the electronics and energy industry is around 1-3% of total amount of flurorinated polymers.

Short-chain perfluorinated polymers are used in very small quantities as ingredients at low concentrations in photoresist and anti reflective coating chemical formulations in semi-conductor photolithography. Short-chain perfluorinated polymers are not becoming part of the final product (the microchip).

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

[2] 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

[3] *Note that the definition of PFAS used in Glüge et al. (2020) is largely consistent but not identical to the definition used for the present study. This may lead to differences in tonnages of PFAS identified in the uses in question. Glüge et al. (2020) focuses on polymeric PFAS with the –CF2– moiety and non-polymeric PFAS with the –CF2–CF2–moiety. This does not include non-polymeric substances that only contain a –CF3 or –CF2– moiety, with the exception of perfluoroalkylethers and per- and polyfluoroalkylether-based substances. For these two PFAS groups, substances with a –CF2OCF2– or –CF2OCFHCF2– moiety are also included.*

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

The Urban Mine Platform indicated that a total weight of 12 500 000 tonnes of electrical and electronic equipment (EEE) was placed on the EEA market in 2020.[5] Zhang et al., (2020)[6] measured indoor dust concentrations of PFAS in urban, industrial, and e-waste dismantling areas. Using a concentration of PFAS in dust from e-waste dismantling areas of maximal 358 ng/g the following volume of PFAS in EEE can be estimated:

Max: 12.5×10^6 (tonnes) * 358 ng/g = 4,475 tonnes PFAS

This PFAS volume is in line with the volumes found by Amec Foster Wheeler (2017) and Glüge et al., (2020) for the electronics sector: respectively 3,500 and 4,000 ton PFAS. But this likely is an underestimation of the actual volume since the concentration was measured in dust.

Because of the limited responses, the quantities presented in table 3 are most likely an *underestimation* of the volumes used in the EEA in both electronic and energy sectors.

The Urban Mine platform estimates a total number of battery cells placed on the EEA market in 2020 is close to 6 billion.[9] Another source reported 11 billion batteries placed on the EEA market plus Switserland in 2018, with a total weight of 239.000 tonnes of which 110,000 tonnes was recycled (Accurect, 2021). 81% was reported to be Alkaline batteries and 6% Lithium-Ion. Assuming a mid point weight percentage of 8%[7] for PFAS substances, the volume PFAS is between 10,000 and 19,000 tonnes per year of which 46% is recycled.

For immersion cooling the current EEA market is said to be 0 tonnes, but with a potential of 1,100 tonnes in 2025.

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

[6] 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

[7] https://www.researchgate.net/figure/Components-of-a-common-Lithium-ion-battery-LIB-PVDF-stands-for-Polyvinylidene-Fluoride_fig1_332575315

Table 3. Estimated PFAS tonnages used in electronics, semiconductor and energy industry and batteries in EEA

Electronics industry including semiconductor *(tonnes PFAS/a)*			
	Range	Average	Relative contribution
Non-Polymers	830-1,500	1,200	28%
Polymers	1,600-4,600	3,100	72%
Total	2,600-6,200	4,300	100%
Semiconductor *(tonnes PFAS/a)*			
Non-Polymers	80-90	85	6%
Polymers	1,300-1,400	1,400	94%
Total	1,400-1,500	1,485	100%
Energy industry *(tonnes PFAS/a)*			
Non-polymers	250	250	17%
Polymers	1,000 – 1,400	1,200	83%
Total	1,300 – 1,600	1,450	100%
Batteries *(tonnes PFAS/a)*			
Non-polymers	unknown		
Polymers	10,000 – 19,000	15,000	
Total	10,000 – 19,000	15,000	

The concentration of PFAS in PEM fuel cells (as an example) is reported to be as following:

Regarding fuel cells, the weight % of fluorinated compounds in a 60-kW fuel cell stack with a total weight of 28.5 kg, amounts to 10%. The weight is distributed as follows:

- 2.5 kg sealing material (TFE-based polymers or fluorine rubber made of fluorinated elastomers). Finding alternatives to the sealing material would have the highest impact on PFAS reduction.
- 0.2 kg ionomer membrane (PFSA ionomer reinforced with some PTFE).
- 0.15 kg PTFE in the Gas Diffusion Layer.

4. Import and Export

The main stakeholders in the electronics and semiconductor industry are primarily located in Asia. In terms of trade figures, European exports of semiconductor devices totalled USD 14.9 billion in 2019, while imports were worth USD 22.9 billion in the same year, making the European Union a net importer of semiconductor devices.[8]

For Energy Asia (China, South Korea, and Japan) remains the worldwide leader in the production of Lithium-ion batteries, with many manufacturers able to produce several (up to 100) GWh per year. The European production capacity on this front is expected to grow over time (from the Benchmark

[8] OEC, 2021. Available at: https://oec.world/en/profile/hs92/semiconductor-devices

Mineral Intelligence). It is clear also solar panels are mainly produced in Asia. No data was received on the amount of imports to Europe.

5. Manufacturing and Market

Electrical and electronic equipment (EEE):

The Urban Mine Platform indicated that a total weight of 12,500,000 tonnes of electrical and electronic equipment (EEE) was placed on the EEA market in 2020.[9]

Stakeholders did not provide specific information on a trend in volumes or quantities of PFAS used in the EEE sectors. However, growth in use of PFAS is expected because of their increasing application in electronics, electrical engineering, fuel cells and hydrogen technology, rechargeable batteries, electroactive (ferro-, pyro-, and piezoelectric) devices, backsheets for photovoltaics etcetera. In general, annual sales (%) of PFAS containing mixtures and articles in the electronics and semiconductor industry in the EEA is expected to annually increase by more than 3% and in some cases to be growing 100%. No information was provided for relative market share of fluorinated electronics to the total electronics market in the EEA.

Energy:

The current rapid growth of population, technology, and global warming caused by fossil fuel sources has encouraged development of alternative clean sources of energy. Fluoropolymers play a major role in this transition. For the energy industry the expected increase in annual sales of PFAS containing mixtures and articles in and outside the EEA is estimated to be more than 15% and in some cases to be expected up to 100%. However, there is no one-to-one relation between sales and the volumes or quantities of PFAS.

The total number of battery cells placed on the EEA market in 2020 is close to 6000,000,000.

Batteries:

For batteries Asia (China, South Korea, and Japan) remain the worldwide leader in the production of Lithium-ion batteries, with many manufacturers able to produce several (up to 100) GWh per year, the European production capacity on this front is expected to grow over time. In 2018 the EU share in global production of Lithium-ion batteries was 3% with a slight expected increase to approximately 5% for today[10]. The 2023 forecasts for Europe show a 13.9% worldwide market share in production capacity (expected worldwide production of 658 GWh)[11]. In addition, estimates for 2028 confirm the expected increase over time in production capacity of Lithium-ion batteries for Europe (the EU-27 Member States) with 18.1% worldwide market share (expected worldwide production of 1102.50 GWh)[10].

[9] http://www.urbanmineplatform.eu/homepage

[10] https://ec.europa.eu/jrc/sites/jrcsh/files/jrc114616_li-ion_batteries_two-pager_final.pdf

[11] Benchmark Mineral Intelligence, Lithium Ion Battery – Megafactory Assessment, September 2018 report

Fuel cells:

The global fuel cell market is forecasted to grow by a CAGR (Compound Annual Growth Rate) of 18 % in the next few years. In particular, the fuel cell market for the automotive industry is expected to grow by a CAGR of 9% by 2021, with increasing demand for fuel cells in material-handling vehicles, light-duty vehicles, buses and the aerospace sector".[12]

According to FCH JU (2019)[13] 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 of the fuel cells systems combined is expected to amount between €500 million (scenario A, characterised by low deployment, low EU production share) and €4 200 million (scenario C, 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.[14]

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.[15] 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.[16] 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.[17]

Immersion cooling:

Two-phase liquid immersion cooling showed promising results in the, important, energy saving of datacentres. It is more energy-efficient however, the potential for emissions is deemed higher[18]. In 2016 the cost of the fluids alone was found to be higher than the cost reduction because of a higher energy efficiency[19].

The data center market is characterized by a strong market concentration with 10 major players controlling more than half (52%) of the market revenues in 2016[20]. The rest of the market is divided among nearly 1,500 vendors. According to the KPMG report for DCI, the EMEA area, data centers operators were 620 in 2016. Globally, data center market is expected to grow by 10% in the coming

12 JRC, 2019, p. 28.

13 FCH JU, 2019

14 FCH JU, 2019, p. 15.

15 Ibid.

16 BCG, 2021, p. 2.

17 BCG, 2021, p. 5.

18 https://www.engineeredfluids.com/slic-cooling-for-electronics

19 Ernest Orlando Lawrence Berkeley National Laboratory 2016.

20 KPMG Report for DCI, 2018, p. 34.

years.[21] 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 (IoT), Data & Analytics, Artificial Intelligence (AI) and – particularly – blockchain and video streaming. In 2019, data centers immersion cooling market was valued at US$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 US$500 million by 2024[22].

Assuming that 5% of the cost for immersion cooling is related to cooling liquids and that price for PFAS cooling liquids is 75 $ / liter, and a density of 1.6 this would require 530 tonnes of PFAS cooling liquids per year. Up to 1% of this can be lost as emissions. If the EU market is 20% of the worldwide market this would mean a use of 1100 t/y and an emission for the EU of 1.1 t/y.

6. Number of production sites

Around 30 companies at EU level that are active in the electronic and energy industry reacted to the first call for evidence. Almost every company (manufactures, imported or distributor) is also a downstream user. However, there are much more companies in the EU but the exact number is not reported.

For immersion cooling 10 major players controlling more than half (52%) of the market revenues in 2016.[23]

7. Emissions

A preliminary estimation of PFAS volumes released to the environment in the reference year 2020 from Electronics and Energy industry is presented in Figure 1-4, respectively. Default release factors (ERC's) from the REACH environmental release categories have been used in the emission characterisation.[24] Product service-life emission to the environment estimates have been derived using standard REACH methodology (ECHA, 2016). This is the most up-to-date version of the guidance.

Next to this, stakeholder response to the summer 2020 Call For Evidence and dedicated stakeholder survey information has been used.

[21] KPMG Report for DCI, 2018, p. 10.

[22] Markets and Markets report Immersion Cooling Market, 2019

[23] KPMG Report for DCI, 2018, p. 34.

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

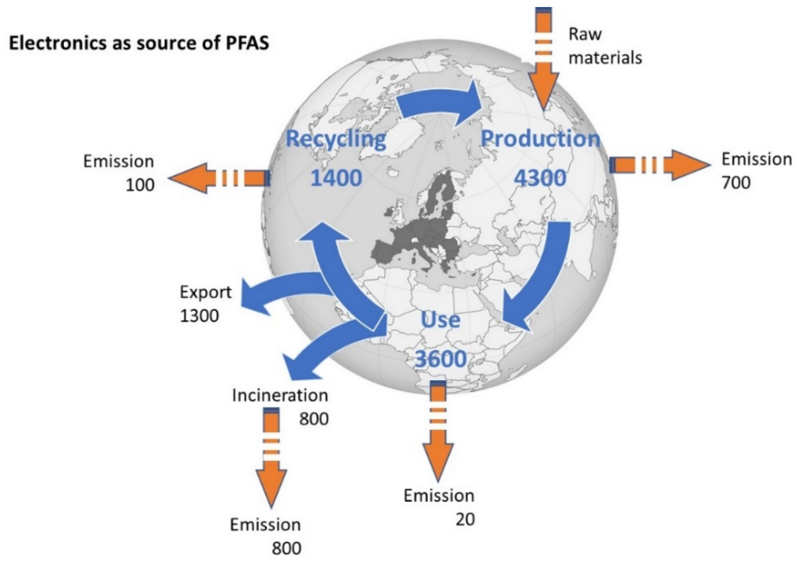

Figure 1. Summary of the estimated PFAS flow and emissions (tonnes/year) in the EEA during the life-cycle of <u>electronics industry (including semiconductors).</u> Reference year 2020. Based on response of companies on the CfE and survey and midpoint calculations with REACH emission factors.

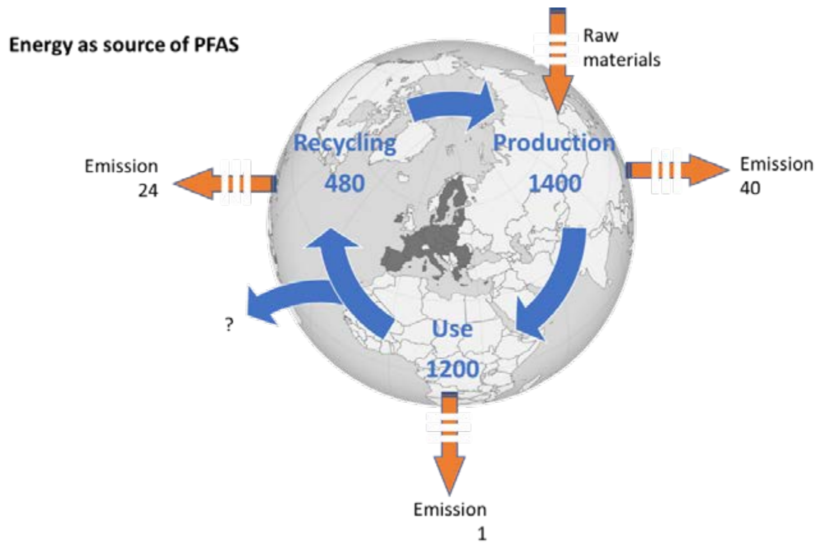

Figure 2. Summary of the estimated PFAS flow and emissions (tonnes/year) in the EEA during the life-cycle of from the <u>energy industry</u>. Reference year 2020. Based on response of companies on the CfE and survey and midpoint calculations with REACH emission factors.

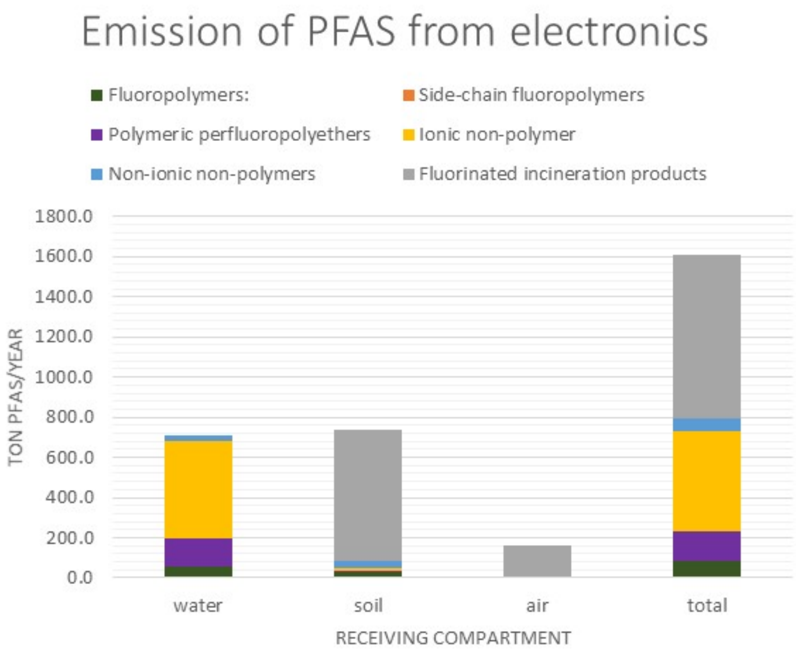

Figure 3. Distribution to environmental compartments of different types of PFAS during the life-cycle of electronics (including semiconductors). Based on midpoint

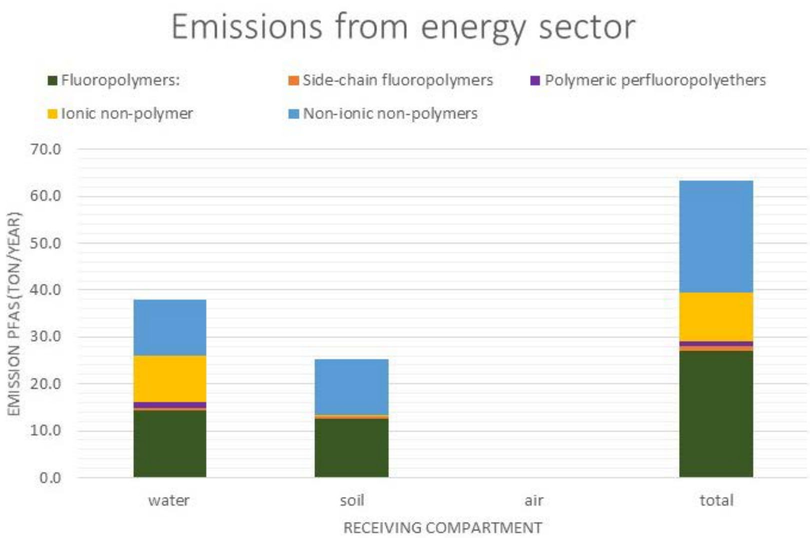

Figure 4. Distribution of emissions to environmental compartments of different types of PFAS from the energy industry excluding batteries

Currently a yearly loss of immersion cooling liquid in 2 phase systems of 1% is said to be industry best practice.

For batteries the PFAS emissions in use-phase are not known but likely neglectable. More significant emissions could occur in the waste stage (but this is out of scope here).

Emission estimates time series Electronics and Energy industry:

The growth in PFAS emissions depends on the growth in the electronics industry (including semiconductors). This growth is not exactly known, therefore three scenarios are shown: 5%, 10 % and 20% growth per year (CAGR). It is a preliminary estimation, 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 5 and 6, the expected growth in PFAS emissions per year is given for the electronics industry and the energy industry.

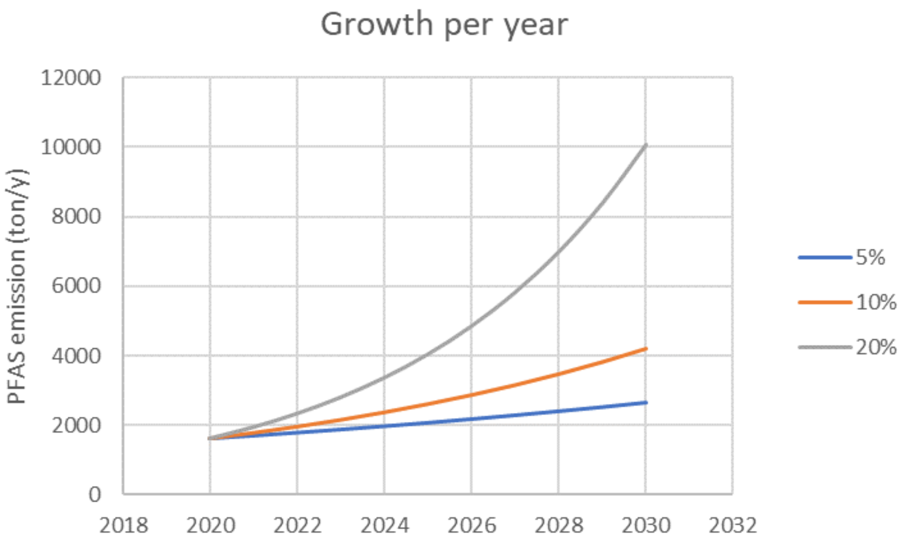

Figure 5. Growth emissions of PFAS from the electronics industry (including semiconductors)

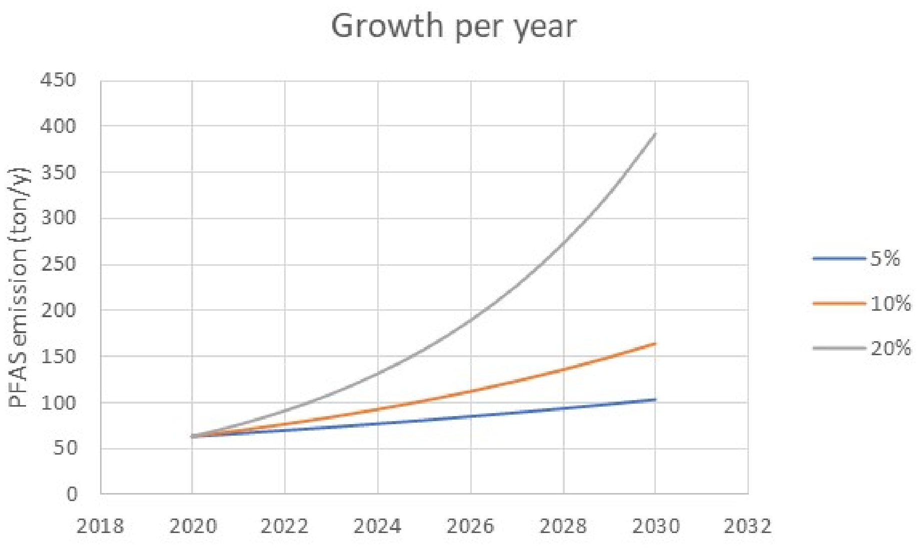

Figure 6. Growth emissions of PFAS from the energy industry (excluding batteries)

8. Alternatives

According to industry stakeholders, few non-perfluorinated substance and technically feasible alternatives are available that can replace the properties necessary for semiconductor manufacturing process chemistries. No single "drop-in" replacement is possible for all semiconductor applications where substitutes exist. Every use has to be re-engineered to see if a replacement material will meet the technology requirements. Moreover, even within the semiconductor industry technologies are not consistent. Alternatives that work for one application or one company, will not necessarily work for another application or another company.

Table 4. List of available non-PFAS substances and technics in Electronics, Semi-conductor and Energy industry

Use categories	Non-PFAS alternatives
Electronics industry and semi-conductor	Ethylene propylene diene monomer (EPDM) and silicone rubbers as alternatives for fluoroelastomers in sealing Silicone materials as alternatives for wire insulation Polyetheretherketone (PEEK) for example for Chip manufacturing For photolithography (hard and not for all applications): hydrocarbon-based greases, Molybdenum disulfide, graphite In semiconductor production Atomic Layer Deposition / Atomic Layer Etching technologies may have potential to reduce the number of photolithography process steps but has not achieved necessary manufacturability to support high volume manufacturing.
Energy industry	Solar panels: For fluoropolymer-based backsheets for photovoltaic cells polyolefin could be an alternative. Other fluorine free backsheets made of polyethylene terephthalate (PET) and/or ethylene vinyl acetate (EVA) can/are also used Cables: Mica and EPDM Seals: Hydrocarbon elastomers Batteries[1]: Solid-state batteries Photolithography: Hydrocarbon-based greases, Molybdenum disulfide, graphite Fuel cells: For PEM membranes: Hydrocarbon membrane and sulphonated polyetheretherketone (PEEK) Reinforcement material as alternative to PTFE: Electrospun polybenzimidazole-type materials Sealings: Some elastomers without fluorine exist and could potentially be used in the future for the Membrane Elect rodes Assembly (MEA) function[2]. For immersion cooling: Synthetic oil[3]

[1]An alternative might be delivered by solid-state batteries, however according to Det Norske Veritas[25] these batteries as there are currently on a low technology readiness level and basic research is still ongoing and estimated costs are estimated to be between $ 400 – 800 /kWh which will hamper market penetration.

[2]As for gas-permeability and cost, the fluorine-free materials are superior to fluorinated elastomers thus also from technical and economical point of view, replacement of these materials is desirable when possible

[3]Synthetic oil (no aromatics, volatile compounds or fluorocarbon components) which are able to achieve an PUE of 1.1.

9. Economic impacts in case of a full PFAS ban

Based on the data from year 2015 for the EU (including UK), the electronics industry used 3,500 tonnes of fluoropolymers (for a value of €50 million) The fluoropolymer group of Plastics Europe uses the same numbers in its communication on fluoropolymers[26]. This enables the industry to manufacture several €billion (e.g., EU semiconductor market was valued approximately €25 billion). The renewable energy industry used 500 tonnes of fluoropolymers (for a value of less than €5 million).

[25] Are solid-state batteries the holy grail for 2030? - DNV

[26] *https://fluoropolymers.plasticseurope.org/index.php/Applications/electronics-industry*

Detailed information on impacts for European industry could not be obtained during the consultation or from research.

Currently the semiconductor industry does not see an option to substitute the fluorine chemistry from their processes immediately. It is assumed that this process will take more than five years.

Impacts on semiconductor yield can be as high as millions of Euros per day, per factory."

In general the industry stakeholder consensus is that PFAS alternatives are not available for the electronic industry and if they are available in due time, the expected transition costs on average exceed €100 million and the expected transition times vary, but are expected to be considerable (3-15 years).

In general the industry stakeholder consensus is also in the semiconductor business that PFAS alternatives are not identified and if they are available in due time the expected transition costs vary from €20-30 million to more than €100 million and the expected transition times vary per use/component, but are expected to be considerable (3-10+ years).

In general the majority of the replies for the energy industry overlap with the electronics and semiconductor business: PFAS alternatives are not identified and if they are available in due time and the expected transition costs vary. Only two replies provide precise estimates: €11 million and €20 million. The expected transition times vary per use/component, but are expected to be considerable. Some stakeholder replies indicate the necessary transition period within the range 3-15 years

In various replies it was indicated that PFAS alternatives should be able to fit mass production, not only the technical feasibility of the substitution. The development of alternatives also needs communication with customers to check if (partly) functional degradation is tolerated.

Respondents (from industry) expect loss of competitiveness and innovation for the EEA. They claim that appropriate transition periods and exemptions are necessary due to the lack of alternatives that could guarantee similar performances of affected products. They have also reported that the restriction would have disrupting effects on many technology products/industries and, in turn, on EEA society.

10. Other impacts in case of a full PFAS ban

Only five replies report a precise estimate of the loss in Earnings before interest, taxes (EBIT) for electronics including semiconductor:

- €150 million (not clear over which time period because the respondent has not provided the annual turnover);
- €1 400 million (over 20 years);
- €20 000 million (over 20 years);
- €50-100 million (over 20 years);
- €1 000 million (over 1 year).

Only two out of these five replies are from companies based in the EEA. After comparing EBIT losses with annual sales, EBIT sales ratios were derived of 20% and 50% for those two companies.

None of the other respondents provide any estimated loss in EBIT.

Only three replies report some estimates of the loss in EBIT for the energy sector (these are the same respondents for the electronics sectors reporting the same expected EBIT losses):

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

No hints on the EBIT-sales ratio can be derived by these two replies.None of the other respondents provide any estimated loss in EBIT.

11. Environmental and social impact

Expected adverse reactions of customers (e.g., redirecting demand towards outside non-EEA markets) have been also reported.

- Manufacturers of raw materials used in PFAS and manufacturers of PFAS: The main economic impact of a ban of PFAS is downstream and the employment effects are expected to be of a larger magnitude for the specific sectors in the scope of this (summary) report. This is more relevant for those companies that are going to face stronger competition, form producers of similar products with better performances.
- Electronic industry and equipment including semiconductors: FluoroCouncil reports that the industry of electronic applications supports more than 53 000 jobs in Europe. Automotive industry also uses PFAS -based electronic components. FluoroCouncil have previously reported 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). FluoroCouncil have previousley reported that the semiconductor industry involves more than 91 000 jobs in Europe.
- Energy sector: FluoroCouncil have previousley reported that the industry of alternative energy applications (e.g., Li-batteries, fuel cells, photovoltaic solar panels) support more than 2 000 jobs in Europe.

Sufficient information was not available to make a reasonable estimate of what share of employees of each of the wide range of diverse downstream user sectors might be affected in the EEA.

In almost none of the replies an exact number of workers who might face layoff due to the restriction of PFAS without proper transitional periods is reported, also taking into account the lack of alternatives. One respondent states that the impact on employment along the EEA supply chain would be huge.

The number of people along the supply chain in the EEA that will be affected according to the other respondents expected to be between 500 to several thousands in the electronics industry and 500-2500 in the semiconductor industry. For the energy industry it also is expected to be between 500-2500.

Overall, the restriction of PFAS is likely to affect the workforce in the whole EEA.

Only very few respondents have stated that the employment impact per country would be: for one respondent in the order of 2-6 workers per country (from five countries); for another respondent 10-20 workers per country; for a third one 50-500 workers (wide variability) per country (from five countries with a total in the range of 800 – 1 050 workers); a fourth one states 20-700 workers (wide variability) per country.

Only very few respondents report specific wage values: one respondent (€30 000 – €35 000 without specifying the country/ies); another respondent adds the wages per country: €39 000 - €58 000 [Some western EEA Countries], €12 000 – €16 000 [Some Eastern EEA Countries]. None of the others replied.

However, sufficient data was not available to reliably extrapolate impacts to the whole EEA market for the three specified sectors (electronics, semi-conductor, energy industry). Stakeholder input suggested that employment in downstream user sectors could be much larger, potentially by several orders of magnitude with respect those for PFAS manufacturers.

<u>Wider economic impact:</u>

The products are widely used across all industries including IT, government, healthcare, education, entertainment, manufacturing, energy, defense, etc. *"A ban on import of the products would have a severe impact on the economies of the EEA countries." (Industry stakeholder).*

Few respondents highlight that competitors outside the EEA will immediately gain market share and the gains for non-EEA competitors (mostly located in Asia) is due to the fact that they can continue to use a technology (using PFAS) that would be restricted to EEA companies.

12. Methods used

Information was collected through literature and internet searches complemented by information from stakeholders. The stakeholder information is based on the Call for Evidence (CfE) requested by the competent authorities of The Netherlands, Denmark, Germany, Norway and Sweden from May to July 2020. While the semiconductor industry was specifically included as a use category in the CfE, this was not the case for the electronics nor the energy industry. Both were marked under the subcategory 'other'. More data was collected via an additional questionnaire using Survey Monkey27 (survey) and consultation of selected stakeholders and trade organizations focusing on both the electronics, semiconductor and energy industry in March/April 2021. The questionnaire was both sent to a selection of the companies that replied to the CfE as well as to the sector organisations that distributed it to their members.

A total of 49 replies that were received through the CfE (summer 2020) and the dedicated stakeholder survey (spring 2021). This input was used to calculate volumes and emissions.

The information received was insufficient to determine the total market share of those companies participating. It is therefore impossible to determine if the volumes and the emission calculations for which those volumes are used provide an accurate picture of the actual volumes and emissions in the EEA.

However, it is clear that companies that provided information, especially those that replied through in the dedicated stakeholder consultation (spring 2021), play important roles in their markets, based on their sales.

[27] www.surveymonkey.com

Additionally, information was obtained through consultation with sector organisations including:

- SEMI, the 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 (only through email) – 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;
- Recharge (did not participate) - European industry association for advanced rechargeable and lithium battery manufacturers and the entire related value chain.

Emissions have been calculated for different stages in the life-cycle of PFAS. Because uncertainties in the estimated volumes and many unspecified actual and patented uses, a sophisticated emission calculation per substance is not possible. Instead, a preliminary approach was used with default emission factors corresponding to different emissions scenarios described by REACH. The life-stages (Production, use, Recycling, Export, Incineration) have been included in the assessment of the emissions.

All the produced PFAS is assumed to enter the use (consumer) phase, except for the solvents (non-ionic non-polymers). It is assumed that 1% of the non-ionic non-polymers is actually used by consumers, and 99% is used as solvent in the production of electronics.

13. Uncertainties

The information presented is primarily based on input from industry stakeholders and was insufficient to determine the total market share of those companies participating. It is therefore impossible to determine if the volumes, and the emission calculations for which those volumes are used, provide an accurate picture of the actual volumes and emissions in the EEA.

It was therefore not possible to assign volume or type of PFAS information to the sub-uses (i.e. presented in table 1). Aggregation of information was done on a higher lever, i.e. per industry.

- Provided volumes were occasionally aggregated for several uses in various sectors; in that case the volumes were equally divided over the sectors.
- Provided volumes were occasionally aggregated for a group of substance under the same use which may underestimate volumes for individual substances; however the total quantities are not affected.
- Some companies did not provide information about the volumes of PFAS, but only on the identity of the substances.
- The response was not precise and specific enough to quantify many different applications in the energy industry.
- There is also quite a bit of uncertainty on future developments like market growth, technical innovation, etc.

Appendix I: Examples of PFAS used

Examples of some PFAS used in Electronic, Semiconductor and energy industry with their Identified properties are presented in the table below. Immersion cooling PFAS are not included here.

<table>
<tr><th></th><th></th><th>Identified properties Electronics</th><th>Identified properties Semiconductor</th><th>Identified properties Energy</th></tr>
<tr><td colspan="2">fluoropolymers</td><td rowspan="12">Non-reactive, stable, low surface tension, non sticking, high purity, Excellent dielectric performance for low signal loss, low off-gassing, ensuring vacuum environment, low dissipation factor, ultra thin, resistant to oil, resistant to water, resistant to sulfur, 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, Adhesion to copper and laminate, Air permeability, Antireflective, Abrasion resistance, Antistatic/Antidust agent, Flame retardancy</td><td rowspan="12">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, antiadhesion, insulation, barrier properties, thermal stability, Unique hydrophobicity, Non flammable</td><td rowspan="12">Chemical/thermal resistance, Antifouling, Sand abrasion, ion transportation, high weatherability, high transparency, corrosion resistance, oleophobic, hydrophobic, 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 repellency, high vapour barrier, high transparency, low flammability, extreme durability</td></tr>
<tr><td colspan="2">9002-84-0, PTFE
24937-79-9, PVDF
68258-85-5, ETFE
25190-89-0, PVFP
25067-11-2, FEP</td></tr>
<tr><td colspan="2">side-chain fluorinated polymers</td></tr>
<tr><td colspan="2">1010423-83-2
1108730-36-4
1538576-70-3
1644456-24-5
889649-57-4</td></tr>
<tr><td colspan="2">non-polymer PFAS</td></tr>
<tr><td>102116-02-9</td><td>1186620-71-2</td></tr>
<tr><td>1064697-81-9</td><td>1311401-25-8</td></tr>
<tr><td>1064698-37-8</td><td>220689-12-3</td></tr>
<tr><td>132182-92-4</td><td>133710-62-0</td></tr>
<tr><td>297730-93-9</td><td>756-12-7</td></tr>
<tr><td>29420-49-3</td><td>1064698-37-8</td></tr>
<tr><td></td><td></td></tr>
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