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Use of PFAS in semiconductor industry

Table of content

1. Introduction and Overview

Semiconductors are essential components of electronic devices and are integral to modern society[i]. They are of strategic importance for both economic growth and national security.

The restriction proposal[ii] in its current form would inevitably jeopardize the functioning of the European semiconductor industry.

Merck Electronics is manufacturer of process chemicals as well as provider of delivery systems for process chemicals used in semiconductor manufacturing in Europe and other countries around the globe. Thus, we produce and import various process chemicals and articles – amongst other, chemicals for photolithography (e. g. photoresist, process and patterning enhancement materials), gases for etching and cleaning of vapor deposition chambers (e.g., hydrofluorocarbons, perfluorocarbons) as well as customized delivery systems for corrosive, toxic, hazardous chemicals, and gases in semiconductor manufacturing plants.

Each of these portfolio segments includes products containing PFAS.

In the absence of a comprehensive derogation for the use of PFAS substances in the semiconductor industry Merck Electronics, as integrated part of the semiconductor supply chain, will have to stop its entire semiconductor business in Europe as there will be no possibility left to import, use, or sell our products. As manufacturing/handling of non-PFAS chemicals used in semiconductor industry also often requires PFAS materials in the respective plants and /or packaging, Merck Electronics would also be affected in regard of manufacturing of non-PFAS process chemicals in the EU for the non-EU market.

The semiconductor industry ecosystem involves several different layers of companies, each serving distinct roles, and the impact on this industry cannot be assessed separately process step by process step without having in mind the potential impact on the whole manufacturing process.

To ensure consideration of the complete value chains necessary to produce these critical products, Merck Electronics has been and is still actively contributing to industry association's comments as e.g., from **SEMI and ESIA** – some of these comments are already submitted, others will be submitted later in course of the consultation phase. Merck Electronics is represented in the respective working group by the US affiliate EMD Electronics.

Besides pointing out Merck Electronics' specific role and potential impacts in this comment we also refer to respective industry association's comments and the comprehensive information provided especially by the SIA PFAS working group in respective white papers and case studies published on the SIA web page (https://www.semiconductors.org/pfas/) .

Specific questions raised regarding the semiconductor use in the documents published by the dossier submitters together with the Annex XV restriction report are directly addressed in the SEMI comment (submitted 26. May 2023, No **4304**).

The socio-economic impact of an implementation of the current draft restriction proposal on worker employment as well as on business figures of Merck Electronics is described in a separate, confidential document.
Considering the evidence provided and the economic impact described in the industry association's comments, complemented with Merck Electronic specific information on the economic impact (in the confidential part of the submission), we ask for an adequate derogation for the use of PFAS materials in semiconductor industry considering the need to use such materials and the extremely long timelines (potentially several decades) for implementation of potential alternatives. This derogation must also include all uses of PFAS in semiconductor manufacturing plants and delivery system equipment.

In this comment Merck Electronics is addressing only the use of PFAS in semiconductor industry.

Additional comments are already - and more will be - submitted separately by Merck, to provide also regarding other PFAS uses a better basis for an adequate regulation of PFAS materials.

2. Need of PFAS in semiconductor production

As mentioned above semiconductor manufacturing is highly integrated, often including multiple process steps, and using multipurpose facilities/plants[iii]. In Figure 1 a general overview on the manufacturing process is shown.

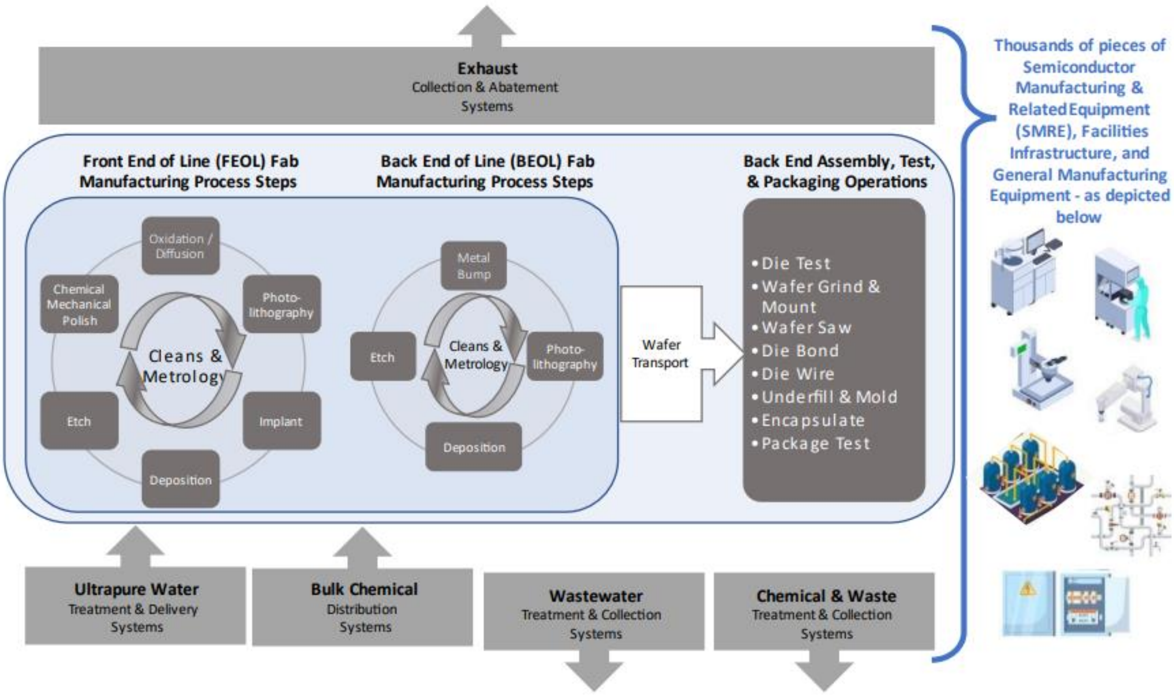

Figure 1: General overview of semiconductor manufacturing process steps, operations and systems evaluated by Semiconductor PFAS Consortium working groups – Copyright © 2023 the Semiconductor Industry Association (SIA). All rights reserved[iv].

Products provided by Merck Electronics are used in many steps of the semiconductor manufacturing process - specifically in the photolithography process (e. g. photoresist, process, and patterning enhancement materials), for etching (gases) and cleaning of vapor deposition chambers (e.g., hydrofluorocarbons, perfluorocarbons) as well as customized delivery systems for corrosive, toxic, hazardous chemicals, and gases in semiconductor manufacturing plants.
Despite already ongoing search for alternatives for PFAS materials in this portfolio some uses in semiconductor industry still require PFAS materials and will so for longer time periods.

Based on our product knowledge and respective insights in the overall semiconductor manufacturing process Merck Electronics contributed to industry association's comments with data and expert knowledge. We therefore do not provide this information here again in full detail but refer also to the ESIA and SEMI comments.

We are in full support of what is submitted as comments to this Annex XV consultation by ESIA (European Semiconductor Industry Association) and SEMI Europe and would be severely affected by a restriction without derogation for the semiconductor manufacturing as lined out in respective comments.

The Semiconductor PFAS Consortium organized under SIA (Semiconductor Industry Association) collects the technical data needed to formulate an industry-wide approach regarding the semiconductor industry's use of per- and poly-fluorinated alkyl substances (PFAS) to support the authorities with their evaluation. The Semiconductor PFAS Consortium represents 69% of worldwide semiconductor manufacturing capital expenditure as well as 70% of global sales of semiconductor equipment in 2021. The Consortium is organized under the auspices of SIA and consisting of industry experts from SIA member companies and other companies throughout the supply chain.

The Semiconductor PFAS Consortium has developed one impact study, six white papers and three case studies that identify PFAS uses in semiconductor manufacturing and assess where use meets the definition of "essential"[v].

To the extent that PFAS-containing formulations are essential to manufacturing semiconductors, the papers present the socioeconomic factors and data that support continued use, under exemptions with near-zero release. To the extent that nonfluorinated alternatives may be available that can satisfy application, specific performance requirements, the papers identify the key steps necessary to develop, qualify and implement new materials into high-volume semiconductor manufacturing. They also outline potential avenues of R&D for new materials[vi].

Therefore, for a more exhaustive description of the use of PFAS in the semiconductor industry, please see **SIA papers**, available on the SIA website[1] and attached to this Annex XV consultation submittal in table 1.

Table 1: Semiconductor PFAS Consortium (Semiconductor Industry Association (SIA)) - technical papers

technical papers	Title	Document
Impact Study	The Impact of a Potential PFAS Restriction on the Semiconductor Sector	PDF The Impact of a Potential PFAS Restr
Whitepaper	Background on Semiconductor Manufacturing and PFAS	PDF Background on Semiconductor Man
Case Study	PFOS and PFOA conversion to short chain PFAS used in the Semiconductor Manufacturing	PDF PFOS and PFOA Conversion to Short
Case Study	PFAS-Containing Photo-Acid Generators used in Semiconductor Manufacturing	PDF PFAS-Containing Photo-Acid Generat
Case Study	PFAS-Containing Surfactants used in Semiconductor Manufacturing	PDF PFAS-Containing Surfactants Used in
Whitepaper	PFAS-Containing Wet Chemistries used in Semiconductor Manufacturing	PDF PFAS-Containing Wet Chemicals Used
Whitepaper	PFAS-containing Fluorochemicals used in Semiconductor Manufacturing Plasma-enabled Etch and Deposition	PDF PFAS_-Containing Fluorochemicals Use

[1] "The Impact of a Potential PFAS Restriction on the Semiconductor Sector"; https://www.semiconductors.org/the-impact-of-a-potential-pfas-restriction-on-the-semiconductor-sector/

Whitepaper	PFAS-Containing Heat Transfer Fluids (HTF) PFAS-containing Heat Transfer Fluids used in Semiconductor Manufacturing	PDF PFAS_-Containing Heat Transfer Fluids
Whitepaper	PFAS-Containing Materials used in Semiconductor Manufacturing Assembly Test Packaging and Substrate processes	PDF PFAS-Containing Materials Used in Se
Whitepaper	PFAS-Containing Lubricants used in Semiconductor Manufacturing	PDF PFAS-Containing Lubricants Used in S
Whitepaper	PFAS-Containing Articles used in Semiconductor Manufacturing	PDF PFAS-Containing-Articles-Used-in-Semic

SEMI Europe developed and will develop further an updated overview on semiconductor industry uses for PFAS. Please see more details in the current "Updated Annex A Table A.49" that is provided in the SEMI comment **4304** of the consultation. This updated table illustrates the depth and complexity of the industry's uses of PFAS categorized by the five core aspects, process chemistries, semiconductor manufacturing equipment, semiconductor manufacturing infrastructure, semiconductor manufacturing support equipment and semiconductor devices. The table will be further developed, and newly identified uses will be added.

In the following section, we would like to look at a few selected examples and go into them in more detail.

Photoacid generators (PAGs)

Merck Electronics as a supplier of Photoacid generators (PAGs) to the semiconductor industry would highlight the PAGs as one example to describe the complex requirements that need to be fulfilled to ensure the device performance in the end.

The PAGs are one key component in the photolithography process which is a critical process step in the mass production of a semiconductor. Material changes for lithographic materials are not easy nor quickly achieved, PAGs in chemically amplified resists having been under development for at least 25 years. There are currently no technologies available to achieve this replacement, and there are legitimate questions as to whether this is possible at all for some photoresists. With that understanding timelines for substitution of PFAS PAGs with non-PFAS PAGs were modeled by experts from SIA (including Merck Electronic experts) and development of alternatives is expected to take 15 or even more than 20 years to reach production. For an alternative to be successful it would have to show acidity comparable to perfluoro sulfonic acids, similar lack of side reactions, lack of volatility, and minimum diffusivity for high resolution patterns[vii].

Additional information, case studies and a more detailed assessment on PFAS containing PAGs and potential replacement can be found on page 37 of SIA PFAS Consortium report "The Impact of a Potential PFAS Restriction on the Semiconductor Sector" and the case study "PFAS-Containing Photo-Acid Generators used in Semiconductor Manufacturing" attached to this Annex XV submittal (table 1).

Please also refer to the SEMI Europe comments for further details on examples on Photoacid generators (PAGs) and fluoroelastomers as the Annex XV dossier was focused on these uses of PFAS. Especially the feasibility of the proposed non-PFAS alternatives put forward by the Annex XV dossier submitters was investigated [viii].

SEMI Assesment of Proposed Alternativ	SEMI Assesment of Proposed Alternativ
SEMI Assessment of Proposed Alternative Photoacid Generators (PAGs)	**SEMI Assessment of Proposed Alternative Fluoroelastomers for Sealing**

Manufacturing Equipment - Delivery systems

Based on the Q&A published by ECHA after the webinar on 5 April 2023, we want to explicitly point out as a second example, the requirement of delivery systems in the complex semiconductor manufacturing process.

In the manufacturing of semiconductors, especially in the step of photolithography, many toxic or corrosive substances need to be handled without any impurification. Additionally, it is required that these substances are delivered to an automated process in a very precise amount over a well-defined time.

To ensure that these substances are delivered in each process step at the right dosage, the right speed, and the right quality, highly complex, versatile, and reliable pumping systems are required.

This can only be achieved with pumps, piping and valves made of or covered with fluoropolymers. For a more detailed elaboration on the necessity of fluoropolymers in the manufacturing process, please find also more details in the white paper "PFAS-Containing Articles used in Semiconductor Manufacturing" from ESIA and the Merck Electronics comment "Use of fluoropolymers in chemical manufacturing plants" (submitted 02. June 2023, No **4450**).

According to the current Q&A 12.6 published by ECHA, use of PFAS materials in such delivery systems would be not in scope of the derogation proposed in the restriction. On page 23 of this Q&A document, it is mentioned that the dossier submitters do not intend to cover equipment in the derogation for semiconductor manufacturing[ix].

A multitude of individual component parts in semiconductor manufacturing equipment is dependent on PFAS substances to provide the compatible, inert, clean, temperature tolerant environment needed for the fluids and gases used in the equipment. Semiconductor manufacturing involves many very reactive chemicals and the necessary sealing performance and safe transport in the delivery system can only be achieved with fluoropolymers due to their extraordinary resistance to chemicals and heat.

Each system is highly specialized and must meet exacting standards. Seal failure can lead to environmental contamination and cause safety hazards and fatal accidents for workers.

Figure 2: Example Pictures of different FlowMaster® Chemical Delivery Systems. Supplies precise blending and delivery of chemicals.

The automated material handling systems we presented here (figure 2 and figure 3) are just two examples with a complex infrastructure that incorporates articles made from or containing PFAS. There are thousands of more individual pieces part of semiconductor manufacturing equipment that is required for one of the many individual process steps - including support functions[x].

Especially Fluoropolymers with their multiple useful characteristics are critical for the safe and efficient manufacturing process. The combined effect of these properties like for example high purity, heat, chemical and permeation resistance, nonflammability, optical and mechanical properties make them indispensable for semiconductor manufacturing equipment. Please refer to the SIA whitepaper "PFAS-Containing Articles used in Semiconductor Manufacturing". In this white paper, equipment used in semiconductor manufacturing process is described in more detail, it focuses heavily on fluoropolymer-containing articles (including fluoroplastics and fluoroelastomers) and their uses in semiconductor manufacturing, non-polymer PFAS-containing materials are also present in articles supplied to the industry, as part of finished articles. You will find there much more examples from simple assembly components that could contain PFAS up to highly complex assembly components or complete handling systems.

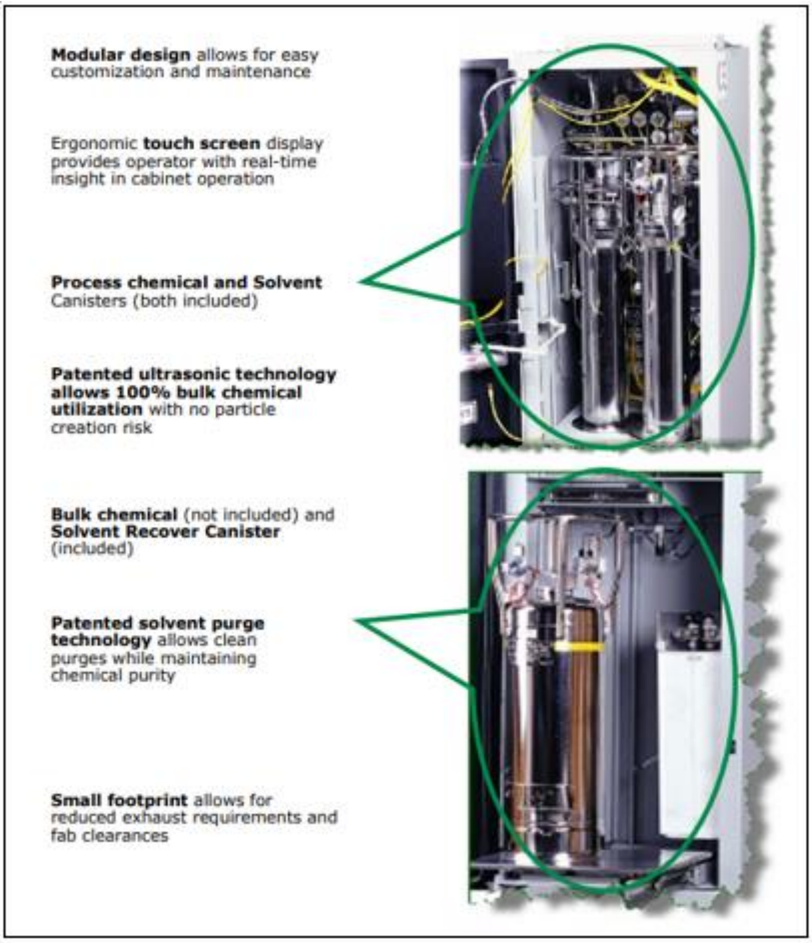

Figure 3: Example picture of a dual-tank chemical refill system CHEMGUARD Gen III for low volatility chemicals. Dual precursor tanks allow for 100% uptime to meet the needs of today's manufacturing fabs or in cutting edge R&D facilities.

The need for such equipment set up is not only required for semiconductor manufacturing: substances manufactured for/processed in electronics or also other industries (e.g. liquid crystals, e.g. intermediates for API, excipients for vaccine, delivery systems for other reactive products or cosmetic industry (cosmetic raw material) require very often the use of fluoropolymers in the production equipment. Please refer to the Merck Electronics comments on " Use of fluoropolymers in chemical manufacturing plants" (submitted 02. June 2023, No **4450**) and "PFAS in lab & R&D use" (submitted 02. June 2023, No **4448**). We have provided data and case studies on the (in)compatibility of different solvents with production materials, and we demonstrate that fluoropolymer materials are the only ones fulfilling the extreme needs in chemical manufacturing – needs given also by regulatory frameworks defining e.g. certain maximum levels of impermeability.
For further examples and case studies, please also refer to the document from SEMI Europe "Comments on Alternatives for Fluoroelastomers in Sealing" which illustrates in more detail why Ethylene propylene diene monomer (EPDM), Silicone rubbers, Aryl Ketone polymer (PEEK) and Hydrocarbon elastomers are not suitable alternatives. These non-PFAS fluoroelastomers are put forward in the Annex XV report as potential alternatives and were therefore analyzed in more detail by SEMI Europe to ascertain their viability for high volume manufacturing purposes.

F-Gases

Merck Electronics as a supplier of gases for the semiconductor manufacturing would like to summarize some key aspects especially about the F-gases.

Perfluorocarbons (PFCs) and Hydrofluorocarbons (HFCs) are fundamental to the manufacturing of semiconductors, e. g. in thin film deposition, plasma etch, wafer clean and deposition chamber cleaning. These gases were studied throughout the decade-long development of the semiconductor manufacturing process. Thus, their unique property to react with silica in a predictable, controllable, and selectable way is well understood and lacks non-fluorinated alternatives. Please see the answer to question 7 by SEMI to this consultation (comment **4304**) for an explanation why the use of alternatives proposed by the dossier submitters create significant environmental and safety concerns. Please note that, as also mentioned in the SEMI comment, the aforementioned process steps are just broad description for hundreds of steps with distinct requirements.

Merck Electronics wants to point out that the EU with its Member States agreed to the Montreal Protocol and its Kigali Amendment, resulting in the regulation (EU) No 517/2014[xi] on fluorinated greenhouse gases (EU F-Gas regulation). These international agreements and European regulation already target the phase down / out of some PFCs and HFCs covering already gases falling under the proposed restriction. Considering this, the proposed restriction is a double regulation of these substances and cripples the semiconductor manufacturing industry in the EU. Especially as during the implementation and the continuous review of the EU F-Gas regulation, it was already noted and considered by the legislators that the semiconductor manufacturing industry is not a big contributor to the trade with or release of F-Gases but strongly depends on their unique properties. Thus, an exemption from the phase down / out or the quota system, respectively, was granted.

In addition, it has to be noted that F-Gases – as most gases – are transported under high pressure. The respective packaging (e. g. gas cylinders) is designed to withstand this pressure and properties of contained gases (e. g. corrosivity). Specifically, the cylinders are lined and screw joints are sealed with fluoroelastomers due to their unique resistance against pressure, heat and corrosivity. Without an exemption for use of fluoroelastomers in packaging material, the transport and import of a variety of gases will not be possible anymore – impacting all industries relying on continuous supply of gases – not only the F-gas depending industry.

3. Waste and Emissions in the semiconductor industry

It is acknowledged that it is difficult to acquire a fully comprehensive PFAS emissions profile for the semiconductor industry. Emissions depend on the use of the PFAS and the complexity of supply chain makes tracing of PFAS-containing materials in individual components and their potential emissions quite difficult for a single company within the supply chain[xii]. Because PFAS have not yet been regulated as a class, traceability for those compounds throughout the supply chain is difficult and would require a multicompany, multistep, multiyear effort to improve the level of knowledge within the supply chain[xiii].

Based on its role in the supply chain, Merck Electronics does not have full information on emissions during production of semiconductor industry-relevant materials and during use of the final products placed on the European market. In this context available data have been shared with the

Semiconductor Industry Association (SIA) who collects confidential or unpublished information from representative companies that is sensitive to their individual business objectives. Please refer to the data collected there. SIA provides data about potential emissions and explains in detail the available EHS controls in Chapter 12 of the SIA paper on the "Background on Semiconductor Manufacturing"[xiv]. EHS controls in semiconductor fabs are described in more detail, including numbers and figures.

You could find an example for PFAS discharges from photolithography processes in SIA paper on "The Impact of a Potential PFAS Restriction on the Semiconductor Sector". The table includes a concrete example for a release mass balance of PFAS containing substances used in photolithography uses.

Furthermore, SEMI has provided emission information on Polyvinylidene fluoride (PVDF), PAGS and lubricants in its Q5 response ((submitted 26. May 2023, No **4304**).

In case of fluoropolymers in industrial use, PFAS are part of the equipment until its end of life, and emissions can be controlled. In case of use of PFAS as chemicals or auxiliaries in Manufacture/Storage/Transport and Quality Control, substances can be used under controlled conditions to minimize exposure to the lowest level possible. The use of substances should not be restricted if the goal of the restriction can be reached by other means like emission controls, other operational conditions and risk management methods.

Fluoropolymers, organic waste, including organic liquids containing PFAS, is typically segregated, collected, and containerized to be treated at an offsite licensed treatment and disposal facility, as a blended fuel by high temperature incineration or reprocessing.

In a hazardous waste incineration plant, waste is treated by high-temperature incineration with a temperature of around 1,100°C. According to Regulation (EU) 2019/1021 and other publications[xv] [xvi] [xvii] [xviii] high-temperature incineration is correlated to temperatures > 1,100 °C and 2 seconds contact time. Under these conditions, fluoropolymers are considered to be destroyed (RAC also proposes similar conditions in case of PFAS incineration in the opinion on the PFAS firefighting foam restriction Annex XV dossier [vi]: "If PFAS containing waste is incinerated or co-incinerated, the temperature shall be at least 1 100 °C").

These conditions are achieved in standard hazardous waste incinerators used for example in Germany as this is already clearly regulated in the Federal Immission Control Act and the 17th Ordinance to this Act (17th BimSchV). Requirements for the design of the furnace, the minimum temperatures and specific limit values for emissions of inorganic and organic pollutants are defined.

Furthermore, a recent publication from the Institute for Technical Chemistry (ITC) at Karlsruhe Institute of Technology (KIT)[xix] provides more precise data on the energetic recycling of fluoropolymers. According to the study, the investigated process, carried out under the defined conditions of waste incineration, represents a safe disposal of fluoropolymers even at lower combustion temperature.

Best management practices for the use, handling, and disposal of PFAS can achieve the environmental objectives without the negative consequences of an outright restriction. Considering additionally that not all substances in scope of the PFAS definition given in the restriction proposal have actually fully identical properties a PFAS regulation should be proportionate to the specific risks posed by different PFAS.

The Semiconductor industry and PFAS Consortium is continuously working to map PFAS uses more fully and release this more detailed view later in 2023, we will actively contribute there with our data.

Release mapping will evaluate the inputs, potential generation, and final release pathways of PFAS within semiconductor manufacturing and will determine key factors influencing final releases.

With adequate risk management measures related to chemicals as well as articles (including fluoropolymers) relevant in the semiconductor industry, exposure to the environment or populations and potential environmental and health risks of PFAS across all product life cycle phases (service, end-of-life, disposal) can be extremely minimized.

Merck Electronics supports the search for substitutes for PFAS and is actively researching for alternatives with own R&D resources. Yet, we do not know whether alternatives with the same technical properties can be found in 5 or 10 years or even longer time periods or if a different technology is required for a certain use. In some cases, fundamental laws of chemistry and physics are making it hard to find other less persistent and less hazardous chemicals as PFAS-free alternatives.

4. Impact of PFAS Restriction on Semiconductor Industry in Europe

Merck is strongly committed to and supports the European Union's goals of the Green Deal. To find the best strategy for a digital and sustainable future, politicians, authorities, and industries must work together and stay in constant dialogue.

With the information provided we hope to contribute to an appropriate regulation of PFAS while avoiding critical impacts on EU semiconductor industry. Given the broad range and complexity of PFAS uses in this area, we are open to a direct exchange allowing us to give more detailed insights.

In the case the semiconductor manufacturing processes, and its preceding steps are not covered by an appropriate derogation (covering e.g., production/import/use of process chemicals, gases, articles, and devices) a stop of semiconductor manufacturing and supply in Europe will result. We want to highlight the comment already provided by ESIA (**4449**): "If this is the case the EU's ability to achieve its six priorities – A European Green Deal, A Europe Fit for the Digital Age, An Economy that Works for People, A Stronger Europe in the World, promoting our European Way of Life, A new Push for European Democracy will simply collapse"[xx].

[i] https://www.semiconductors.org/pfas/ - Background on Semiconductor Manufacturing and PFAS; 2023
[ii] Annex XV Restriction Report: Proposal for a Restriction: Per- and polyfluoroalkyl substances (PFASs) https://echa.europa.eu/documents/10162/1c480180-ece9-1bdd-1eb8-0f3f8e7c0c49
iii https://www.semiconductors.org/pfas/: Background on Semiconductor Manufacturing and PFAS; 2023 - Appendix B: Semiconductor and Supply-Chain Complexity
[iv] https://www.semiconductors.org/pfas/ - Background on Semiconductor Manufacturing and PFAS; 2023
[v]https://www.semiconductors.org/pfas/ - Background on Semiconductor Manufacturing and PFAS; 2023

[vi] 2023 the Semiconductor Industry Association (SIA).

- Background on Semiconductor Manufacturing and PFAS; 2023
- Case Study PFOS and PFOA Conversion to Short-Chain PFAS Used in Semiconductor Manufacturing
- Case Study PFAS-Containing Surfactants Used in Semiconductor Manufacturing
- Case Study PFAS-Containing Photo-Acid Generators Used in Semiconductor Manufacturing
- White Paper PFAS-Containing Fluorochemicals Used in Semiconductor Manufacturing Plasma-Enabled Etch and Deposition
- White Paper PFAS-Containing Heat Transfer Fluids Used in Semiconductor Manufacturing
- White Paper PFAS-Containing Materials Used in Semiconductor Assembly, Test and Substrate Processes
- White Paper PFAS-Containing Wet Chemistries Used in Semiconductor Manufacturing
- White Paper PFAS-Containing Lubricants Used in Semiconductor Manufacturing
- White Paper PFAS-Containing Articles Used in Semiconductor Manufacturing

[vii] SEMI Europe (2023); SEMI Assessment of Proposed Alternative Photoacid Generators (PAGs)
[viii] SEMI Europe (2023); SEMI Assessment of Proposed Alternative Photoacid Generators (PAGs)
[ix] https://echa.europa.eu/documents/10162/2156610/230405_upfas_webinar_qa_ds_en.pdf/3f47fdcc-17c5-4b37-b758-720bb7e462f3?t=1687893645025
On p.23:
"How is semiconductor manufacturing defined in relevant the proposed potential derogation? Does this also cover manufacturing equipment?
12.6 The proposed potential derogation for the semiconductor manufacturing process is intended to cover PFAS used in the production of a semiconductor but not PFAS in the equipment used to produce semiconductors."
[x] https://www.semiconductors.org/pfas/PFAS Consortium white paper, "PFAS-Containing Articles Used in Semiconductor Manufacturing."
[xi] https://eur-lex.europa.eu/eli/reg/2014/517/oj
[xii] https://www.semiconductors.org/pfas/PFAS Consortium white paper, "PFAS-Containing Articles Used in Semiconductor Manufacturing."
[xiii] https://www.semiconductors.org/pfas/white paper PFAS-Containing Materials Used in Semiconductor Manufacturing Assembly Test Packaging and Substrate Processes
[xiv] https://www.semiconductors.org/pfas/Background on Semiconductor Manufacturing and PFAS; 2023
[ii] Yamada, T., Taylor, P. Buck, R. Kaiser, M. Giraud, R. (2005): Thermal Degradation of Fluorotelemer Treated Articles and Related Materials. Chemosphere 61, 974-984.
[iii] UNEP-POPs (2021): UNEP/POPS/COP10/INF20: Guidance on best available techniques and best environmental practices for the use of perfluorooctane sulfonic acid, perfluorooctanoic acid, and their related compounds listed under the Stockholm Convention, p. 29-30, Meeting Documents(brsmeas.org)
[iv] Umweltbundesamt (2020), Texte 137/2022, Sanierungsmanagement für lokale und flächenhafte PFAS Kontaminationen Anhang C: Sanierungsverfahren[xvii])) on persistent organic pollutants, thermal treatment processes in particular are suitable for recycling or disposing of waste containing PFAS
[v] UBA; Das Magazin des Umweltbundesamtes, Schwerpunkt; 01, 2020. PFAS -gekommen um zu bleiben
[vi]RAC OPINION ON AN ANNEX XV DOSSIER PROPOSING RESTRICTIONS ON PFAS IN FIREFIGHTING FOAMS (ECHA/RAC/RES-O-0000007226-75-01/F)
[xix]Gehrmann et al.; Pilot-Scale Fluoropolymer Incineration Study: Thermal Treatment of a Mixture of Fluoropolymers under Representative European Municipal Waste Combustor Conditions, Karlsruhe Institute of Technology (KIT), 2023
[xx] Esia comment: 4449