Socio-Economic Analysis of a potential REACH Restriction on Fluoropolymers

Teflon™ Perfluoro Alkoxy

Revised Final Report

prepared for

APM division of Chemours

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RPA

Risk & Policy Analysts

Socio-Economic Analysis of a potential REACH Restriction on Fluoropolymers

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Executive Summary

Scope and methodology

An EU REACH Annex XV Restriction Proposal is being prepared for Per- and polyfluoroalkyl substances (PFAS) by five European countries. The definition used by these countries in the Registry of Intentions means fluoropolymers will fall within the scope of this restriction. Risk & Policy Analysts Ltd (RPA), UK, have been engaged by Chemours Advanced Performance Materials (APM) division to undertake a Socio-Economic Analysis (SEA) of the aforementioned Restriction in a non-use scenario versus a continued use scenario as well as an Analysis of Alternatives (AoA). The focus will be on the fluoropolymer perfluoro alkoxy (PFA, CAS 26655-00-5), trademarked by Chemours as Teflon™ PFA.

The purpose of this study is to provide APM with information to understand the impacts and unintended consequences of the proposed Restriction under a continued use versus non-use scenario. *The non-use scenario is envisaged as a complete ban of PFAS from 2025 (a restriction on formulation concentrations would result in a de facto ban), which is assumed to be in full effect from 2026 accounting for a grace period to scale down production and sell remaining stocks*. The assessment period is ten years (2026-2035), a theoretical timeframe for alternatives to be developed.

To obtain data for the study, RPA carried out a systematic literature review (with valuable input from Chemours APM) and developed a survey which consisted of a questionnaire sent to a targeted list of stakeholders and follow-up telephone meetings between selected stakeholders and RPA. Stakeholders selected for this study included entities throughout the supply chain of Teflon™ PFA including moulders and converters, wet processing equipment manufacturers and fabrication plant owners. In total, RPA received nine responses to a targeted questionnaire and conducted six interviews with these stakeholders.

Teflon™ PFA and assessed sector

The fluoropolymer in the scope of the study, Teflon™ PFA, is used in a variety of industries and sectors such as chemical processing, electronics, semiconductor manufacturing, pharmaceutical and biotechnology sectors. In discussion with Chemours, the sector chosen to be the focus of this study is Teflon™ PFA used in semiconductor manufacturing equipment. Additionally impacts on the automotive sector was assessed in the event the EU could no longer manufacture its own semiconductor chips.

Teflon™ PFA is an inert, highly stable and insoluble polymer. It possesses several properties such as chemical and temperature resistance and is melt processable, making it an ideal material used in semiconductor manufacturing equipment. The resistance of this material to the extreme conditions conveyed during the semiconductor manufacturing process is what allows it to have an incredibly long lifetime in these conditions and ultimately enables the manufacture of chips. The semiconductor chip has evolved greatly over the last 40 years providing computing power essential to modern day society and are present in every sector and electronic device.

Teflon™ PFA is imported into Europe to the Chemours' Dordrecht site, Netherlands, and there is no processing of this material in Europe by Chemours.

Hazard properties

Due to the properties of Teflon™ PFA, it is considered to be persistent in the environment. However, it is not bioaccumulative or toxic due to its high molecular weight and insolubility, meaning uptake would be difficult and is unlikely to cross biological membranes. Currently, the polymer does not have any harmonised hazard classification and labelling.

Case study: Semiconductors

Semiconductors were chosen to be the focus of this study as a restriction on using Teflon™ PFA would have the largest impact on this market in the European Union. Semiconductor fabrication operate with the use of Teflon™ PFA to produce the core infrastructure of lithography machines and chemical distribution systems such as tubes, piping and components that transport chemicals across the fab and process tools. Access to Teflon™ PFA to produce manufacturing infrastructure and equipment to enable semiconductor manufacturing under a *continued use scenario* is essential and without it the semiconductor industry in the EU would cease. Not only that, but the success of Europe securing its supply of chips and its global market share in the sector is indirectly dependent on the use of Teflon™ PFA. The European Chips Act and the European Industrial Strategy are focused on the development and improvement of Europe's semiconductor industry to reduce its dependency on imports and propel Europe forward into an ever more digital age.

In addition to semiconductors, RPA did an assessment on the impacts this restriction would have on the automotive industry. The electrification of vehicles is essential to the success of the Green Deal, Fit-for-55 Strategy, and Sustainable and Smart Mobility Strategy. The autonomy and electrification of vehicles are dependent on semiconductors. It can thus be inferred that the success and delivery of these objectives and strategies rely also on semiconductors.

A total of five European policy objectives, directives and strategies were identified as being dependent on semiconductors and therefore dependent on Teflon™ PFA:

- *The European Green Deal;*
- *Sustainable and Smart Mobility Strategy;*
- *Fit-for-55;*
- *The European industrial strategy; and*
- *The European Chips Act.*

If the use of Teflon™ PFA is restricted, and the manufacture of semiconductor chips in the EU would cease, this would have large impacts on the EU objectives and strategies, as well as large knock-on effects to other industries. In reality some of these objectives, such as the European Chips Act, will simply become impossible in the event of a restriction being placed on fluoropolymers such as Teflon™ PFA.

Alternatives

In the analysis of alternatives an assessment of non-PFAS materials were identified as potential alternatives to Teflon™ PFA used in the semiconductor manufacturing industry. The assessment did not identify any materials as a suitable alternative to Teflon™ PFA used in the manufacture of semiconductor chips. Materials assessed included stainless steel, polypropylene, polyvinyl chloride, and polyether ether ketone. While these materials can be used in other high-performance applications, they did not simultaneously possess all the required properties that are needed to successfully enable semiconductor manufacture.

Chemical resistance and purity are extremely important to the manufacturing process and the semiconductor chips themselves. Traditional metal options such as stainless steel and copper have the potential to contaminate process chemistries with metal ions that could result in reduced production yields and wafer defects. Additionally, they did not have the corrosion and chemical resistance required to transport and store highly corrosive process chemistries. Polyvinyl chloride and polypropylene were also assessed as potential alternatives due to their widespread use in many applications. For polyvinyl chloride, the use of plasticisers to make the material more processable risks the introduction of contaminants into components. While polypropylene is known for its mouldable qualities and is a material that is melt processable, it is classed as a thermoplastic and will become liquid at its melting point (130°C). This is significantly lower than the operating temperatures (260°C) needed for semiconductor manufacturing. These plastics also do not possess the chemical resistance needed and would require components to be replaced in as little as one year versus Teflon™ PFA that stays within the manufacturing system for decades. Lastly, polyether ether ketone was assessed and although used in some areas of the semiconductor manufacturing process when absolutely necessary its extremely cumbersome to process and is not viable to manufacture many intricate components. It can also be prone to kinking and has absorptive qualities.

Rationale and impact in the EU

A PFAS restriction that bans the use of Teflon™ PFA in Europe would have immediate and significant long-lasting effects on the European semiconductor manufacturing industry. In addition, resounding knock-on effects would be felt throughout numerous other industries reliant on this technology.

Without Teflon™ PFA the European semiconductor industry would collapse. Immediately making almost every sector reliant on importation of semiconductor chips from Asia and North America. Europe would lose its 10% global semiconductor chip market share and consequently fail to fulfil the objectives in the EU Chips Act and other EU strategic objectives.

Chemours Impact

Under a continued use scenario, it is estimated that Chemours would import a total of 7,700 to 9,300 tonnes of Teflon™ PFA into the EU for use in semiconductor manufacturing and other uses. *These imports translate to a revenue and profit of €423 million to €1.0 billion and €294 million to €706 million respectively, over the assessment period.* ***Of these imports between 3,000 and 4,700 tonnes will be specifically imported for use within the semiconductor industry generating revenues of between €169 million and €508 million resulting in profits of between €117 million and €353 million.***

Under a non-use scenario, ***Chemours APM will be forced to cease all their Teflon™ PFA related activities in Europe. This will result in a total loss of all revenue and profits stated above for both semiconductor and other uses of Teflon™ PFA. In addition to this, 629 individuals will face being made unemployed incurring a further social cost of over €111 million.***

At present Chemours APM have a diverse range of projects in their research and development portfolio across several sites in Europe. Over the assessment period APM will spend nearly €91 million on PFAS related R&D. This R&D is connected to PFAS but is not directly exploring alternatives to fluoropolymer materials. There is additional spending of €190 million on operational R&D to develop and improve their manufacturing processes and logistics chains. Under a non-use scenario, APM would move its fluoropolymer related R&D to outside of Europe as there would be no European sales portfolio to fund these investments. This is due to all APM products being fluoropolymers which would all become restricted.

Downstream Impact

The semiconductor supply chain reliant on access to Teflon™ PFA is estimated to generate profits of over €63.4 billion under a continued use scenario. This essential supply chain subsequently permits the automotive sector to operate and generate profits of over €206 billion during the assessment period. This is likely to be an underestimation.

Under a non-use scenario this supply chain within Europe would cease operations leading to economic losses of €63.4 billion. In addition to this over 21,000 employees would face redundancy incurring a further social cost of over €3.1 billion.

The automotive industry is highly reliant on semiconductors as all modern cars, especially electric vehicles have more and more electronic systems requiring processors to function. Therefore, while the automotive sector is not reliant on Teflon™ PFA itself, it is reliant on the chips that are made with the help of the Teflon™ PFA . Under a non-use scenario when just considering Teflon™ PFA, the automotive sector would be expected to switch to importing 100% of the chips it needs to operate which would not result in a loss of sales or profits. There would however still be damage to the European economy in terms of supply chain security and balance of trade implications. If a wider fluoropolymer ban is considered however chips would no longer be able to be imported as well leading to the automotive industry in Europe to collapse. This would result in an economic loss of €206 billion and see over 1.14 million people unemployed incurring a social cost of over €236 billion. However, since all electronic devices use a form of semiconductor chip, integrated circuit, or transistor, it can be assumed that all electronic and technology sectors will be impacted to some degree. A wider implication assessed is the use of fluoropolymers in a wide range of electronic components that enable around 50% of Europe's GDP. ***Therefore, it can be assumed that 50% of Europe's GDP, or €7.25 trillion, will be affected if all fluoropolymers are restricted.***

Therefore, overall access to Teflon™ PFA under the continued use scenario will permit great value to be generated and distributed across Europe but also for key strategic aims to be achieved that would otherwise not be met.

Semiconductor manufacturers are planning to make investments worth tens to hundreds of billions of Euros into the establishment of new production facilities in Europe. These plans and investments are in line with the EU Chips Act and include e.g. Intel's plans to invest over €80 billion across several Member States and GlobalFoundries Inc. and ST Microelectronics $6 billion plan to construct a joint fabrication facility in France. There could be additional billions lost with as an estimated nine fabrication facilities are expected to begin construction in Europe by 2023. Semiconductor fabs cannot operate without the use of Teflon™ PFA to produce the core infrastructure machines and chemical distribution systems that transport chemicals across the fabrication and process tools. Industry sources have indicated that a restriction would place intolerable and unworkable conditions onto government subsidy proposed under the European Chips Act. Therefore, a restriction will result in the total loss of all current and future semiconductor investment and manufacturing capacity and the semiconductor industry will cease operating in the European market and focus on better geographies for investment such as North America and South Korea.

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Glossary

Acronym	Full name
AoA	Analysis of Alternatives
APM	Advanced Performance Materials (Division of Chemours)
CAGR	Compound annual growth rate
CAS	Chemical abstracts service
CLP	Classification Labelling and Packaging
CPVC	Chlorinated polyvinyl chloride
CRC	Corporate responsibility commitment
DMSO	Dimethyl sulfoxide
DO	Dissolved oxygen
EBA	European battery alliance
EC	European commission
ECHA	European Chemicals Agency
ECTFE	Ethylene chlorotrifluoroethylene
EEA	European Economic Area
ESIA	European semiconductor industry association
EU	European Union
EV	Electric Vehicle
FEP	Fluorinated ethylene propylene
FGEW	Functional group equivalent weight
FOC	Fluorinated organic chemical
FPG	Fluoropolymers product group
GDP	Gross domestic product
GHG	Greenhouse gases
HCl	Hydrochloric acid
HDPE	High density polyethylene
HF	Hydrogen fluoride
HFP	Hexafluoropropylene
HP	High purity
ICE	Internal combustion engine
IP	Intellectual property
IRDS	International Roadmap for Devices and Systems
IXM	Ion exchange materials
LED	Light emitting diode
NACE	"nomenclature statistique des activités économiques dans la Communauté européenne", the Statistical Classification of Economic Activities in the European Community
MMAD	Median mass aerodynamic diameter
MRI	Magnetic resonance imaging
MW	Molecular weight
MWD	Molecular Weight Distribution
OECD	Organisation for economic co-operation and development
OEM	Original equipment manufacturers
PBT	Persistent, bioaccumulative, toxic

Acronym	Full name
PC	Personal computer
PEEK	Polyether ether ketone
PFA	Perfluoro alkoxy
PFAS	Per- and polyfluorinated substances
PFSA	Perfluoro sulfonic acid
PLC	Polymer of Low Concern
PP	Polypropylene
PRODCOM	Production Communautaire. An annual survey for the collection and dissemination of statistics on the production of industrial (mainly manufactured) goods, both in value and quantity terms, in the European Union
PTFE	Polytetrafluoroethylene
PVC	Polyvinyl chloride
PVDF	Polyvinylidene fluoride
RAC	Risk assessment committee
REACH	Registration, evaluation, authorisation and restriction of chemicals
RFG	Reactive functional groups
RMOA	Regulatory management options analysis
SDS	Safety data sheet
SEA	Socio-economic analysis
SEAC	Socio-economic analysis committee
SEMI	Semiconductor equipment and materials international
STOT SE	Specific target organ toxicity single exposure
STOT RE	Specific target organ toxicity repeat exposure
SVHC	Substance of very high concern
THF	Tetrahydrofuran
TFE	Tetrafluoroethylene
TOC	Total oxidisable carbon
TSS	Thermal Specialised Solutions
UV	Ultraviolet
VOC	Volatile organic compound
vPvB	Very persistent, very bioaccumulative

1 Introduction

1.1 Background to the study

Per- and polyfluoroalkyl substances (PFAS) are a group of widely used synthetic organic chemicals whose properties are attributed to very strong, stable and apolar carbon-fluorine bonds. Five European countries made up of Norway, Germany, Denmark, Sweden and The Netherlands are currently preparing a restriction dossier due to be published in January 2023 under the EU REACH Regulation (EC) 1097/2006 (REACH). In the Registry of Intention of the PFAS restriction[1], PFAS are defined as "fluorinated substances that contain at least one fully fluorinated methyl (CF_3^-) or methylene (CF_2^-) carbon atom (without any H/Cl/Br/I atom attached to it)". This definition is similar to the Organisation for Economic Co-operation and Development (OECD) definition[2] that specifies a few noted exceptions, being "any chemical with at least a perfluorinated methyl group ($–CF_3$) or a perfluorinated methylene group ($–CF_2–$) is a PFAS." The substance subject of this study is the high-performance fluoropolymer Teflon™ perfluoro alkoxy (PFA) that fall under this PFAS definition.

1.2 Study objectives

This study aims to objectively demonstrate the impact of a potential REACH Restriction of PFAS on Chemours APM division and its downstream customers. The overall objective of this study is to develop a Socio-economic Analysis (SEA) for the continued use of Teflon™ PFA versus the non-use scenario. The non-use scenario used in this study is envisaged as a complete ban of PFAS, meaning a ban on fluoropolymers and consequently Teflon™ PFA from 2025.

In particular, this study aims to develop a SEA for Teflon™ PFA when used in the semiconductor manufacturing industry.

1.3 Approach and methodology

The RPA study team has collected and analysed data to answer the study objective. Data has been collected on the:

- Applications relevant to the study to understand the end-uses and actors in the supply chain;
- Alternatives to the substances that are under investigation or currently available;
- Response of businesses and society to a restriction, to quantify impacts and compare to other regulatory measures.

Several data sources were used to obtain relevant information concerning the properties of PFAS in the semiconductor sectors including:

- Analysis of the grey and academic literature for chemical and mechanical properties of the substances under study;
- Questionnaires, interviews and data collected via responses to our questions in consultation with Chemours APM and its subject matter experts, as well as their downstream customers.

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1 Registry of Restriction intentions until outcome found here https://echa.europa.eu/registry-of-restriction-intentions/-/dislist/details/0b0236e18663449b accessed November 2022

2 OECD. Series on Risk Management No. 61, 2021. available at https://www.oecd.org/env/ehs/risk-management/series-on-risk-management-publications-by-number.htm accessed November 2022

1.4 Structure of this report

The structure of the remainder of this report is as follows:

- Section 2 Substances within the Scope of the Study: describes the structure, properties and regulatory context of Teflon™ PFA;
- Section 3 Chemours: describes the processing activities at Chemours' EU sites which involve Teflon™ PFA;
- Section 4 Sectors and uses for Teflon™ PFA: discusses the role of Teflon™ PFA in the semiconductor sector;
- Section 5 Hazard properties: describes the hazards associated with Teflon™ PFA, their release to the environment and the release of residual monomers;
- Section 6 Analysis of Alternatives: alternative materials to Teflon™ PFA are examined in their ability to replace PFAS in the use cases within the scope of this study.
- Section 7 Continued use scenario: assesses the socioeconomic landscape within Chemours APM and its downstream users should an exemption to the PFAS restriction be provided for the use cases in the scope of this study;
- Section 8 Non-use scenario: assesses the socioeconomic landscape of within Chemours APM and its downstream users should a PFAS restriction prohibit the use of Teflon™ PFA in the use cases within the scope of this study;
- Section 9 Conclusions: information gathered in this study is collated and a final commentary is made on the availability of alternatives and the overall effects of a PFAS ban versus the continued use scenario.

2 Substances within the Scope of the Study

2.1 Fluoropolymers

The polymer within the scope of this study is Teflon™ PFA (perfluoro alkoxy CAS 26655-00-5, EC 682-550-7).

This polymer belongs to a group of polymers known as fluoropolymers. Fluoropolymers are a sub-group of per- and polyfluoroalkyl substances (PFAS) as per the Organisation for Economic Co-operation and Development[3] (OECD) definition, as they contain a fully fluorinated methyl group ($-CF_3$). Teflon™ PFA is a copolymer, meaning that it is formed from two or more different types of monomers, i.e. tetrafluoroethylene (TFE) and perfluoro alkyl vinyl ether (PxVE) comonomers.

Polymers, and therefore fluoropolymers, are currently not subject to registration under REACH. As such, a full picture concerning the production tonnage volumes of these substances in the EU is not complete. Polymers, including fluoropolymers, are not considered as high a concern toxicologically as non-polymeric substances due to their very high molecular weights. This makes transport across biological membranes, such as the skin or gut-lining, unlikely. Additionally, the volume of fluoropolymers makes up <1% of global polymer production[4].

The presence of uniquely stable carbon-fluorine bonds provides fluoropolymers with outstanding chemical properties, making them a high-performance and unparalleled family of substances. Fluoropolymers have a unique set of properties, including durability, stability, and mechanical strength in harsh conditions, as well as chemical inertness, permeation resistance, non-wetting, non-stick and high resistance to temperature, fire, and weather[5].

Due to their properties, fluoropolymers have applications in many sectors including automotive, aerospace, environmental control, energy production and storage, medical, pharmaceutical, chemicals industry and electronics that are not easily replaceable with other substances or materials. The added benefits of using fluoropolymers in these applications include increased equipment reliability resulting in longer product use life, reduced spills and releases, and enabling vehicles to meet EU emission and safety standards.

2.2 EU Regulatory context

Since the announcement of the five countries' intention to publish a broad restriction of PFAS[6] in the EU, industry has maintained that fluoropolymers be excluded for several reasons. An independent Regulatory Management Options Analysis (RMOA)[2] was commissioned by PlasticEurope's Fluoropolymers Product Group (FPG), concluded that restriction under REACH was not an effective

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[3] https://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/terminology-per-and-polyfluoroalkyl-substances.pdf accessed July 2022

[4] Based on 2.44 million tonnes of fluoropolymers produced in 2020 found here https://www.chemanalyst.com/industry-report/fluoropolymer-market-315 and 367 million tons of polymers produced in 2020 found here https://www.statista.com/statistics/282732/global-production-of-plastics-since-1950/. Accessed November 2022

[5] https://fluoropolymers.plasticseurope.org/application/files/5416/5104/8333/20211104_FP_RMOA_Final_3.pdf accessed September 2022

[6] https://echa.europa.eu/registry-of-restriction-intentions/-/dislist/details/0b0236e18663449b accessed August 2022

tool for the adequate risk management of these substances and does not align with the need to ensure a high level of human health and environmental protection in the EU. Instead, the FPG propose a broad derogation for fluoropolymers, supplemented by a Voluntary Industry Initiative to ensure that industry will address situations of concern related to the manufacture and use of fluoropolymers.

2.2.1 Perfluoro alkoxy

Perfluoro alkoxy is marketed by Chemours under the commercial name Teflon™ PFA (Figure 2-1). It is a copolymer resin, available in pellet, powder or dispersion form, and is used in the chemical processing, electronics, semiconductor, pharmaceutical, and biotechnology sectors.

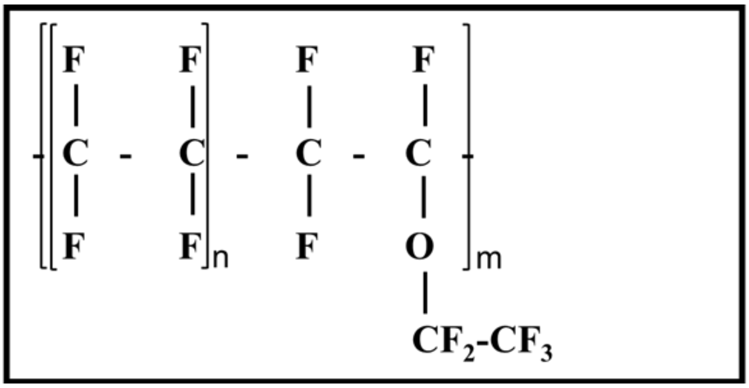

Figure 2-1: Chemours structure of perfluoro alkoxy
*Source: **Image provided by Chemours***

The commercial product is the copolymer of tetrafluoroethylene (CAS 116-14-3, EC No. 204-126-9) and perfluoro alkyl vinyl ethers (PAVEs) (perfluoro propyl vinyl ether (PPVE, CAS 1623-05-8, EC No. 216-600-2) and perfluoro ethyl vinyl ether (PEVE, CAS 10493-43-3, EC No. 234-018-7)) with similar properties to Teflon™ PTFE. A significant difference between these two polymers is the alkoxy substituents of Teflon™ PFA making it melt processable, whereas Teflon™ PTFE is not[7]. Additionally, Teflon™ PFA is resistant to almost all solvents and chemicals[8]. One of its main uses today is for its corrosion and impurity protection when handling high purity chemicals in the semiconductor and chemical processing industry[9]. The substance has a melting point of 300-310°C and can be processed into various components of all shapes and sizes due to its high melt strength and MIT flex life value >15,000 – 20,000 cycles. (Table 2-1).

7 https://www.processtechnology.com/pfa-ptfe-whats-the-difference#:~:text=Differences%20in%20alkoxy%20substituents%20allow,techniques%2C%20whereas%20PTFE%20is%20not. Accessed November 2022

8 https://www.processtechnology.com/pfa-ptfe-whats-the-difference#:~:text=Differences%20in%20alkoxy%20substituents%20allow,techniques%2C%20whereas%20PTFE%20is%20not. Accessed November 2022

9 https://www.teflon.com/en/industries-and-solutions/industries/semiconductor-manufacturing accessed July 2022

Table 2-1: Properties of perfluoro alkoxy	
Property	**Value**
CAS No.	26655-00-5
EC No.	682-550-7
Tensile Strength (23-250°C)	3,600-1,800 psi, 14-25 MPa
Elongation (23-250°C)	300-480 %
Flexural Strength (23°C)	No break at flexure (D 790)
Impact Strength (Izod)	No break
Yield Strength (23°C)	1740 psi, 12 MPa
MIT Folding Endurance (0.20mm, 8 mil film)	>20,000 cycles
Density	2120-2170 kg/m^3
Melting Point	300-310°C
Thermal Conductivity	0.209 W/m·K
Service Temperature	-250 – 260°C
Processing Temperature	370-395°C
Source documents https://www.fluorotherm.com/technical-information/materials-overview/pfa-properties/ accessed September 2022 *https://www.teflon.com/en/-/media/files/teflon/teflon-pfa-440hpa-product-info.pdf?rev=63ef51ddbf6d4d099c097c67394c5215&hash=7E68C9C2B50FB30FA23461E14D8E2803 accessed November 2022*	

A portfolio (Table 2-2) of melt processable high purity PFA resins (Teflon™ PFA HP) are available from Chemours. These high purity grades of Teflon™ PFA have fully fluorinated stabilised end groups, meaning they will no longer be reactive or cling to metal ions. In addition, these grades have low levels of extractables, higher stress crack resistance and improved flex life (>15,000 – 20,000 cycles) compared to standard grades of PFA. Teflon™ PFA HP Plus is similar to PFA HP with the additional benefits of improved flex life or chemical stress crack resistance. Additionally, Teflon™ C PFA combines the properties or standard Teflon™ PFA with anti-static properties[10].

Table 2-2: Chemours grades of PFA for semiconductor applications		
Grade	**Description**	**Applications**
Teflon™ PFA 400HP Series	Fully fluorinated resins tailored to meet chemical fluid handling industry requirements for high purity and minimum extractables	Injection moulding for high purity applications (fittings, valve bodies, filter housings), sheet lining for high purity chemical delivery systems
Teflon™ PFA 900HP Plus Series	Similar purity to 400HP series, but with improved flex life, chemical stress crack resistance and prevent microbial build-up	Similar uses as 400HP series, but with longer lifetime
Teflon™ PFA C-960, C-980	Provides components with an anti-static property for applications that require this. Such as the semiconductor and chemical processing industries.	Cables, tubing, linings, and moulded parts that require static dissipative performance
Source: https://www.teflon.com/en/products/resins/pfa-resins accessed July 2022		

10 https://www.teflon.com/en/-/media/files/teflon/teflon-pfa-c960-product-info.pdf accessed August 2022

As a polymer, Teflon™ PFA is not a REACH registered substance and does not have a harmonised classification and labelling under Regulation (EC) No. 1272/2008. Registered users of the substance self-classified the substance and accounted for three notifications on the ECHA website. The registrants notified the polymer as not classified[11].

[11] https://echa.europa.eu/fr/information-on-chemicals/cl-inventory-database/-/discli/details/212887 accessed 2022

3 Chemours sites and Corporate Responsibility Commitments

3.1 Chemours sites in Europe

Chemours APM business has manufacturing and blending activities in three sites in Europe: Dordrecht in the Netherlands, Villers-St-Paul in France, and Mechelen in Belgium. Advanced Performance Materials (APM) division operates at all three sites. The Dordrecht site is shared with the Thermal & Specialised Solutions (TSS) division of the company, but the majority of the site is used by APM for the manufacture of fluorinated monomers, fluoropolymers and fluoroelastomers.

Teflon™ PFA is imported by Chemours into Europe from the United States in varying forms such as pellets powders, or dispersions. Once received at the Dordrecht site, Teflon™ PFA is stored in a warehouse before shipment to the customers. Any waste (e.g., returned complaint material) that is received is either reprocessed, resold as second grade material or disposed of by incineration through authorisation waste handling companies.

3.1.1 Emissions abatement

There are no emissions pertaining to the polymerisation of Teflon™ PFA in Europe. All processing of Teflon™ PFA fluoropolymers takes place outside Europe.

While there is processing of monomers, polymerisation aids and other fluoropolymers and fluoroelastomers at the Dordrecht site, this is out of the scope of the study and emissions abatement will only be discussed briefly on a global level.

Chemours has made a year 2030 Corporate Responsibility Commitment[12] (CRC) to reduce greenhouse gases produced during manufacture by 60% relative to a 2018 baseline and to achieve net-zero operation emissions by 2050. Additionally, Chemours is looking to reduce air and water process emissions of fluorinated organic chemicals by 99% and to reduce their landfill volume by 70% relative to a 2018 baseline. These reduction objectives are based on global levels and are not site specific.

For air and water process emissions of fluorinated organic compounds, Chemours has already achieved a 40% reduction relative to the 2018 baseline. These values are presented within the CRC report.

These goals are being achieved through the installation of abatement systems to reduce fluorinated organic compound emissions to both air and water. Chemours manufacturing plant at Dordrecht has emissions currently below the tightened environmental permit levels.

In 2021, improvements to water treatment processes were made at three of Chemours' sites. These improvements include the thermal destruction of addition emission streams, installation of adsorption technology for aqueous waste streams and recovery to reuse in the chemical manufacturing process[13].

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12 https://www.chemours.com/en/-/media/files/corporate/crc/2021/chemours-responsibility-commitment-report.pdf accessed August 2022

13 Chemours 2021 Corporate Responsibility Commitment Report https://www.chemours.com/en/-/media/files/corporate/crc/2021/chemours-responsibility-commitment-report accessed September 2022

The exposure risks to workers are mitigated through measures depending on the physical state of the PFAS material, potential hazards of the material, and the degree of potential exposure. All workers working closely with these hazardous materials are fully trained on the hazards, procedures and protective measures that should be taken. Protective measures put in place to protect workers from exposure include dermal and respiratory personal protective equipment or the use of ventilation. Each facility using PFAS materials have risk assessments performed to evaluate the potential for worker exposure and to ensure these risks are controlled. The chemical processes using PFAS materials are within closed systems. If these closed systems need to be opened for maintenance or sampling of the chemical process for example, the requirements for opening the system are defined in authorised operating procedures or permits.

4 Sectors and uses for Teflon™ PFA

4.1 Discussion on all uses

In the following sections the uses of Teflon™ PFA will be discussed with a focus on the semiconductor industry, and the importance of semiconductor chips to the automotive industry. This end use has been selected as the main focus area for the use of Teflon™ PFA in this report.

Teflon™ PFA materials are used in many applications in addition to semiconductor manufacturing such as the chemical processing, electronics, pharmaceutical and biotechnology sectors. Teflon™ PFA can be used in many products including tubing, wiring and cabling, moulded parts, and pipe lining, among others. The substance is available in different forms such as coatings and films or dispersions, each with varying grades of purity[14]. Further applications using PFA include filtration housings, heat exchangers, pump housing, fittings, and others[15]. PFA's resistance to almost all solvents and chemicals, in addition to its flame resistance and high dielectric strength make it an attractive option to use in processes that operate under extreme conditions (e.g., highly corrosive, extreme temperature variations etc.)[16].

4.2 Semiconductor industry

The semiconductor industry is a fast-growing sector globally, producing semiconductor chips which are essential for modern technology and electronic devices used everywhere in society. The advancement of semiconductors has led to improved system efficiency, energy savings, and the micro scaling of electronics, in addition to advancements in communication, healthcare, transportation, clean energy, and military system technology.

Not only are semiconductor chips essential to modern technology, but they are "strategic assets for key industrial value chains"[17]. The digital transformation of society has seen new markets for the chip industry emerge, such as highly automated vehicles, the cloud, the Internet of Things (IoT), connectivity (5G/6G), space/defence, computing capacity and supercomputers[18]. To secure the EU's supply, and resilience and technological leadership in semiconductor technology, the European Commission proposed the European Chips Act to help the EU achieve its targeted digital and green transition[19]. After the Covid-19 pandemic, a chip shortage was experienced globally having a knock-on effect throughout multiple sectors. As an example, the EU automotive sector experienced vehicle production reduced by one third in 2021 in some Member States [20]. This demonstrated the reliance society and industries have on the stability of the semiconductor industry. The European Chips Act will look to increase Europe's production and market share of semiconductor technology, further

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14 https://www.teflon.com/en/products/resins/pfa-resins accessed July 2022

15 https://www.processtechnology.com/pfa-ptfe-whats-the-difference#:~:text=Differences%20in%20alkoxy%20substituents%20allow,techniques%2C%20whereas%20PTFE%20is%20not. Accessed November 2022

16 https://www.processtechnology.com/pfa-ptfe-whats-the-difference#:~:text=Differences%20in%20alkoxy%20substituents%20allow,techniques%2C%20whereas%20PTFE%20is%20not. Accessed November 2022

17 https://ec.europa.eu/commission/presscorner/detail/en/ip_22_729 accessed November 2022

18 https://ec.europa.eu/commission/presscorner/detail/en/ip_22_729 accessed November 2022

19 https://ec.europa.eu/commission/presscorner/detail/en/ip_22_729 accessed November 2022

20 https://ec.europa.eu/commission/presscorner/detail/en/ip_22_729 accessed November 2022

develop the skills to become a global leader in the field and reduce the EU's dependency on imports to secure the supply of semiconductors[21].

4.2.1 Semiconductor manufacturing

Semiconductors possess elements of both electrical conductors and insulators and are typically made from base materials such as silicon and germanium, with silicon being the most widely used[22]. In the overall manufacturing of semiconductor wafers and chips there are 400 to 600 steps that take place over one to two months[23]. Based on information gathered during consultation it is understood that the manufacture and production of semiconductor chips is carried out entirely within ultra-pure environments (See Figure 4-1).

Figure 4-1: Semiconductor chip fabrication plant
Source: https://www.protocol.com/enterprise/intel-euv-fab-chips accessed November 2022

Although the wafers are never exposed to air, the clean room environments are maintained through filtering systems removing nanosized particles from the air[24]. Workers in semiconductor manufacturing facilities are required to wear cleanroom suits to avoid human contamination. The process is conducted entirely in a closed system meaning any chemical exposure to workers is low or negligible. This gives a clear representation of how sensitive semiconductor manufacturing processes and devices are to contamination.

21 https://ec.europa.eu/commission/presscorner/detail/en/ip_22_729 accessed November 2022
22 https://www.hitachi-hightech.com/global/products/device/semiconductor/properties.html accessed July 2022
23 https://www.hitachi-hightech.com/global/products/device/semiconductor/metrology-inspection.html accessed July 2022
24 Downstream user consultation 2022

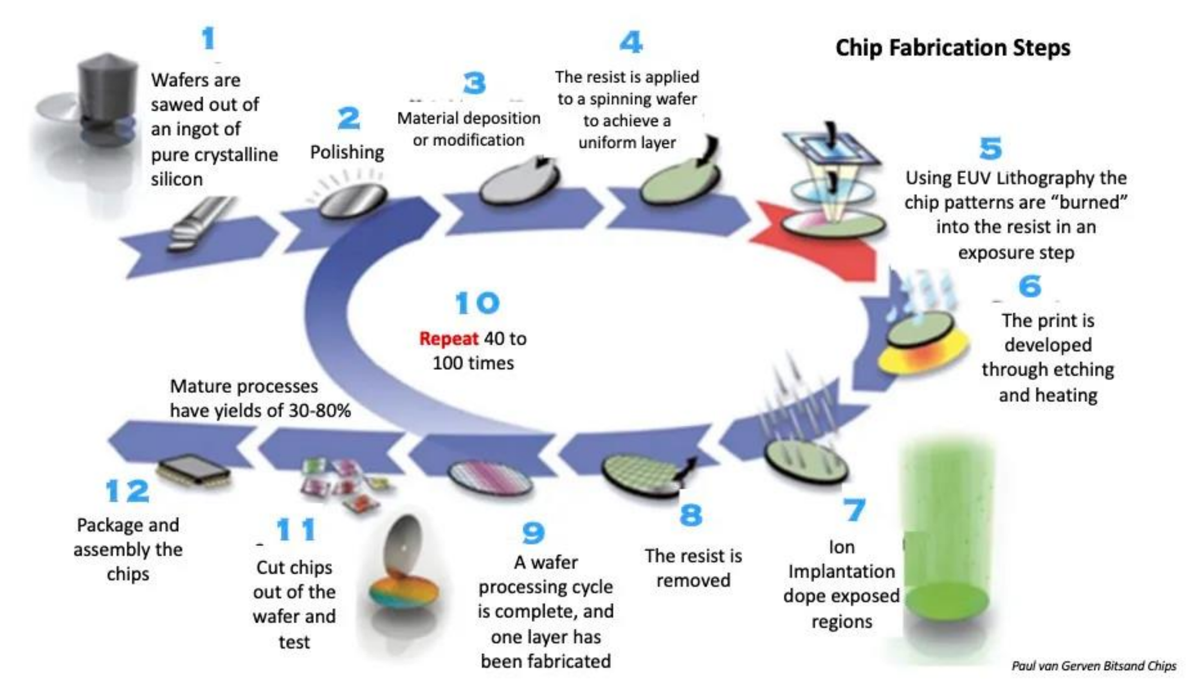

Figure 4-2: Semiconductor chip fabrication timeline
Source: *https://steveblank.com/2022/01/25/the-semiconductor-ecosystem/* accessed June 2022

In semiconductor manufacturing during a process (See Figure 4-2) known as doping, impurities are added to the pure wafer elements (silicon, germanium) to cause changes in the conductivity of the materials' surface (step 3 in Figure 4-2)[25]. After polishing and film deposition, the wafer will have transistors formed on its surface and undergo several subsequent processing steps. During film deposition, the wafer is coated with a thin film that will form the wiring and transistors and is then coated with a photoresist (step 4 in Figure 4-2). The circuit pattern is then projected on the photoresist using a lithography machine (step 5 in Figure 4-2)[26]. Once the photoresist is developed it is used to process the film into the shape of wiring or other components (steps 6 to 9 in Figure 4-2)[27]. This forms one layer of the circuit, and this process is then repeated to form multiple layers of circuits. After the formation of a layer there are inspection steps to ensure the patterns have been fabricated correctly. In the case that a defect is found the process will be stopped to address the errors[28]. There are many metrology and inspection points that are established at critical points in the manufacturing process[29]. Upon completion of the manufacturing and inspection process, the wafers are cut into individual chips or dies and are then packaged (steps 11 to 12 in Figure 4-2) according to the final product it will be used in (See Figure 4-3).

[25] https://www.semiconductors.org/semiconductors-101/what-is-a-semiconductor/ accessed July 2022
[26] https://www.hitachi-hightech.com/global/products/device/semiconductor/process.html accessed July 2022
[27] https://www.hitachi-hightech.com/global/products/device/semiconductor/process.html accessed July 2022
[28] https://www.hitachi-hightech.com/global/products/device/semiconductor/process.html accessed July 2022
[29] https://www.hitachi-hightech.com/global/products/device/semiconductor/metrology-inspection.html accessed July 2022

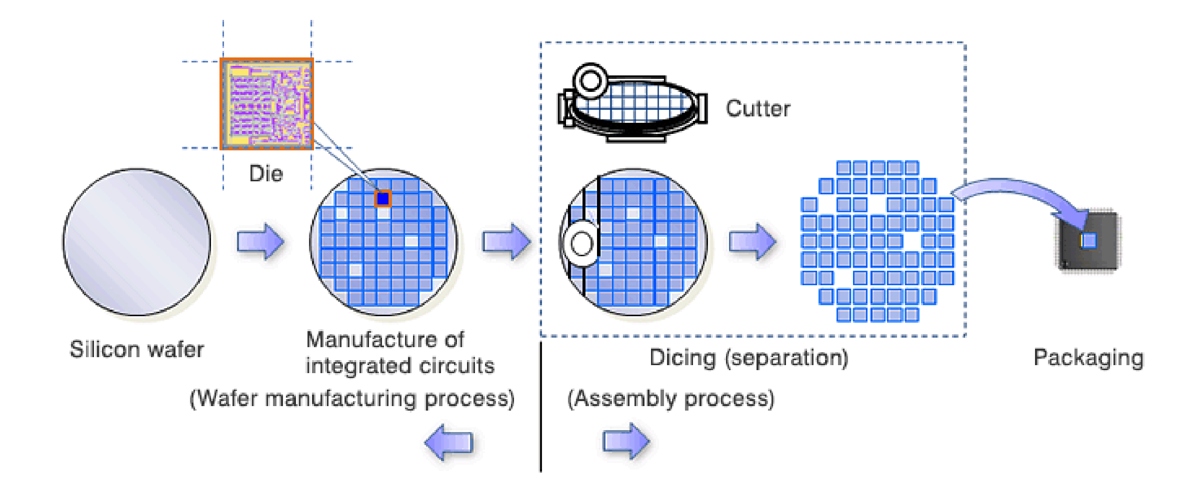

Figure 4-3: Die cutting process
Source: *https://www.hitachi-hightech.com/global/products/device/semiconductor/metrology-inspection.html* accessed July 2022

The above briefly demonstrates the complexity of the semiconductor manufacturing process. The following sections will discuss the standards, and roles and benefits of Teflon™ PFA in the semiconductor manufacturing process, as well as key end use sectors for semiconductors.

4.2.1.1 Standards governing semiconductor manufacture

SEMI standards are established and written by various players within the semiconductor industry and outline various methods of determination and purity levels of component materials used in semiconductor manufacturing[30]. SEMI standards are not legally binding, and it is not an industry requirement to assess and conform to, however they are often considered as *de facto* requirements. Typically, testing and cleanliness requirements are established between raw material supplier and component manufacturer.

Standard SEMI 57 is a specification used in ultra-pure water transport that outlines what needs to be assessed, for example metallic and ionic contaminants (Table 4-2). SEMI F40[31] is a practice for how to prepare components or pellets for testing, for example a seven-day extraction test is conducted where the component is placed in water for seven days to determine what contaminants are leached out. These tests are not a requirement unless a fabrication plant or equipment manufacturer asks for proof of material cleanliness. More specifically, Teflon™ PFA components and resin are monitored for impurities including metallic, ionic and total organic compounds according to SEMI C90[32]. Standard SEMI C90 outlines methods for testing acceptable maximum levels for extractable iron content for Teflon™ PFA resins and components. A revision of SEMI C90 is currently underway to add other metal extractable limits to the standard and align more with SEMI F57 and end user requirements. It is important to remember that materials chosen should have the mechanical properties required and

[30] https://www.semi.org/en/products-services/standards
[31] SEMI F40 - Practice for Preparing Liquid Chemical Distribution Components for Chemical Testing
[32] SEMI C90 – Test Method and Specification for testing PFA Materials used in Liquid Chemical Distribution Systems

be compatible with the operating temperature of the application and the methods used for bacteria reduction, including ozone, UV light and/or hydrogen peroxide[33] (Table 4-1, Table 4-3).

Table 4-1: SEMI standard requirements	
Standard	**Contamination Limits**
SEMI C90 – test method and specification for testing PFA materials used in liquid chemical distribution systems	<5 µg/m² for extractable iron following an extraction method below: Resin – 5% nitric acid 70°C for 4 hours Components – 5% nitric acid ambient 24 hours
SEMI F40 – practice for preparing liquid chemical distribution components and neat polymers for chemical testing	Extraction methods: Tested as received Resin and Components – UPW 85°C 7 days
SEMI F57 – specification for polymer materials and components used in UPW and liquid chemical distribution systems	SEMI F57-0622 specifies that pellet testing frequency, form of the material, surface area calculation methods, contamination limits and units reported shall all be part of a negotiated agreement between raw material suppliers and component manufacturers. (Table 4-2)

Table 4-2: SEMI F57-0622 Limits	
Ionic Contaminant	**Ionic Extraction Limits (µg/m²)**
Ammonium	≤100
Bromide	≤100
Chloride	≤100
Fluoride	≤2000
Nitrate	≤100
Nitrite	≤100
Phosphate	≤100
Sulphate	≤10
Metallic Contaminant	**Metallic Extraction Limits (µg/m²)**
Aluminium	≤5
Arsenic	≤2
Antimony	≤2
Barium	≤15
Boron	≤30
Cadmium	≤2
Calcium	≤10
Chromium	≤1
Copper	≤10
Iron	≤5
Lead	≤1
Lithium	≤2
Magnesium	≤2
Manganese	≤5
Nickel	≤1
Potassium	≤10

33 https://global.ihs.com/doc_detail.cfm?document_name=SEMI%20F57&item_s_key=00502180 accessed May 2022

Table 4-2: SEMI F57-0622 Limits	
Sodium	≤10
Strontium	≤0.5
Titanium	≤2
Tin	≤2
Vanadium	≤2
Zinc	≤5
Total organic carbon	≤4000

Components made from a different or new material need to be qualified in accordance with specifications usually determined further down the supply chain by fabrication plants. Fabrication plants will ask for data and proof that these new material components are pure and durable enough to be used. This can be a lengthy process and can take numerous years to qualify new materials. Typically, it will take three to five years to get base data on how the material will perform in the applications and determine its viability for use. Installation would then have to wait until there is a shut down or until the fabrication plant is forced to replace it. To qualify a new material could take a minimum of twice this time.

Table 4-3 presents a non-exhaustive list of component property requirements that are needed for use in the semiconductor manufacturing process. These properties may be referred to in the Analysis of Alternatives (Section 6) and used to assess the viability of alternative materials.

Table 4-3: Component property requirements for semiconductor manufacturing	
Property	**Description**
Purity	Must meet high purity performance requirements for semiconductor manufacturing for low leaching potential and low particle shedding. The following address surface extractable ionic and metallic contamination limits, as well as total organic carbon extraction limits. The IRDS 2022 Yield Enhancement Report[34] specifies estimated cleanliness requirements in next node generation manufacturing. The IRDS and SEMI work in collaboration to develop these standards and drive yield management solutions. SEMI F57 SEMI C90 SEMI F51 SEMI F104
Low Coefficient of Friction	Wear resistance (e.g., bearing performance), purity, article lifetime
Temperature stability (high and low)	Continuous operating temperature up to 260°C
Chemical and Permeation Resistance	Must be compatible with: wastewater treatment systems, chemical distribution fluids, acids and caustics per SEMI F61 Resistant to corrosion Absence of hydrocarbons Chemical inertness UV resistance Resistance to bacterial or bio-growth
Processability	Easy to mould or extrude
Non-flammability	Must pass FM 4910 standard for use in semiconductor manufacturing processes

[34] https://irds.ieee.org/editions/2022/irds%E2%84%A2-2022-yield-enhancement accessed November 2022

Table 4-3: Component property requirements for semiconductor manufacturing	
Property	**Description**
Mechanical characteristics	Stability, elasticity, flexibility, low friction, low surface energy
Resistant to outgassing	Allows for compliance to SEMI F57 requirements for total organic carbon extraction limits Produces acceptable low VOC contamination even under conditions of chemical welding
Electrical Performance	Dielectric, Resistance (static and DC discharge), tracking properties (quality of whether carbon tracks can form in the material), triboelectric, electrically insulating
Article Lubrication	Low volatility in vacuum environment Long term retention of viscosity
Repellence properties	The material should not absorb water or moisture. A weathering study for Teflon™ PFA showed a moisture absorption of <3% after 24 hours in water at ambient temperature, followed by 2 hours at boiling water.

These extremely stringent standards and testing requirements is what make it difficult for other materials to simultaneously meet the requirements needed, rendering them not feasible.

4.2.2 Role of Teflon™ PFA in semiconductor manufacturing

The preciseness and complexity of semiconductor manufacturing requires the use of materials that enhances and compliments this process. The extensive procedures, with many stages and inspection points, demands environments and materials that are robust and do not impede on production. The use of ultra-pure materials reduces the contamination factor and ultimately result in higher product yields. Semiconductor manufacturers rely on Teflon™ PFA to prevent contamination, corrosion, and leaching in chemical fluid-handling systems that transport critical process fluids throughout the fabrication plant.

A node often refers to different generations of circuits or chips and is essentially the size of the transistor[35]. The current node technologies are at 7 nm, with the next targets being 2 to 5 nm. The smaller a technology node, the smaller the feature size. This means smaller transistors therefore, increasing the number of transistors on a wafer leading to a more powerful and efficient chip[36]. New technology nodes require increased fluid-purity levels to reduce contaminants and defects and ultimately maintain acceptable wafer yields, putting greater demands on fluid-handling systems. As nodes shrink, so does the size of critical defects and the total acceptable particle count. The International Roadmap for Device and Systems (IRDS) collaborates with the SEMI organisation to establish control measures to ensure the reliability of systems is the main focus for development as node size decreases.

Teflon™ PFA based fluid handling equipment allows the transfer of the purest and most reliable materials from chemical distribution to wet etch and planarization processes with low risks of contamination[37]. There are target purity levels that are established for chemicals used in the manufacturing process, extreme care is taken so as not to introduce contamination from the source of chemical storage. The same level of care is observed further downstream the distribution process. The semiconductor chip manufacturing process is entirely automated and the carriers (boats), wands

35 https://anysilicon.com/semipedia/technology-node/ accessed September 2022

36 https://anysilicon.com/semipedia/technology-node/ accessed September 2022

37 https://www.teflon.com/en/industries-and-solutions/industries/semiconductor-manufacturing accessed November 2022

and robotic arms that transport and move the wafers throughout manufacturing can also be made from Teflon™ PFA[38]. Particle generation or shedding can occur at these points where components are moving[39]. As stated in the IRDS Yield Enhancement 2022[40] "*The performance characteristics of many of the process chemicals that are used for etching, plating, CMP and cleaning depend heavily on the amount and type of foreign material present as well as the consistency from batch to batch that is used in the process. The integrated effects of variability in the performance of these chemistries will play a significant role in the defect control within the manufacturing process*."

As the industry's requirements have evolved to become ever more demanding, the development of improved generations of fluoropolymers is critical to meet the needs of the industry.

Teflon™ PFA is an inert fluoropolymer that possesses qualities to enable the delivery of high purity fluids and the transportation of the wafers throughout the manufacturing process without contamination. This is achieved as Teflon™ PFA has very low leaching potential and particle shedding, as well as high levels of corrosion resistance and durability, meaning it can be used directly for manufacturing components[41], such as process vessels, pipes and fittings, tubing, valves and pumps, storage and transport containers, filters, and sensors[42]. These components come in contact with process chemistries used during the etching or rinsing stages, as well as with the wafer itself. The intrinsic qualities of Teflon™ PFA provides optimal technical functionalities and do not present any risks to disrupt the sensitive manufacturing process.

Materials used to make tubing and other components used in chemical distribution that come in direct contact with process chemistries need to be resistant to corrosive chemicals for an extended duration, as well as having low moisture permeation[43]. Specific purity grades of Teflon™ PFA allows excellent surface smoothness to be achieved. This contributes to enhanced cleanability and faster flushing times to guarantee low levels of particulates in process chemistries[44] (See Figure 4-4). When a fabrication plant starts up the components and tubing used will be flushed to ensure tubing and components are clean and a good particle baseline is established before production begins. Sometimes, this flushing is done for upwards of 6 months[45]. A smooth surface ensures there are no particles being trapped and built up while also reducing flushing time to ensure a quicker start up.

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[38] Downstream user consultation June 2022

[39] *INTERNATIONAL ROADMAP FOR DEVICES AND SYSTEMS™ 2022 UPDATE YIELD ENHANCEMENT THE IRDS IS DEVISED AND INTENDED FOR TECHNOLOGY ASSESSMENT ONLY AND IS WITHOUT REGARD TO ANY*. (2022).

[40] *INTERNATIONAL ROADMAP FOR DEVICES AND SYSTEMSTM 2022 UPDATE YIELD ENHANCEMENT THE IRDS IS DEVISED AND INTENDED FOR TECHNOLOGY ASSESSMENT ONLY AND IS WITHOUT REGARD TO ANY. (2022).*

[41] https://www.teflon.com/en/industries-and-solutions/industries/semiconductor-manufacturing accessed July 2022

[42] https://www.teflon.com/en/industries-and-solutions/industries/semiconductor-manufacturing accessed July 2022

[43] https://www.teflon.com/en/-/media/files/teflon/teflon-semicon-brochure.pdf accessed July 2022[43] https://www.teflon.com/en/-/media/files/teflon/teflon-semicon-brochure.pdf accessed July 2022

[44] https://www.teflon.com/en/-/media/files/teflon/teflon-semicon-brochure.pdf accessed July 2022[44] https://www.teflon.com/en/-/media/files/teflon/teflon-semicon-brochure.pdf accessed July 2022

[45] APM personal communication 2022

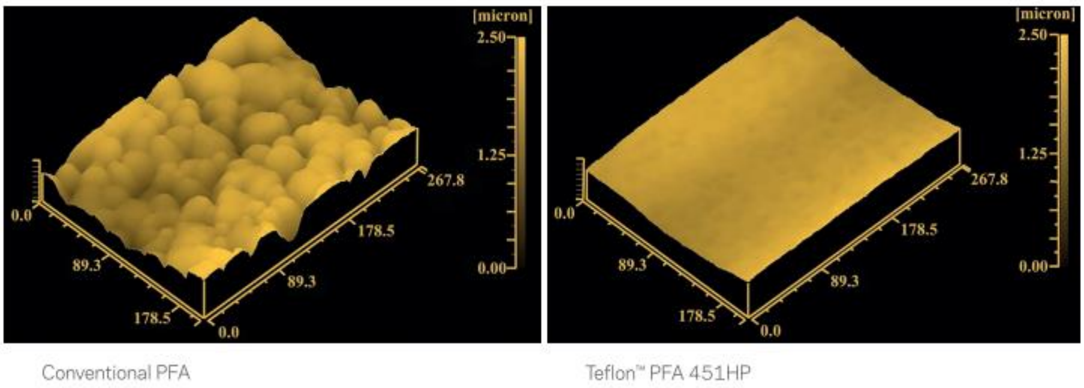

Figure 4-4: Surface smoothness comparison of conventional PFA and Teflon™ PFA 451HP
Source: https://www.teflon.com/en/-/media/files/teflon/teflon-semicon-brochure.pdf?rev=92a3c5d5cd884fffbddeb5221cce4ad2 accessed July 2022

Typically, materials or components used in the semiconductor manufacturing process should meet industry standards such as SEMI F57[46] (a specification used in ultra-pure water transport that outlines what needs to be assessed, for example metallic and ionic contaminants) and SEMI C90[47, 48] (which outlines methods for testing acceptable maximum levels for extractable iron content for Teflon™ PFA resins and components) among others. These extremely stringent standards make it difficult for other materials to meet them, while simultaneously possessing the physical and chemical properties (e.g., chemical/corrosion resistance, high purity, durability and thermal resistance) needed for semiconductor applications. Since Teflon™ PFA can be used in varying components throughout the process, it has an established importance with benefits largely due to the inertness of the polymer and its complimentary properties.

4.2.2.1 Benefits of Teflon™ PFA

Teflon™ PFA offers a combination of properties and performance characteristics that other materials cannot meet simultaneously. These inherent properties of Teflon™ PFA are what makes it suitable for use in the semiconductor manufacturing process. Its ability to remain functional at a range of temperatures, including at continuous operating temperature of up to 260°C combined with its very high chemical resistance make it the ideal material for semiconductor manufacturing. Teflon™ PFA is inert to a variety of very harsh chemicals (See Table 6-2), including:

- Strong mineral acids;
- Inorganic bases;
- Inorganic oxidants;
- Organic acids;
- Organic solvents;
- Fluorocarbons.

46 https://store-us.semi.org/products/f05700-semi-f57-specification-for-polymer-materials-and-components-used-in-ultrapure-water-and-liquid-chemical-distribution-systems? accessed July 2022

47 https://store-us.semi.org/products/c09000-semi-c90-test-method-and-specification-for-testing-perfluoroalkoxy-pfa-materials-used-in-liquid-chemical-distribution-systems? accessed July 2022

48 https://www.teflon.com/en/industries-and-solutions/industries/semiconductor-manufacturing/high-purity accessed July 2022

Teflon™ PFA has superior stress crack resistance, excellent flex life and UV performance to perform in the demanding high-stress manufacturing environment[49]. Additionally, its unsurpassable mechanical properties mentioned in Section 2.2.1 add to these benefits as it is inherently strong due to its tensile strength, flexural strength and Izod impact strength. Teflon™ PFA enables the semiconductor manufacturing industry and therefore enabling many other sectors in the EU and attributing to 50% of EU GDP. Additional benefits of PFA here are extended lifetime of components compared to traditional plastics having to be replaced every year or few years, that could result in additional expenses and downtime of the fabrication plant.

In summary, the main functionalities offered by Teflon™ PFA to enable the semiconductor manufacturing process include (see 6.1.1 for a description of these properties):

- Superior chemical and corrosion resistance to almost all solvents and chemicals;
- Extremely low leachability, permeability and low particle shedding;
- High continuous operating temperatures and melt processability;
- Low coefficient of friction;
- Good dielectric properties and
- Superior crack resistance at high temperature.

The functionality and role of Teflon™ PFA will be discussed in further detail in Section 6.1.1.

4.2.3 Overview of the semiconductor industry

The unique properties of fluoropolymers enable the production of semiconductor chips. It can be assumed, based on information gathered during consultation, that without fluoropolymers the manufacture of these chips would be severely impacted or cease altogether, consequently impacting a large number of industries. Semiconductors are used in a wide variety of industries and applications and are found in almost every electronic device[50], including computers, smartphones, cameras, televisions, life-saving medical devices, washing machines, refrigerators, and cars etc. Semiconductors enable the use of technologies that underpin today's society, which would not be able to function in the same way (knowledge sharing, digital communication) should their use be restricted.[51]

The European Semiconductor Association (ESIA) reported in February 2022 that semiconductor sales in Europe have increased by 27.3% compared to 2020 with the market reaching €47.22 billion in 2021[52]. In July 2022, global semiconductor sales were approximately €49.0 billion with sales in Europe reaching €4.46 billion[53]. This equates to an increase in European sales of 15.2% versus the same month in 2021. It was observed that growth across all end-use areas was consistent, being led by wired communication, consumer, and computer uses[54]. Recent data indicates the automotive chip market represents 37% of European semiconductor sales and is the biggest end-use sector in Europe[55]. The

[49] https://www.teflon.com/en/industries-and-solutions/industries/semiconductor-manufacturing accessed July 2022
[50] https://www.hitachi-hightech.com/global/products/device/semiconductor/life.html accessed July 2022
[51] https://www.semiconductors.org/semiconductors-101/what-is-a-semiconductor/ accessed July 2022
[52] https://www.eusemiconductors.eu/sites/default/files/ESIA_WSTS_PR_2112.pdf
[53] https://www.eusemiconductors.eu/sites/default/files/ESIA_WSTS_PR_2207.pdf accessed November 2022
[54] https://www.electronicspecifier.com/news/european-semiconductor-sales-up-20-4-year-on-year accessed July 2022
[55] https://www.eusemiconductors.eu/esia accessed November 2022

global automotive integrated circuit market is expected to grow 23% in 2022 due to the shift to electric vehicles and enhanced safety features[56].

4.2.3.1 Semiconductors used in the automotive industry

The use of semiconductors in the automotive sector is experiencing a high growth rate at a CAGR of 8.4% with expected growth from 59.22 billion in 2022 to 103.85 billion in 2029[57]. This market growth is due to the increased use of battery powered vehicles and in self-driving cars. A vehicle today is likely to contain 5,000 to 8,000 semiconductor chips[58]. This number can expect to increase as vehicles become more autonomous. By 2030 it is estimated that half a vehicles value will be in the vehicles electronic systems, meaning that 50% of a vehicles cost will be for semiconductor components[59].

Semiconductor chips are used in multiple functions of the vehicle, such as auto braking and stabilisation systems, airbags, lambda sensors, LED headlights, air conditioning systems, optimised motor power consumption and EV batteries, to name a few[60]. Additionally, the advancements of onboard computer systems to predict traffic patterns and road closures as well as collision avoidance require the systems to read and process millions of lines of code per second. Semiconductors ensure a car's systems can be connected and deliver this in real-time[61]. Figure 4-5 shows the areas in an internal combustion engine vehicle where semiconductor chips are essential to the fail-safe automation of these systems.

[56] SEMI West 2022 Day 1 **SEMI Market Symposium** agenda can be found here: https://www.semiconwest.org/programs/market-symposium

[57] https://www.fortunebusinessinsights.com/automotive-semiconductor-market-106780 accessed November 2022

[58] Entegris, & Inc. (n.d.). *Examining the Small, Medium, and Large of Preventing Automotive Latent Defects White paper*

[59] Entegris, & Inc. (n.d.). *Examining the Small, Medium, and Large of Preventing Automotive Latent Defects White paper*

[60] https://auto.hindustantimes.com/auto/news/heres-where-all-you-can-find-semiconductor-chip-in-vehicles-41642934664014.html accessed July 2022

[61] https://www.azom.com/article.aspx?ArticleID=20354 accessed July 2022

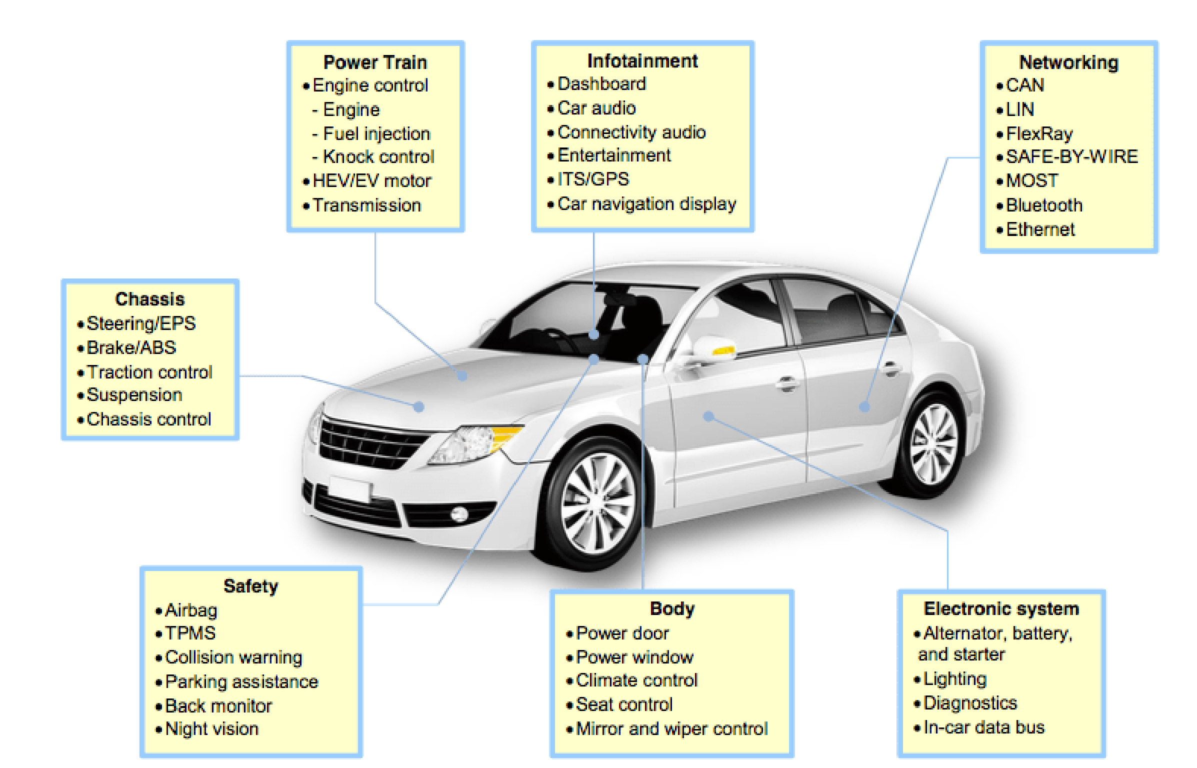

Figure 4-5: Areas of an automobile where semiconductors are esential
Source: *https://semiengineering.com/foundries-accelerate-auto-efforts/ accessed July 2022*

While there are some applications where semiconductors are used, and a device failure may be inconvenient but not critical (such as in a household washing machine) semiconductors used in automobiles are essential to the functioning of important systems to safely operate the vehicle. As shown in the Figure above, the importance of reliability of systems such as sensing, power steering and emergency braking are critical to the safety of passengers. See Figure 4-6 for the average lifetime expectancy of chips in different applications. This demonstrates the importance of chip reliability in automotive vehicles.

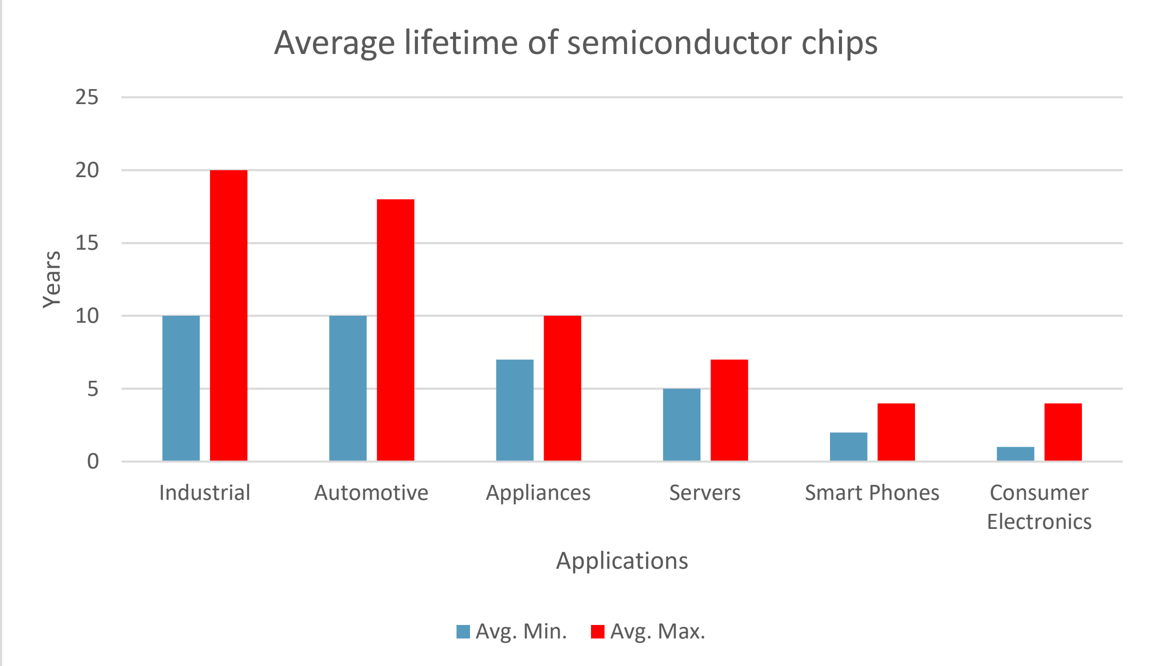

Figure 4-6: Average chip lifetime
Source: *INTERNATIONAL ROADMAP FOR DEVICES AND SYSTEMS™ 2022 UPDATE YIELD ENHANCEMENT THE IRDS IS DEVISED AND INTENDED FOR TECHNOLOGY ASSESSMENT ONLY AND IS WITHOUT REGARD TO ANY*. (2022).

As vehicles rely heavily on automated systems the criticality of identifying semiconductor chip defects increases significantly. Chip defects are typically classified in three categories: large (killer) defects, medium defects, and small (latent) defects (See Figure 4-7). As the size of a defect decreases so does its ability of being detected by a metrology system[62]. Latent defects and contaminants (particles, gels, metal ions, and organics) that are embedded in the chip layers that go undetected will cause reliability failures over time, such as electromigration, oxide breakdown, hot carrier injection, stress-induced cracking and negative bias temperature instability. These failures can result in latent defects causing system failures in vehicles months or years after installation. These system failures could lead to costly recalls or passenger fatalities.

[62] Entegris, & Inc. (n.d.). *Examining the Small, Medium, and Large of Preventing Automotive Latent Defects White paper*

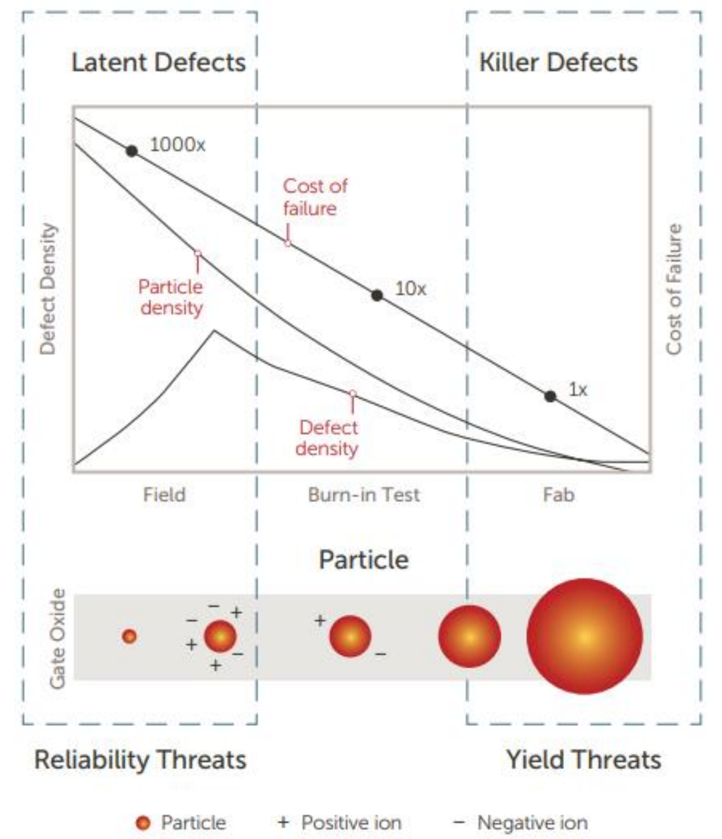

Figure 4-7: Semiconductor chip defects
Source: Entegris, & Inc. (n.d.). Examining the Small, Medium, and Large of Preventing Automotive Latent Defects White paper.

The electrification and autonomy of motor vehicles has increased pressure on semiconductor fabrication plants to prevent or identify latent defects before they are installed. The removal of large (killer) defects has been the main focus of automotive chip suppliers to improve chip yields[63], but the control of latent defects has since become a priority. Latent defects related to particle and metal ion contamination will likely introduce new reliability levels. This can be achieved through more advanced filtration purification steps in combination with metrology inspection. In addition, the purity of materials and process fluids will likely shift and adapt more stringent standards to ensure particle and metal ion contamination is eliminated.

The advancement of autonomous automobiles is closely linked to the use of semiconductors[64]. As mentioned previously, semiconductors are a critical component in making electric powered vehicles assisting second-hand CO_2 emission reductions and oil dependency.

4.2.3.2 Semiconductors in other applications

Semiconductors are important components to most modern technology and consumer electronics, including computers, gaming consoles, kitchen appliances, smart phones, and medical devices among

[63] Entegris, & Inc. (n.d.). *Examining the Small, Medium, and Large of Preventing Automotive Latent Defects White paper*

[64] https://www.azom.com/article.aspx?ArticleID=20354 accessed July 2022

others. As seen in Figure 4-8, semiconductors are used in every digital device and are essential in technology advancements.

Figure 4-8: Applications semiconductors are used in
Source: SEMI Chemical Watch Presentation 27 November 2020
https://www.semi.org/sites/semi.org/files/2020-12/SEMI%20Chemical%20Watch%20Presentation.pdf
accessed August 2022

For example, semiconductors are used in numerous medical devices including magnetic resonance imaging (MRI) machines, pacemakers, portable ultrasound devices, ventilators, insulin pumps, blood gas analysers, blood pressure monitors, and patient monitors[65]. Pacemakers are expected to last for an extended period of time and contain two different semiconductors that work together. Semiconductors used in insulin pumps allows the devices to be wireless and tubeless, as well as providing detection technology[66].

4.2.4 Supply chain

Chemours provides Teflon™ PFA in its resin pellet or powder form to component moulders and converters. Moulders and converters melt the Teflon™ PFA to mould and form the material to specified components. The components are then sent on to wet process equipment manufacturers and contractors/engineering companies. The contractors/engineering companies are typically hired by wet process equipment manufacturers or fabrication plants to design and install new equipment. Wet process equipment manufacturers then use these components to build the equipment and lithography machines used in the semiconductor chip manufacturing process. This equipment is then sold on to fabrication plant owners, who then manufacture the semiconductor chips. See Figure 4-9.

[65] https://www.waferworld.com/post/semiconductors-and-the-medical-industry-a-guide accessed July 2022
[66] https://www.waferworld.com/post/semiconductors-and-the-medical-industry-a-guide accessed July 2022

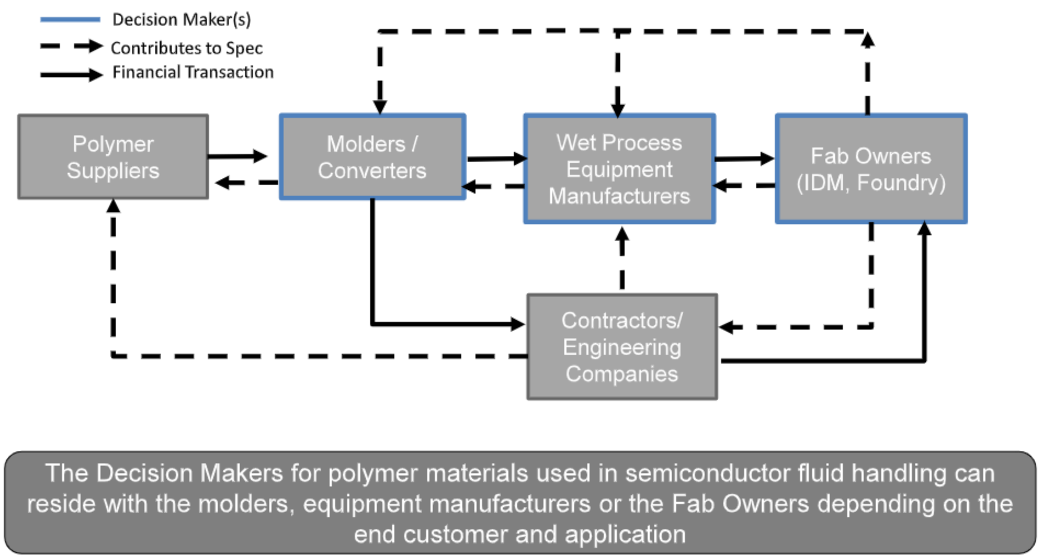

Figure 4-9: **Semiconductor supply chain overview**
Source: APM personal communication 2022

The decision makers that influence material specification can be at any point in the supply chain depending on the end customer and application. For example, component manufacturers establish specification requirements with the raw material supplier in order to meet the needs of the fabrication plants.

5 Hazard properties

This section will present the hazard properties of Teflon™ PFA. This includes its monomers and any processing aids that are used during the polymerisation process. Fluoropolymers are a specific sub-category of PFAS and are high molecular weight polymers and can be assessed according to criteria to determine its hazard level[67]. The OECD Expert Group on Polymers concluded that "Polymers of low concern are those deemed to have insignificant environmental and human health impacts"[42]. The remainder of this section will discuss these criteria and present the key values for the substances within this study.

Due to the large molecular weight of polymers, they are considered too large (> 1000 – 10000 Dalton) to cross biological membranes and exhibit hazardous properties. Molecular weight is the most commonly used criteria when assessing polymers[42]. Polymers presenting the most potential health concerns will have a number average molecular weight (M_n) <1000 Dalton (Da) and oligomer content >1%[42]. Monomers, oligomers, and degradation products from the polymerisation process are smaller and therefore can potentially cross biological membranes and therefore have the potential to be hazardous. It is important that the oligomer % and residual monomers are considered to assess the leachability of the polymer, values are presented in Table 5-1.

The presence of Reactive Functional Groups (RFGs) can be associated with adverse human health and ecotoxicology[42]. The Functional Group Equivalent Weight (FGEW) determines if the RFGs are diluted by polymeric material and is used as an indication of how reactive the polymer is[42]. The polymeric charge is important to consider because charge can influence how a polymer acts and its properties. For example, cationic polymers have been associated with aquatic toxicity (Henry et al. 2018) (see Table 5-1).

In summary, according to Henry et al. (2018) and the OECD[68], the properties affecting a polymer assessment include the following:

- Molecular Weight (MW): A polymer with a low molecular weight could indicate a potential for health and ecotoxicological concerns.
- Polymer composition: This relates to the monomers, oligomers and processing aids used during polymerisation. These will have lower molecular weights potentially making them more hazardous.
- Polymer charge: Charge can influence how a polymer acts and its properties including, physical properties, fate, ecotoxicity, and human toxicity.
- Structural features: This includes its reactive functional groups (RFGs) and particle size.
- Solubility and stability: Low solubility in water and n-octanol demonstrate the inability of fluoropolymers to actively cross cell membranes and bioaccumulate. While stability shows the durability of the polymer and likelihood of breaking down into smaller molecules.

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67 Henry, B. J., Carlin, J. P., Hammerschmidt, J. A., Buck, R. C., Buxton, L. W., Fiedler, H., Seed, J., & Hernandez, O. (2018). A critical review of the application of polymer of low concern and regulatory criteria to fluoropolymers. *Integrated Environmental Assessment and Management*, *14*(3), 316–334. https://doi.org/10.1002/IEAM.4035 accessed September 2022

68 *JOINT MEETING OF THE CHEMICALS COMMITTEE AND THE WORKING PARTY ON CHEMICALS, PESTICIDES AND BIOTECHNOLOGY DATA ANALYSIS OF THE IDENTIFICATION OF CORRELATIONS BETWEEN POLYMER CHARACTERISTICS AND POTENTIAL FOR HEALTH OR ECOTOXICOLOGICAL CONCERN JT03258707 Document complet disponible sur OLIS dans son format d'origine Complete document available on OLIS in its original format*. (2009). https://www.oecd.org/env/ehs/risk-assessment/42081261.pdf accessed September 2022

Each of these properties will be assessed for the substances within this study.

5.1 Perfluoro alkoxy hazard properties

Perfluoro alkoxy (CAS 26655-00-5, EC 682-550-7) is the copolymer of tetrafluoroethylene (CAS 116-14-3, EC 204-126-9), perfluoro propyl vinyl ether (PPVE, CAS 1623-05-8, EC No. 216-600-2) and perfluoro ethyl vinyl ether (PEVE, CAS 10493-43-3, EC No. 234-018-7). It is a high-performance thermoplastic material that is used in many applications.

5.1.1 Classification and labelling

Like all polymers, Teflon ™ PFA is not a REACH registered substance and does not have a harmonised classification and labelling under Classification Labelling and Packaging (CLP) Regulation (EC) No. 1272/2008. Self-classification of substance registrants on ECHA report a total of 3 notifications of classification and labelling[69], with each notifier registering it as "not classified". Given the inert nature of the polymer, hazardous properties are not expected.

The representative EU Safety Data Sheet (SDS) for PFA Fluoroplastic Resin 450HP X indicates it is not hazardous[70].

Tetrafluoroethylene (TFE, CAS 116-14-3, EC 204-126-9), a monomer used in the production of PFA , is a REACH registered substance and currently a harmonised classification and labelling under Regulation (EC) No. 1272/2008 is not published but has been adopted by The Committee for Risk Assessment (RAC). The Committee developed their opinion in December 2019[71] and was in agreement that the substance should be classed as carcinogenic category 1B under Regulation (EC) No. 1272/2008. The dossier evaluation has been concluded and the opinion adopted, however, it has not yet been published. The registration dossier[72] classifies the substances as extremely flammable gas (H220), gas under pressure (H280), STOT SE 2 (H371, kidney), and carcinogenic 1B (H350). The latter is aligned with the adopted opinion of the RAC in an assessment of regulatory needs that was carried out in 2018.

Perfluoro propyl vinyl ether (PPVE), a comonomer used in the production of PFA, is a REACH registered substance but does not have a harmonised classification and labelling under Regulation (EC) No. 1272/2008. The registration dossier[73] classifies the substance as an eye irritant 2 (H319). There are currently no assessments for regulatory need for this substance.

Perfluoro ethyl vinyl ether (PEVE), a comonomer used in the production of PFA, is a REACH registered substance but does not have a harmonised classification and labelling under Regulation (EC) No. 1272/2008. The registration dossier[74] classifies the substance a flammable gas 1A (H220) and a liquefied gas (H280). There are currently no assessments for regulatory need for this substance.

69 https://echa.europa.eu/information-on-chemicals/cl-inventory-database/-/discli/details/212887 accessed September 2022

70 PFA Fluoroplastic Resin 450HP X SDS No. 1854290-00012 Chemours; 9 December 2020

71 https://echa.europa.eu/documents/10162/becfc8d6-8a83-a81e-27d7-abadc6c7b585 accessed September 2022

72 https://echa.europa.eu/registration-dossier/-/registered-dossier/15453 accessed November 2022

73 https://echa.europa.eu/registration-dossier/-/registered-dossier/23696/2/1 accessed November 2022

74 https://echa.europa.eu/registration-dossier/-/registered-dossier/21612 accessed November 2022

5.1.2 Perfluoro alkoxy (PFA) characteristics

Table 5-1 presents the characteristics of PFA.

Table 5-1: Assessment criteria for a polymer of low concern	
Criteria	**Value**
Polymer composition (must have C, H, Si, S, F, Cl, Br, or I covalently bound to C)	Yes
Molecular Weight Characteristics:	
M_n > 1000 Da and oligomer content < 1%	200,000 – 450,000
Molecular Weight Distribution (MWD) ÷ number average M_n (M_n and heterogeneity of MW distribution indicate if majority are >1000 or <1000 Da, which could penetrate the cell)	1.7
Wt % oligomer (5% for <1000 Da oligomer, 2% for <500 Da oligomers)	Negligible
Polymer composition:	
Residual monomer	<50 ppb
Ratio of residual monomers to MW (more low MW monomer content per mole increases bioavailability and hazard potential)	$\sim 10^{-13}$
Polymer charge (cationic polymers associated with aquatic toxicity; polycationic with adverse human health effect)	Neutral
Reactive functional groups (RFGs) (some highly reactive functional groups associated with adverse human health and ecotoxicology effects, e.g., acrylates, isocyanates, anhydrides, aziridines)	<1
Functional group equivalent weight (FGEW) (the lower the FGEW, the more reactive the polymer and the higher the potential for health and environmental impact) (defined as the ratio of M_n to the number of functional groups in the polymer)	$>10^5$
Low molecular weight leachables (MW < 1000 Da able to enter cell)	No active leachables by USP class V1 (121°C)
Physio-chemical properties:	
Water solubility (water solubility <10 mg/L showed generally low health concerns; 10 mL/L to 10000 mg/L had potential health concern)	Practically insoluble or insoluble
Lipid solubility	Practically insoluble or insoluble
Octanol- water partition coefficient, Log K_{ow} (higher K_{ow} associated with lipophilicity and a high potential to bioaccumulate or bioconcentrate)	N/A
Hydrolysis (breaking into M_n < 1000 Da increases hazard potential)	Stable
Light (hv) (breaking into M_n < 1000 Da increases hazard potential)	Stable
Biodegradation (aerobic and anaerobic) (breaking into M_n < 1000 Da increases hazard potential)	Stable
Thermal stability and normal operating temperatures	260°C

Table 5-1: Assessment criteria for a polymer of low concern	
Criteria	**Value**
Particle size (median mass aerodynamic diameter, MMAD, should be >5 µm)	50-250 µm (powders)
Source: Henry, B. J., Carlin, J. P., Hammerschmidt, J. A., Buck, R. C., Buxton, L. W., Fiedler, H., Seed, J., & Hernandez, O. (2018). A critical review of the application of polymer of low concern and regulatory criteria to fluoropolymers. *Integrated Environmental Assessment and Management*, *14*(3), 316–334. https://doi.org/10.1002/IEAM.4035	

As reported in OECD (2009), Henry et al. 2018, and EC (2020)[75] state that substances with a Mn > 1000 Da and oligomer content <1% are not expected to be absorbed through the skin and present health hazards. PFA has a Mn range of 200,000-450,000 Da, thus larger than the 1000 Da criterion, a molecular weight distribution of 1.7 and a negligible oligomer content of less than 1%. These values indicate that PFA does not present any potential hazardous concerns, based on these criteria.

The polymer will contain up to 50 ppb of the monomers used with the ratio of residual monomer to Mw being negligible ($\sim 10^{-13}$). Additionally, there are no active leachables and the residual content of processing or polymerisation aid in Teflon™ PFA is low and therefore is likely not of concern.

The polymer has no charge and does not contain any reactive functional groups. These characteristics indicate that the polymer is of low toxicological concern according to criteria.

The particle size of the powder is 50-250 µm. The other physio-chemical properties reported in Table 5-1 do not indicate that Teflon™ PFA is potentially hazardous (the polymer is not soluble in water or lipids, and no degradation is expected).

5.1.3 Environmental properties

Due to the high molecular weight, toxicity to soil, aquatic or sediment organisms is not likely. According to the substances SDS, there is no data available regarding these studies.

PFA is insoluble in water, therefore there is no potential of toxicity to aquatic organisms. The large molecular weight of the polymer means that biological uptake is not expected to take place, and therefore no toxicity to sediment and soil organisms, as well as bioaccumulation, is expected[76].

The polymer is inert, and it is not biodegradable based on its structure. PFAS are known to be very persistent and stable in the environment[77]. Overall, there are not many data on the environmental properties, but toxicity appears to not be of concern, as well as bioaccumulation, due to the inherent properties of the polymer. The substance is considered to be persistent, without bioaccumulative or

[75] European Commission, Directorate-General for Environment, Bougas, K., Corden, C., Crookes, M., et al., *Scientific and technical support for the development of criteria to identify and group polymers for registration/evaluation under REACH and their impact assessment : final report*, Publications Office, 2020, https://data.europa.eu/doi/10.2779/890644 accessed September 2022

[76] European Commission, Directorate-General for Environment, Bougas, K., Corden, C., Crookes, M., et al., *Scientific and technical support for the development of criteria to identify and group polymers for registration/evaluation under REACH and their impact assessment : final report*, Publications Office, 2020, https://data.europa.eu/doi/10.2779/890644 accessed September 2022

[77] https://echa.europa.eu/hot-topics/perfluoroalkyl-chemicals-pfas accessed April 2022

toxic properties, persistence is less of a concern. This conclusion is also supported by the Canadian assessment of PFA[78].

5.1.4 Human health properties

There is limited data available on the toxicity of PFA to humans. Its large molecular weight means uptake would be difficult and it's unlikely to cross biological membranes. There is no data available on its bioaccumulation potential. Teflon™ PFA is not at risk of being dispersed via air in the form of dust particles and therefore does not pose an inhalation risk.

Low-molecular weight fluorinated monomers and the products of thermal decomposition of fluoropolymers, however, can be acutely toxic and harmful to health. Caution must be used when processing fluoropolymers in order for fluoropolymers to remain in their inert and non-hazardous state. Fluoropolymer handling guidelines[79] have been published and address the main routes for release of harmful substances from fluoropolymers.

The SDS indicates the thermal decomposition products of PFA to be hydrofluoric acid, carbonyl difluoride, carbon dioxide and carbon monoxide. These decomposition products present several hazards (see Table 5-2).

Table 5-2: Thermal decomposition products of PFA

Substance	Workplace exposure limits (Time Weighted Average)	Hazard Properties
Carbonyl Fluoride (COF_2)	2 ppm	Acute Toxicity - Inhalation (Cat. 2) Skin Corrosion/Irritation (Cat. 1) Serious Eye Damage (Cat. 1) Specific target organ toxicity - Single Exposure (Cat. 1) (lungs)
Carbon Monoxide (CO)	25 ppm	H220 Flammable gases (Cat.1) H331 Acute toxicity - Inhalation (Cat. 3) H360D Reproductive toxicity (Cat 1A) H372 Specific target organ toxicity - repeated exposure, inhalation (Cat. 1)
Carbon Dioxide (CO_2)	Asphyxiant, may cause dizziness in concentrations greater than 5%	Does not have a harmonised classification and labelling 1,185 notifications H280 Gas under pressure, may explode if heated H281 Refrigerated liquid, may cause cryogenic burns
Hydrofluoric acid (HF)	3 ppm 2.5 mg/m^3	H300 Acute toxicity, Oral (Cat. 2) H330 Acute toxicity, Inhalation (Cat. 2) H310 Acute toxicity, dermal (Cat.1) H314 Skin corrosion (Sub-cat 1A) H318 Serious eye damage (Cat. 1)

Source: Chemours SDS 1854608-00008 9 December 2020

78 Search for CAS 26655-00-5 on https://canadachemicals.oecd.org/Search.aspx accessed September 2022

79 *Guide for the Safe Handling of Fluoropolymer Resins*. (2021). https://fluoropolymers.plasticseurope.org/application/files/6216/3178/0517/Fluoropolymers_Safe_Hand_EN__June_2021.pdf accessed September 2022

5.1.5 PBT/vPvB assessment

REACH Annex III and XIII present the persistent, bioaccumulative and toxic (PBT) and very persistent and very bioaccumulative (vPvB) criteria, and the information requirements that can be used in the PBT/vPvB assessment.

P/vP – persistency: the half-life of PFA is not measured in any compartments but is expected to be in the order of years, therefore exceeding vP criteria. Therefore, PFP meets the P/vP criteria.

B/vB – bioaccumulation: Due to the large molecular weight of the substance it is not expected to bioaccumulate.

T – toxicity: the substance is not classified as carcinogenic (category 1A or 1B), germ cell mutagenic (category 1A or 1B), or toxic for reproduction (category 1A, 1B or 2), nor is there other evidence of chronic toxicity, as identified by the substance meeting the criteria for classification: specific target organ toxicity after repeated exposure (STOT RE category 1 or 2). There is no data available to confirm on toxicity, however due to its lack of water solubility and other characteristics suggesting it is a polymer of low concern, it is likely the substance is not T.

Based on the above information, it is possible to conclude that PFA is P, not B, and not T according to Annex III to the REACH Regulation. Similarly, it is possible to conclude that PFA is vP and not vB. Overall, PFA does not meet the PBT/vPvB criteria.

5.1.6 Conclusions on PFA hazards

The polymer is inert and based on its characteristics it is unlikely to have any toxicological hazards. The available information indicates that the hazard of concern is persistency.

6 Analysis of Alternatives

This Analysis of Alternatives (AoA) provides an analysis on the feasibility of potential alternatives to Teflon™ PFA in the semiconductor sector. It will assess the potential alternatives' economic feasibility, technical feasibility, availability, and hazard properties. As the proposed restriction covers all PFAS, the focus of this AoA will be on non-PFAS alternative materials. This section will be referenced in the non-use scenario to better predict the associated impacts of a potential restriction.

Further details on the semiconductor manufacturing processes are discussed in Sections 4.2.

6.1 Alternatives to Teflon™ PFA in semiconductor manufacturing

6.1.1 Performance requirements of materials used for fluid handling in semiconductor manufacturing

PFAS are used throughout the manufacturing of semiconductor chips, from refrigerants to lubrication oils and greases, manufacturing equipment components and factory infrastructure[80]. The components used in the semiconductor manufacturing process that have particularly high-performance requirements are those that convey process chemistries (fluids) such as, ultra-pure water and chemicals, and manufacturing equipment components that directly handle the wafer[81].

More specifically, Teflon™ PFA is used in numerous components throughout the semiconductor manufacturing process including, process vessels, pipes and fittings, tubing, valves and pumps, storage and transport containers, filters, and sensors[82]. Teflon™ PFA will be used in these components due to its chemical and corrosion resistance to convey highly corrosive chemicals. In addition, the required functionality of materials used for such components include the ability to maintain low contamination (high purity and low particle shedding), and structural integrity when in contact with highly corrosive chemicals and high temperatures. See Table 6-1 for descriptions of these required properties.

Table 6-1: Essential material properties used for components in equipment used for semiconductor manufacturing

Property	Description
Low leaching potential and impurities	Substances used for the transportation of ultra-pure fluids must have very low leaching potential (less than 100 part per trillion[83]) to ensure there are no impurities, such as metal ions, that will contaminate the fluids via leaching from the equipment materials. Any materials in contact with the wafer must be free from impurities to maintain an ultra-pure environment.
Low particle shedding	During the manufacturing process there are many moving parts that could shed particles through operation, the material used should be resistant to this to minimise the generation of contaminant particles.
Low surface roughness	In line with low particle shedding, a material with a rough surface will more easily trap particles and make cleaning processes more intensive. See Section 4.2.2 on fabrication plant start up times.

80 https://www.semi.org/en/blogs/semi-news/fluorinated-chemicals-are-essential-to-semiconductor-manufacturing-and-innovation accessed November 2022

81 Downstream user consultation June 2022

82 https://www.teflon.com/en/industries-and-solutions/industries/semiconductor-manufacturing accessed June 2022

83 https://www.asahi-america.com/images/x-assets/PDF/Article_Plastics_in_Chemical_Processing_and_Semiconductor.pdf accessed November 2022

Table 6-1: Essential material properties used for components in equipment used for semiconductor manufacturing	
Property	**Description**
Chemical resistance	The material should be chemically inert so as not to react, break down or generate contaminants when in contact with the ultra-pure chemicals.
Corrosion resistance	The material must be able to withstand corrosive chemicals over a prolonged period so as not to react, breakdown or generate contaminants when in contact with the ultra-pure chemicals.
Moisture resistance	The material should be resistant to moisture and not have any absorptive qualities as this can break down the material or risk bacteria growth.
Durability	The material should be durable and resistant to cracking to ensure the pressurised water does not break the piping structure. A higher molecular weight and/or comonomer content corresponds with higher resistance to cracking.
Crack resistance	The tubing process is dynamic with temperature changes and there is a lot of bending that can lead to stress. If the material is not resistant microcracks can form and there will be loss of material into the surroundings and potential contamination introduced
Weldability	High weldability is required to ensure piping units can be assembled specifically in relation to the facility layout without weakening the piping or resulting in gaps between units.
Source: Downstream User Consultation	

Low leaching potential and high purity of component materials is extremely important to ensure there are no impurities or contamination present during the processes carried out for semiconductor manufacturing. As the total amount of tolerable contaminants decreases the cleanliness and corrosion resistance of materials becomes more critical, with impurities being measured on the ppb or ppt level. The ability of Teflon™ PFA products to supply ultra-pure fluids and be used as equipment components throughout the semiconductor manufacturing process without impurities is a significant benefit over the more traditional choices for piping, such as copper or stainless steel, which have a significantly higher leaching potential than Teflon™ PFA. Due to Teflon™ PFA's molecular structure, it has the ability to hold its shape at operating temperatures of the applications but is also melt processable. It is resistant to chemicals and corrosion throughout the lifetime of the semiconductor manufacturing process making it the ideal material used for this application.

Lithography machines are highly complex and contain over 100,000 different components[84]. These systems will replicate billions of transistors on the surface of the wafer substrate. In the lithography process the circuit patterns are written on the silicon wafers using a light-sensitive polymer known as a photoresist to develop 3D patterns on the wafer[85]. During this process, the transfer steps can be repeated more than 30 times to build one circuit, connecting and aligning to previously transferred circuit layers. Within these highly complex systems it is important there is no contamination from equipment components such as particle shedding or leaching of materials onto the wafers as this can cause defects (See Section 4.2.3 for information on defects).

84 https://www.cnbc.com/2021/12/10/asmls-high-na-euv-lithography-machine-is-set-to-transform-chipmaking.html accessed September 2022

85 https://spie.org/publications/fg06_p1-2_semiconductor_lithography?SSO=1 accessed September 2022

Before a new layer is formed, the previous layer will be inspected for defects such as scratches, spin defects, particle contamination, or hot spots[86] (see Figure 6-1). There are a wide range of defects that can occur, and some may be undetected until the final stage or after use (for latent defects see Section 4.2.3). Defects can be identified using analysis tools to detect killer and medium sized defects anywhere within the wafer layers[87]. However, due to node size continuing to decrease the ability to identify and quantify, latent defects on a subatomic level are difficult to identify even with the most powerful analytical tools[88]. The industry is in the midst of developing methods and tools for these advanced node structures alongside how the process can be kept clean enough to deliver these advanced nodes. The purity, inertness and physical integrity of materials in the manufacturing process helps mitigate and limit defects by eliminating routes of contamination before being introduced into the process. This is the reason fluoropolymers particularly Teflon™ PFA are critical in enabling chip manufacturing.

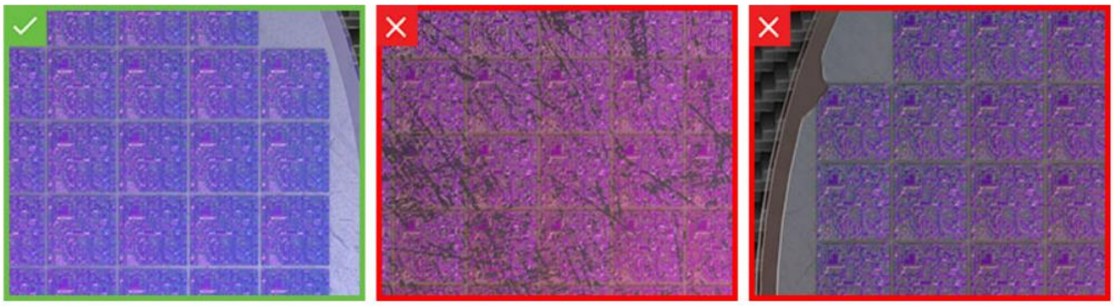

Figure 6-1: Examples showing defected wafers
Source: https://www.cognex.com/industries/electronics/semiconductors/wafer-defect-inspection accessed September 2022

Semiconductors are manufactured under standards which place demanding requirements on both the wafer and chemical impurity levels (See Section 4.2.1.1). During the wet etching process semiconductor wafers are cleaned, etched, and cleaned again. Teflon™ PFA components are used in this process to ensure that the wash fluids remain free from contamination from the tubing and valves used in the transfer of the wash fluid[89].

The slightest impurities in the materials and fluids used within manufacturing could incur costly amounts of downtime and damage, while also influencing the production yield of usable chips.

6.1.2 Role of Teflon™ PFA in the semiconductor industry

Teflon™ PFA is a key material to achieve contaminant free process chemistries and equipment components and is found in almost every step of processing from packaging, facility infrastructure and manufacturing tools[90]. Semiconductor wafers are very fragile, meaning the smallest contamination or

86 https://www.cognex.com/industries/electronics/semiconductors/wafer-defect-inspection accessed September 2022
87 https://www.cognex.com/industries/electronics/semiconductors/wafer-defect-inspection accessed September 2022
88 APM personal communication 2022
89 https://www.teflon.com/en/industries-and-solutions/industries/semiconductor-manufacturing/etching accessed June 2022
90 https://www.semiconductors.org/public-statement-of-the-semiconductor-pfas-consortium/ accessed September 2022

particle can damage the entire chip and inhibit the device performance making it unusable[91]. This section of the report will present a high-level screening of potential alternatives to Teflon™ PFA for use in the semiconductor industry.

As mentioned in Section 4.2, the semiconductor manufacturing process is extremely intricate and requires the utmost precision to achieve efficient functionality of each chip yielded. The majority of items a wafer comes in contact with will be made from Teflon™ PFA or other PFAS materials[92].

6.1.3 Assessment of alternatives

While there has been extensive research into alternatives in the semiconductor industry, a material that can meet all the essential properties mentioned above and provide equal performance to Teflon™ PFA has not been identified. Teflon™ PFA meets the industry standards and provides all required performance characteristics without any additives, softeners, or fillers eliminating additional routes of contamination into the process.

Alternative materials making up components must also be FM 4910[93] certified to be used in clean rooms as wet benches, housing, tanks, piping etc[94]. The materials/components must meet this standard for fire propagation and smoke generation to avoid possible contamination from fire. Current listed materials that are certified under FM 4910 to be used as cabinets and workstations in clean rooms are:

- Flame retardant polypropylene;
- Polyvinyl chloride (PVC) and Chlorinated polyvinyl chloride (CPVC);
- Polyvinylidene fluoride (PVDF);
- PFA; and
- Ethylene chlorotrifluoroethylene (ECTFE)[95].

The wider group of fluoropolymers for fluid handling that are certified under FM 4910 are fluorinated ethylene propylene (FEP), PFA, PTFE, ethylene tetrafluoroethylene (ETFE), ECTFE, polychlorotrifluoroethylene (PCTFE), and PVDF[96].

6.1.3.1 Metals

To avoid metal ion contamination and corrosion, the material should ideally be a high-performance plastic and for that reason traditional metal options such as copper, stainless steel, or other metals are ruled out. It is unlikely these metals would meet performance standards for low metallic ion extractable limits in SEMI F57, C90 and the IRDS Yield Enhancement Tables (See Section 4.2.1.1). Stainless steel does not have suitable chemical resistance to withstand the chemicals used during the

91 https://angstromtechnology.com/the-value-of-cleanrooms-for-semiconductor-applications/ accessed September 2022
92 Downstream user consultation
93 FM 4910 is a fire-retardant property standard for materials used in clean room applications. Contamination from a fire could put a chip manufacturer out of business for weeks or even permanently. Materials passing the cleanroom protocol can be listed in the Approval Guide https://www.fmapprovals.com/approval-guide accessed November 2022
94 https://www.curbellplastics.com/Research-Solutions/Industry-Solutions/Markets/Semiconductor-and-Electronics-Manufacturing-Equipm/Wet-Benches-and-Cleanrooms accessed September 2022
95 https://www.curbellplastics.com/Research-Solutions/Industry-Solutions/Markets/Semiconductor-and-Electronics-Manufacturing-Equipm/Wet-Benches-and-Cleanrooms accessed September 2022
96 https://www.curbellplastics.com/Research-Solutions/Industry-Solutions/Markets/Semiconductor-and-Electronics-Manufacturing-Equipm/Wet-Benches-and-Cleanrooms accessed September 2022

semiconductor manufacturing process. Information gathered during consultation, confirmed that steel was investigated and tested as an alternative material but was not suitable in terms of cleanliness and lifetime, due to corrosion and inadequate UV light resistance[97]. Copper also would not be able to withstand the corrosive chemicals used during the manufacturing process. However, it is common for metals to be used in areas where fluoropolymers do not have the burst pressure requirements that are needed. In these instances, metals are only used when absolutely necessary, and sometimes coated with a liquid PFAS resin[98], followed by adequate filtration to ensure contamination of metal ions is low. Noble metals such as gold, platinum and palladium play a vital role in the manufacture of semiconductor chips. They are used in the semiconductor manufacturing process during the evaporation and sputtering processes where they are deposited onto the shield kit. They are favoured here because of their high electrical conductivity, meaning nanograms of gold can be used to make electrical connections between the chip and the lead frame[99]. However, they are unsuitable for use in the transport of ultra-pure chemistries for semiconductor manufacturing due to their electrically conductive properties.

6.1.3.2 Polypropylene and polyvinyl chloride

Other plastics assessed as potential alternatives include polypropylene (PP) and polyvinyl chloride (PVC). These plastics are widely used and available in various applications and industries. However, these materials do not offer the required amount of chemical resistance to be used within the semiconductor manufacturing process although they meet FM 4910 for use in clean rooms. Chemical compatibility charts[100,101,102] demonstrate the resistance of plastics and various chemicals used during the semiconductor manufacturing process (See Table 6-2). Additionally, these materials do not hold their shape at the temperatures required to operate semiconductor processes. On its own PVC is hard and brittle with poor heat stability and requires the use of additives known as plasticisers such as phthalates[103,104] or other softeners. The addition of these substances can introduce the potential of more contamination with plasticisers known to have migratory qualities potentially leaching into the ultrapure chemistries[105]. Alternatively, PVC could be chlorinated to make chlorinated polyvinyl chloride (CPVC). This material is resistant to more chemicals than traditional PVC and can withstand higher temperatures, however its migratory qualities and chemical resistance are not suitable for use within semiconductor manufacturing. While polypropylene is known for its mouldable qualities and is a material that is melt processable, it is classed as a thermoplastic and will become liquid at its melting point (130°C) [106]. This is significantly lower than the operating temperatures (260°C) needed for semiconductor manufacturing.

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97 Downstream User Consultation 2022

98 Information gathered through consultation 2022

99 https://link.springer.com/content/pdf/10.1007/BF03214833.pdf accessed September 2022

100 https://www.plasticsintl.com/chemical-resistance-chart accessed 2022

101 https://www.graco.com/content/dam/graco/ipd/literature/misc/chemical-compatibility-guide/Graco_ChemCompGuideEN-B.pdf accessed September 2022

102 https://www.polyfluor.nl/en/chemical-resistance/pfa/ accessed September 2022

103 Petersen, R. v. (1976). LEACHABLE COMPONENTS AND BIOCOMPATABILITY OF PVC MEDICAL DEVICES. *Mechanisms of Toxicity and Metabolism*, 181–190. https://doi.org/10.1016/B978-0-08-020544-1.50024-8

104 https://www.creativemechanisms.com/blog/everything-you-need-to-know-about-pvc-plastic accessed September 2022

105 Erythropel, H. C., Maric, M., Nicell, J. A., Leask, R. L., & Yargeau, V. (2014). Leaching of the plasticizer di(2-ethylhexyl)phthalate (DEHP) from plastic containers and the question of human exposure. *Applied Microbiology and Biotechnology*, *98*(24), 9967–9981. https://doi.org/10.1007/S00253-014-6183-8 accessed September2022

106 https://www.creativemechanisms.com/blog/all-you-need-to-know-about-polypropylene.-part-2 accessed September 2022

Although, not used in the manufacturing process steps that have direct contact with process chemistries or wafers, PVC and PP are still used in the semiconductor industry. Based on information gathered during consultation, PVC is typically used to build the frame or structure of lithography equipment. While PP is used in areas of the process where purity is not a factor, for example piping for waste streams. However, 70-75% of the mass of the lithography machines are made of fluoropolymers (PFA or PTFE).

6.1.3.3 Polyether ether ketone (PEEK)

The high-performance polymer known as polyether ether ketone (PEEK) is a commonly used plastic in the aerospace and engineering industries, known for its high mechanical strength and temperature resistance[107]. Although used in many high-performance applications, it was highlighted in consultation that PEEK use in the semiconductor industry may not be technically feasible due to its absorptive potential of some solvents. These include solvents such as methylene chloride, dimethyl sulfoxide (DMSO), tetrahydrofuran (THF), sulfuric and nitric acid. Additionally, PEEK is prone to "kinking" when bent at a sharp angle for long durations[108]. The processability of PEEK may also present further challenges in comparison to PFA. The melting point of PEEK (343°C) is slightly higher than PFA (300-310°C) and will therefore require more energy to process. Information gathered during consultation confirmed the difficulties PEEK would present during component processing. The volume of components and tubing needed would make it very challenging to manufacture. Mechanical testing is carried out to determine the performance of plastics, including tests such as tensile elongation and Izod impact strength, among others. The tensile elongation of PEEK is 50% elongation versus its initial size whilst PFA shows 300% elongation versus initial size at room temperature[109]. Additionally, PFA is melt processable allowing it to be stretched further and moulded into various sized tubes and components. The Izod impact strength test showed PFA had no breaking point while PEEK showed a break at 1.55 ft*lbs/in (82.8 J/m), this demonstrates improved strength and resistance of PFA in relation to PEEK. Although, PEEK may not be a suitable alternative to transport process chemistries, other components throughout the semiconductor manufacturing process may be able to be made from PEEK but only when absolutely necessary.

6.1.3.4 Overall conclusions of assessed alternatives

As seen from the information presented in Table 6-2 and Table 6-3, matching the performance characteristics of PFA is very difficult leading to the conclusion that from the alternatives considered, none of them represent a technically viable replacement to Teflon™ PFA in the semiconductor industry. Consultations with key stakeholders within the semiconductor industry were in agreement of these findings, i.e. stating that PFA is the only material that can meet the stringent standards required within the industry.

Throughout the semiconductor manufacturing process hundreds of chemicals are used of varying degrees of corrosivity. The infrastructure of semiconductor chemical transportation systems must be able to withstand these aggressive chemicals without breaking down, absorbing, or reacting for long durations. Presented in Table 6-2 are a few of the chemicals used throughout the process and how the alternatives, presented above, compared to Teflon™ PFA in chemical performance.

For example, piranha etch solution made from sulfuric acid and hydrogen peroxide is used to clean residues from the silicon wafers and strip residue while oxidising metals leaving the surface

[107] https://omnexus.specialchem.com/selection-guide/polyetheretherketone-peek-thermoplastic accessed September 2022
[108] Downstream user consultation
[109] https://www.plasticsintl.com/material-property-matrix accessed September 2022

hydrophilic[110]. This is beneficial for subsequent manufacturing steps. To safely use this chemical mixture, specialised equipment is required to handle and transport it due to the highly corrosive properties of the mixture. While some metals may be resistant to this solution, they could still leach impurities and contaminate it. As such these solutions are contained mostly with fluoropolymers, which show minimal leaching and suitable corrosion resistance.

Table 6-2: Chemical compatibility of materials used in semiconductor manufacturing

Chemical	Concentration %	PFA	CPVC	PEEK	Polypropylene	PVC	Stainless Steel
Acetic acid aq.	10	A	A	A	B	A	B
Alcohols, aliphatic		A	*	A	B	*	A
Aqua regia		A	C	*	C	C	D
Chlorine aq.	10	A	A	A	B	A	D
Citric acid aq.	10	A	A	A	A	A	A
Detergents, organic		A	A	A	A	A	A
Fluorine, dry		A	A	D	D	C	D
Hydrochloric acid aq.	0.4	A	A	A	A	A	D
Hydrofluoric acid aq.	4	A	B	D	A	B	D
Hydrogen peroxide aq.	0.5	A	A	A	A	A	B
Hydrogen peroxide aq.	1	A	A	A	A	A	B
Hydrogen peroxide aq.	3	A	A	A	B	D	B
Hydrogen sulphide aq.	SAT	A	A	A	A	A	A
Ozone		A	A	A	C	B	*
Phosphoric acid aq.	0.3	A	A	A	A	A	A
Phosphoric acid aq.	3	A	A	A	A	A	A
Phosphoric acid aq.	10	A	A	A	A	A	A
Potassium chloride aq.	90	A	A	A	A	A	A
Sodium bicarbonate aq.	50	A	A	A	B	A	A
Sodium hypochlorite 15% (chlorine bleach)		A	A	A	A	A	B

110 https://www.modutek.com/how-piranha-etch-is-used-in-silicon-wafer-cleaning/#:~:text=The%20mixture%20heats%20up%20rapidly%20and%20is%20often,the%20temperature%20and%20keep%20the%20etch%20rate%20constant. Accessed November 2022

Table 6-2: Chemical compatibility of materials used in semiconductor manufacturing							
Chemical	**Concentration %**	**PFA**	**CPVC**	**PEEK**	**Polypropylene**	**PVC**	**Stainless Steel**
Sulphuric acid aq.	2	A	A	A	A	A	D
Sulphuric acid aq.	5	A	A	A	A	A	D
Sulphurous acid aq.	10	A	A	A	A	A	C
Urea		A	A	*	A	A	A

Source: *https://www.plasticsintl.com/chemical-resistance-chart*
https://www.polyfluor.nl/en/chemical-resistance/pfa/
https://www.slideshare.net/alexsung1975/chemre
https://www.graco.com/content/dam/graco/ipd/literature/misc/chemical-compatibility-guide/Graco_ChemCompGuideEN-B.pdf accessed September 2022
Compass Publications Chemical Resistance Guide for Plastics, ISBN 1-889712-03-5
** No data available*
A= No attack - green
B= Slight attack by absorption, small reduction in mechanical properties - amber
C= Moderate attack, material will have limited life - red
D= Material will decompose or dissolve - red

As seen above in Table 6-2, the chemical resistivity of any of the alternative materials is not adequate enough for the use of each of the ultra-pure chemical transportation uses in semiconductor manufacturing. The use of these alternative materials could result in worker exposure or injury if the components become compromised by chemical attack. This could result in leaks or breakages causing chemical spills. There could also be an increase in the rate of component replacement as chemicals use would break down these alternative materials quicker than the current PFA based systems.

Table 6-3 highlights how the potential alternatives considered in this assessment perform against the main criteria for consideration in semiconductor manufacturing. These can also be compared against Teflon™ PFA. The table indicates that no alternative material can simultaneously meet all the technical requirements needed to enable semiconductor manufacturing.

Table 6-3: Screening materials for use in semiconductor processes								
Material	**Meets Standard FM 4910**	**Low leachability**	**Low particle shedding**	**Chemical resistant, moisture resistant**	**Corrosion resistant**	**Durability, crack resistance, temperature resistance**	**Fire resistant**	**Processability and weldability**
Teflon™ PFA	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Good
Copper	No data	Metal ion contamination	Eliminated due to leaching potential					
Stainless steel	No data	Metal ion contamination	Eliminated due to leaching potential					
Noble metals	No data	Metal ion contamination	Eliminated due to leaching potential					
PEEK	No data	Yes	No data	Okay	Yes	Okay	Yes	Poor

Table 6-3: Screening materials for use in semiconductor processes								
Material	**Meets Standard FM 4910**	**Low leachability**	**Low particle shedding**	**Chemical resistant, moisture resistant**	**Corrosion resistant**	**Durability, crack resistance, temperature resistance**	**Fire resistant**	**Processability and weldability**
PP	Yes	Yes	No data	Okay	Yes	No[a]	Yes	Good
PVC/CPVC	Yes	Yes	No data	Okay	Yes	No[b]	Yes	Good

Source: RPA study team analysis
Notes
[a] *will lose shape at operating temperature*
[b] *will lose shape at operating temperature. Hard and brittle on its own. CPVC better than PVC.*

The remainder of this section will discuss the implications of implementing an alternative, if one were to become available, into the semiconductor industry including the timeline and costs in which it would take to achieve this. Discussed as well will be the risks posed to the industry if an alternative is used that is not suitable.

6.1.3.5 Availability

If an alternative material that presents the same performance as Teflon™ PFA became available, the implementation into the manufacturing process would be extremely long, potentially over 40 years before a new process is matured[111]. Based on information gathered during consultation, the evolution of the current semiconductor industry took 45 years to achieve its current performance level. Any change to the process, including materials, could have significant effects and would need to go through extensive testing to ensure both performance levels have not dropped and also to solve unforeseen problems. The qualification process of a new novel material could take up to 10 years on its own from invention to commercialisation, Figure 6-2 presents the qualification stages to integrate any change into the manufacturing process. Once a material has been identified to be suitable for use in the manufacturing process, it then needs to be demonstrated to users (fabrication plants) that it would not damage or decrease the performance of their products. The construction of new modules using an alternative material would need recertification and due to the complexity of the manufacturing machine, its redesign could take up to 20 years, including safety testing and meeting qualification standards[112].

[111] Downstream user consultation
[112] Downstream user consultation

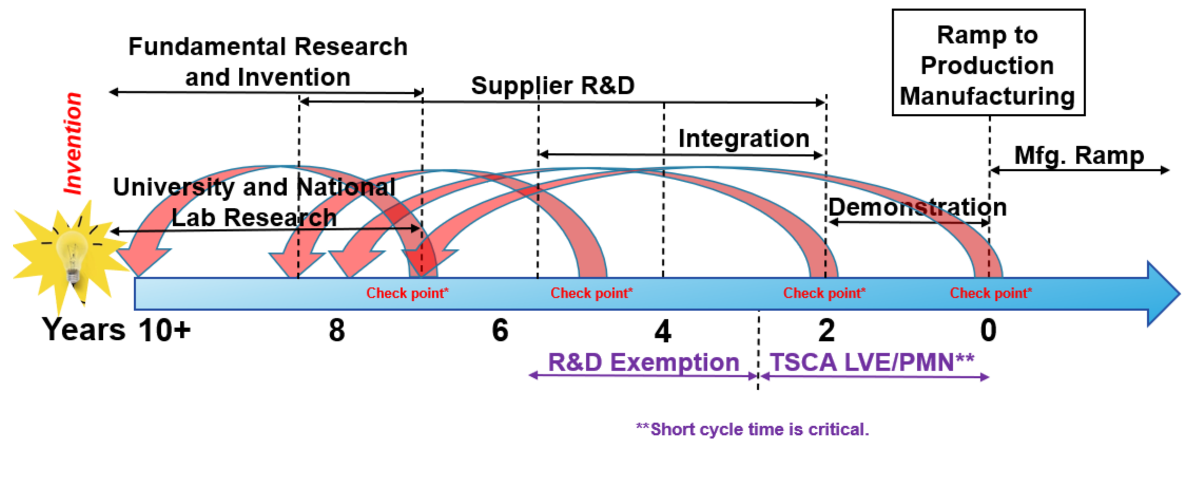

Figure 6-2: Qualification stages to integrate changes into existing manufacturing process
Source: Downstream user consultation

Semiconductor technology advancements have driven the innovation of ultra-pure materials used in the sector, with chip fabricators demonstrating the needs of production equipment to OEMs in order to achieve chip performance standards[113]. The projection shown in Moore's Law[114], that the number of transistors will double every two years, has put pressure on the industry to continuously improve and scale down this technology. As well as the push for the development of artificial intelligence, driving the production of micro sized chips also means an evolution of materials used is needed[115]. However, as stated in the previous section these types of materials are limited and the properties and characteristics are largely filled by Teflon™ PFA or other PFAS.

Currently there are no available alternatives to replace Teflon™ PFA in the semiconductor process, and as there has not been a need to replace it the development and readiness of any such non-PFAS material is far from reaching market availability.

6.1.3.6 Risks associated with incorporating new materials

The implementation of an alternative material, if one were found, would take a significant amount of time. This is due to the process that is in place to ensure the purity levels, and hence the quality of semiconductor chips, are maintained and continue to meet present standards. The implementation of a new material into the process would require extensive time to incorporate into the process and undergo testing. Any materials that do not allow the same level of purity would potentially affect the percentage yield of chips and introduce costly or fatal defects. Similarly, the present density of components on current generation chips could not be achieved.

If more impurities are present, that leads to the risk of introducing defects onto the wafer structure inhibiting the performance of the chip. This could lead to latent defects in the chip, impacting the function of the final product, potentially putting consumers at risk. Additionally, transistors need to

[113] https://www.eeworldonline.com/semiconductor-manufacturing-past-present-and-future/ accessed September 2022
[114] https://www.synopsys.com/glossary/what-is-moores-law.html accessed September 2022
[115] https://www.eeworldonline.com/semiconductor-manufacturing-past-present-and-future/ accessed September 2022

be replicated extensively and the materials used have a direct impact on replicability to ensure there are no defects that would compromise the functionality of a wafer[116].

Fabrication plants and OEM equipment manufacturers are driving the process and developing how they make their products. In order to phase out fluoropolymers, or more specially Teflon® PFA, they would need to change the chemistries that are being used. This would be a huge undertaking and could require complete redesign of fabrication plants. The implementation of a new material in the manufacturing process of semiconductor chips could cease production for decades due to the qualification processes needed, as previously discussed. As there is already a supply chain issue affecting the volume of chips produced[117], an additional hurdle could ultimately lead to electronic device shortages, such as smartphones, cameras, computers, medical devices and automobiles causing as these industries to become reliant on importation of chips from other continents.

6.1.3.7 Development and implementation costs

PFAS materials are among some of the most expensive plastics that can be used, therefore the costs associated with a switch to a non-PFAS alternative could likely be absorbed by manufacturers. According to Plastics Europe, the average cost of fluoropolymers produced in the EU in July 2022 was €21,000 per ton vs €2,200 per ton for PVC. This figure demonstrates how costly PFAS materials are in comparison to other plastics. It can be inferred that if the industry could switch to a cheaper viable alternative, it would likely have done so.

The costs to develop, qualify and implement materials would be a large initial investment. The total cost would be hard to predict as this has not been done before, however, it can be assumed that research and development of materials would be extremely costly. As well as demonstrating its performance through testing, such as leach out testing and corrosion resistance.

6.1.4 Conclusions

The development of the semiconductor chip has made significant advances since the 1970s and over the last 40 to 50 years, chips have become an integral part of everyday life found in almost every sector[118]. With these technology advancements the use of ultra-pure materials has become significantly more important. Therefore, it can be recognised that production of semiconductor chips is enabled by the materials used to produce manufacturing infrastructure such as tubing, valves and other components. With currently no viable alternatives to simultaneously deliver the performance requirements equivalent to Teflon™ PFA, a PFAS restriction on impacting fluoropolymers such as Teflon™ PFA in Europe would have immediate and significant long-lasting effects on the European semiconductor manufacturing industry. In addition, knock-on effects would be felt throughout numerous other industries reliant on semiconductor technology.

Without Teflon™ PFA the European semiconductor industry would likely collapse, immediately making almost every sector reliant on importation of semiconductor chips from Asia and North America. Europe would lose its 10% global semiconductor chip market share and consequently fail to fulfil the objectives in the EU Chips Act. For a full picture on the associated European profit and employment losses please refer to Section 8.

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[116] https://www.ibm.com/thought-leadership/innovation-explanations/mukesh-khare-on-smaller-transistors-analytics accessed September 2022

[117] https://www.jpmorgan.com/insights/research/supply-chain-chip-shortage accessed September 2022

[118] https://www.hitachi-hightech.com/global/products/device/semiconductor/history.html accessed June 2022

The performance requirements for materials, which are all met by Teflon™ PFA, is what makes the switch to another material so difficult. These extremely rigid standards must be met by any potential alternative to maintain the current performance levels. Metal alternatives risk the potential for metallic impurities and contaminants to be introduced into the process that could result in wafer defects. While other plastic alternatives could also leach impurities into the ultra-pure chemicals. Additionally, both alternative options (metals and plastics) do not have the chemical resistance needed for the application. This reduced chemical resistance could result in injury or increased component turnover leading to downtime, increased waste, and higher expense.

In the event that an alternative material is found to meet the performance characteristics required to be used within this industry, it would take decades to redesign, qualify, and implement the material into the manufacturing process. This would therefore not be economically viable and would have huge knock-on effects to industries that rely on semiconductor chip technology. While there continues to be research and innovation to improve semiconductor processes using current materials, there are no advancements in the discovery of a material that meets the performance requirements of fluoropolymers and more specifically, Teflon™ PFA. Therefore, this analysis of alternatives finds that there are currently no viable alternatives to the use of Teflon™ PFA in the semiconductor industry.

7 Continued use scenario

7.1 Introduction

This section sets out the continued use (or baseline) scenario for the Advanced Performance Materials (APM) division of Chemours and its downstream users in relation to the manufacture, export, import, sale, and use of Teflon™ PFA. The scenario assumes that APM will be able to import, manufacture, place on the market and use Teflon™ PFA without any restriction. It also assumes that all downstream users will be able to purchase and use Teflon™ PFA products offered by APM and these same downstream users will be able to manufacture finished articles that are either partly or wholly composed of fluoropolymers or use fluoropolymers during their respective manufacturing processes.

The continued use scenario will focus on the current import of the products Teflon™ PFA. Specifically, this socio-economic analysis will focus on the import of Teflon™ PFA used in components to convey process chemistries and components for wafer handling during the manufacture of semiconductors.

Reference and extrapolation to other applications within the semiconductor markets are also made at a higher level. Chemours already holds a strong position in the supply chain of this product within Europe, meaning they possess significant market share. This market is expected to adapt and change significantly in response to global pressures, but APM intend to retain their market capitalisation. Alongside use specific information for APM this section will also present wider market and supply chain information for the various players and sectors for the above stated uses of Chemours APMs products.

7.2 Imports and profits

This section presents various economic indicators for Chemours APM business division. The indicators discussed are the import tonnes of Teflon™ PFA, the size of these import markets in terms of the revenue earned from their import and the profits generated from the sale of these materials for the uses described above. The RPA study team has extrapolated data by using reported 2021 import and sales data from Chemours APM to predict the import, sales, and profits of the business division up to and including the end of 2035. The data has been extracted from surveys created by RPA and answered by Chemours APM. The RPA study team has presented tonnage, value, and profit figures from 2021-2035 to demonstrate how each market will develop between now and the possible start of a restriction. However, only the figures from 2026-2035 are considered and discussed within the analysis of the continued use scenario. The assessment period being employed for this continued use scenario is from 2026-2035, which considers the expected time the restriction will be in place as well as a phase-out period. The timeline will be in the non-use scenario, as discussed in more detail in section 8. This assessment period (ten years) reflects a possible timeframe for alternatives and new chemicals to be identified in the event fluorine-based chemicals can no longer be utilised; however, it is expected that the full development and implementation of new materials, chemistries, technologies and techniques within the semiconductor industry could take in excess of 40 years. However, a more detailed explanation for the reasoning behind the 2026-2035 timeframe is provided in Section 8.1. It should be noted that the following report sections will refer to Chemours Teflon™ PFA product name and not the monomers used to create them.

7.2.1 Teflon™ PFA imports and profits

Teflon™ PFA is produced and sold in various grades of purity by Chemours APM for use in various sectors, however it is the material of choice for use within the fluid handling/chemical distribution process during the manufacture of semiconductors. At present Chemours APM does not polymerise or manufacture Teflon™ PFA and its resins within the EU27/EEA and instead imports this material to supply the various markets dependent on this fluoropolymer. In 2021 between 250 and 300 tonnes of Teflon™ PFA in total were imported into the EU27/EEA for both semiconductor related uses and other uses. The global growth in demand for Teflon™ PFA is increasing at a rate of roughly 8%, however, Europe is currently seeing its demand for the material increase at a higher annual rate of 12%[119]. This increased level of demand is the result of large amounts of investment set to occur within industries dependent on Teflon™ PFA, such as the semiconductor industry which between 2019 and 2021 is estimated to have invested $53 billion and $235 billion global on new foundries and equipment respectively[120]. A detailed explanation as to the reasons why demand for Teflon™ PFA is increasing in the semiconductor industry is provided below following the split between semiconductor Teflon™ PFA uses, and other uses being presented. Using this baseline figure and annual growth rate the RPA study team have extrapolated the total tonnes of Teflon™ PFA which will be imported into the EU27/EEA from 2021-2035 and these estimates are presented in Table 7-1.

Table 7-1: Estimated total tonnes of Teflon™ PFA imported into the EU27/EEA

Year	Lower bound (tonnes)	Upper bound (tonnes)
2021	250	300
2022	280	336
2023	314	376
2024	351	421
2025	393	472
2026	441	529
2027	493	592
2028	553	663
2029	619	743
2030	693	832
2031	776	932
2032	870	1,044
2033	974	1,169
2034	1,091	1,309
2035	1,222	1,466
Assessment period total	7,732	9,278
Grand total	9,320	11,184

Source: RPA study team analysis

As can be seen from the above the current quantities of Teflon™ PFA being imported into Europe by 2035 are set to increase fivefold compared to 2021. Total imports will rise from between 250 and 300 tonnes in 2021 to between just over 1200 and just under 1500 tonnes in 2035, representing a rapidly growing market in the short and long term. Over the course of the assessment period from 2026-2035 a total of between 7700 and 9300 tonnes will be imported into the EU27/EEA.

Presented in Table 7-2 is the split between semiconductor related uses of Teflon™ PFA and other industrial uses as provided to the RPA study team by APM during consultation. Of the total annual tonnes of Teflon™ PFA (250 to 300 tonnes) imported in 2021, between 100 and 150 tonnes was imported specifically for use within the semiconductor industry. Therefore, making it the single biggest market to use Teflon™ PFA imported by Chemours APM.

[119] Source: internal communication between APM and RPA and APM questionnaire response

[120] SEMI West 2022 Day 1 **SEMI Market Symposium**. Agenda can be found here: https://www.semiconwest.org/programs/market-symposium

Table 7-2: Estimated tonnes of Teflon™ PFA imported into the EU27/EEA by use			
	PFA used in semiconductor industry		
Year	Lower bound (tonnes)	Upper bound (tonnes)	Other PFA uses (tonnes)
2021	100	150	150
2022	112	168	168
2023	125	188	188
2024	140	211	211
2025	157	236	236
2026	176	264	264
2027	197	296	296
2028	221	332	332
2029	248	371	371
2030	277	416	416
2031	311	466	466
2032	348	522	522
2033	390	584	584
2034	436	655	655
2035	489	733	733
Assessment period total	3,093	4,639	4,639
Grand total	3,728	5,592	5,592
Source: RPA study team analysis			

Over the course of the assessment period, between 3000 and 4700 tonnes of Teflon™ PFA will be imported into the EU27/EEA for use within the semiconductor industry in the fluid handling/chemical distribution process. Likewise, nearly 4700 tonnes of Teflon™ PFA will be imported for use in other industrial settings. The reason the demand for Teflon™ PFA for use within the semiconductor industry is set to increase, is due to the continued global push on demand from the semiconductor industry. The global pressure being placed on the demand for Teflon™ PFA from the semiconductor industry is arising from two requirements:

Firstly, there is a continuing upward trend in the demand for semiconductors; with more and more industries introducing technology to their products the demand for semiconductor chips to enable this will continue to grow rapidly. Prior to the COVID-19 pandemic there was already a global chip shortage developing. Exacerbated by the pandemic, this shortage to hit extreme levels causing it to have a profound impact on the output of other critical industries such as consumer electronics, automobiles, defence, and internet infrastructure. The global shortage is causing an exponential increase in the capacity of the semiconductor industry. Substantial levels of investment, worth an estimated 100 billion dollars over the next two years, are being made in both the North America and European regions as manufacturing diversifies away from sole reliance on Asia based manufacturing. Therefore, the already present demand for more chips and the expanding capacity of the industry is creating a compounded increase in the demand for Teflon™ PFA as the semiconductor industry expands to meet the global demand being caused by both consumer and political pressures such as the European Chips Act.

Secondly to this is the global requirement for more advanced chips on a regular basis. For a semiconductor chip to become more advanced it must possess greater compute power which in turn requires more transistors. The semiconductor industry from 1965 to 1975 doubled the number of transistors on chips every year and since 1975 has followed what has become known as Moore's Law whereby the number of transistors on a semiconductor chip doubles every two years[121]. Adhering to this law is becoming more and more difficult due to complexities in further reducing the size of

[121] https://www.britannica.com/technology/Moores-law accessed September 2022

transistors (to allow more to be placed onto a chip) and accurately replicating transistors many billions of times over. To continue to reduce the size of transistors and upgrade the quality of semiconductors, exceptionally clean and sterile environments are required and to achieve this very high purity and, non-reactive materials are required in the manufacturing process. Therefore Teflon™ PFA is the material of choice for the semiconductor industry. New high purity grades of Teflon™ PFA being introduced to market will allow the semiconductor industry to continue this process of improvement and thus is a second reason the demand for Teflon™ PFA is set to greatly increase over the course of the assessment period.

Even though only a few thousand tonnes of Teflon™ PFA is set to be imported over the course of the assessment period the size of the market these materials supply is substantial given their very high market price. Chemours APM sell Teflon™ PFA resins for between €40,000 and €80,000 per tonne. Using these sale prices, the RPA study team has estimated the value of the market these imports supply. This was done by multiplying the 2021 tonnages by the aforementioned sale prices to establish the base revenue and then growing the revenue streams by a 20% annual growth rate, being experienced by Chemours for their Teflon™ PFA products. These estimates are presented in Table 7-3.

Table 7-3: Estimated revenue from the sale of Teflon™ PFA imports by use

	Semiconductor use		Other uses	
Year	Lower bound (€)	Upper bound (€)	Lower bound (€)	Upper bound (€)
2021	4,000,000	12,000,000	6,000,000	12,000,000
2022	4,620,000	13,800,000	6,920,000	13,800,000
2023	5,330,000	16,000,000	7,990,000	16,000,000
2024	6,140,000	18,400,000	9,200,000	18,400,000
2025	7,090,000	21,300,000	10,600,000	21,300,000
2026	8,180,000	24,500,000	12,300,000	24,500,000
2027	9,400,000	28,300,000	14,200,000	28,300,000
2028	10,900,000	32,700,000	16,300,000	32,700,000
2029	12,600,000	37,700,000	18,900,000	37,700,000
2030	14,500,000	43,500,000	21,800,000	43,500,000
2031	16,700,000	50,200,000	25,100,000	50,200,000
2032	19,300,000	57,900,000	29,000,000	57,900,000
2033	22,300,000	67,000,000	33,400,000	67,000,000
2034	25,700,000	77,000,000	38,600,000	77,000,000
2035	29,700,000	89,000,000	44,500,000	89,000,000
Assessment period total	169,280,000	507,800,000	254,100,000	507,800,000
Grand total	196,460,000	589,300,000	294,810,000	589,300,000
Source: RPA study team analysis				

It can be seen here again that the value of the market for Teflon™ PFA used in the semiconductor industry is substantial, but so too is the value of the Teflon™ PFA used for other industrial uses. The value of Teflon™ PFA over the assessment period used within the semiconductor industry is between €169 and €508 million, with the value of sales of Teflon™ PFA for other uses standing between €124 and €249 million. Relatively small annual quantities of material are therefore producing extremely valuable markets and these quantities of Teflon™ PFA are also enabling even more high value markets to exist along the downstream supply chain for semiconductors, which is discussed and valued in more detail in Section 7.4. The combined value of the above tables is presented in Table 7-4.

Table 7-4: Estimated total revenue from the sale of Teflon™ PFA imports

Year	Lower bound (€)	Upper bound (€)
2021	10,000,000	24,000,000
2022	11,500,000	27,700,000

Table 7-4: Estimated total revenue from the sale of Teflon™ PFA imports		
Year	Lower bound (€)	Upper bound (€)
2023	13,300,000	32,000,000
2024	15,400,000	36,900,000
2025	17,700,000	42,500,000
2026	20,500,000	49,100,000
2027	23,600,000	56,600,000
2028	27,200,000	65,400,000
2029	31,400,000	75,000,000
2030	36,300,000	87,000,000
2031	41,800,000	100,000,000
2032	48,300,000	116,000,000
2033	55,700,000	134,000,000
2034	64,000,000	154,000,000
2035	74,000,000	178,000,000
Assessment period total	422,800,000	1,015,100,000
Grand total	490,700,000	1,178,200,000
Source: RPA study team analysis		

The import of Teflon™ PFA therefore supplies a market within Europe that will be valued at between €422 million and €1.02 billion over the assessment period based on revenue of the product. While these products may ultimately be imported their value and importance in the supply chain of semiconductors cannot be underestimated and this element of criticality compensates substantially against the impact of importing into the EU/EEA. At the same time, however, the sale of these products takes place within the EU/EEA meaning that substantial profits are generated within the region allowing significant amounts of value and economic growth to be experienced by the wider European economy.

For the sale of Teflon™ PFA, Chemours APM is experiencing a substantial variability in profit margin due to efficiencies they have developed during their research and development and due to the high selling price of this proprietary material. The margin between 2021 and 2026 is set to increase further as additional economies of scale and efficient business practices are implemented and realised. The exact value of this variable margin cannot be disclosed for reasons of confidentiality. The Table 7-5 and Table 7-6 provide the estimated annual profits that will be generated by Chemours APM. These estimates were arrived at by applying the increasing variable profit margin to the above revenue figures for 2021-2026 and from 2026 onwards the higher margin range has been applied to the revenue figures found above for Teflon™ PFA. All the figures above and below have been rounded to three significant figures and therefore there is the possibility for slight discrepancies between the figures, but these are minimal and simply a result of the presentation of rounded figures.

Table 7-5: Estimated profits from the sale of Teflon™ PFA by use				
	Semiconductor use		Other uses	
Year	Lower bound (€)	Upper bound (€)	Lower bound (€)	Upper bound (€)
2021	2,480,000	7,440,000	3,720,000	7,440,000
2022	2,930,000	8,790,000	4,400,000	8,790,000
2023	3,460,000	10,400,000	5,190,000	10,400,000
2024	4,090,000	12,300,000	6,130,000	12,300,000
2025	4,820,000	14,500,000	7,230,000	14,500,000
2026	5,690,000	17,100,000	8,530,000	17,100,000
2027	6,560,000	19,700,000	9,840,000	19,700,000
2028	7,570,000	22,700,000	11,400,000	22,700,000
2029	8,730,000	26,200,000	13,100,000	26,200,000
2030	10,100,000	30,200,000	15,100,000	30,200,000

Table 7-5: Estimated profits from the sale of Teflon™ PFA by use				
	Semiconductor use		Other uses	
Year	Lower bound (€)	Upper bound (€)	Lower bound (€)	Upper bound (€)
2031	11,600,000	34,900,000	17,400,000	34,900,000
2032	13,400,000	40,300,000	20,100,000	40,300,000
2033	15,500,000	46,400,000	23,200,000	46,400,000
2034	17,900,000	53,600,000	26,800,000	53,600,000
2035	20,600,000	61,800,000	30,900,000	61,800,000
Assessment period total	117,650,000	352,900,000	176,370,000	352,900,000
Grand total	135,430,000	406,330,000	203,040,000	406,330,000
Source: RPA study team analysis *Estimations are excluding fixed cost*				

Teflon™ PFA used in the semiconductor industry is the largest single application for PFA sold by Chemours APM this also results in the profits attributable to this application being substantial. The profits generated by the sale of Teflon™ PFA for use in this industry are between €117 and €353 million over the course of the assessment period, representing up to 50% of the total profits generated per year. Likewise, the profit generated from the sale of Teflon™ PFA for other uses over the assessment period stands between €176 and €353 million. The generation of profits on this scale from the supply of relatively small quantities of material underpin the value and vitality of these products to this supply chain. While it is recognised by the supply chain that fluoropolymers of this high purity nature are particularly expensive, they do allow significant profits to be generated by Chemours APM but also by the whole supply chain given the value of the industries these materials are utilised in which are further discussed in Section 7.4.

Table 7-6: Estimated total profits from the sale of Teflon™ PFA		
Year	Lower bound (€)	Upper bound (€)
2021	6,200,000	14,900,000
2022	7,330,000	17,600,000
2023	8,650,000	20,800,000
2024	10,200,000	24,500,000
2025	12,100,000	28,900,000
2026	14,200,000	34,100,000
2027	16,400,000	39,400,000
2028	18,900,000	45,400,000
2029	21,800,000	52,400,000
2030	25,200,000	60,500,000
2031	29,100,000	69,800,000
2032	33,500,000	80,500,000
2033	38,700,000	92,900,000
2034	44,700,000	107,000,000
2035	51,500,000	124,000,000
Assessment period total	294,000,000	706,000,000
Grand total	338,480,000	812,700,000
Source: RPA study team analysis *Estimations are excluding fixed cost*		

Overall, the total estimated **profits generated by Chemours APM from the sale of Teflon™ PFA over the course of the assessment period is between €294 and €706 million.** It should again be noted that the assessment period is the sum of only years 2026-2035 and the grand total is the sum of all years in the above table from 2021-2035. These profit levels are substantial for Europe to benefit from as these profits in the range of hundreds of millions of Euros allow for significant tax revenues to be enjoyed by Member State governments and for substantial levels of investment, research, and development to take place within Europe. Also given the current volatility in the semiconductor industry given current global shortages and rapid push for capacity increases could cause these estimations to be underestimates. If current demand for semiconductors and breakthroughs in semiconductor transistor size develop, there could be an even higher level of demand for production capacity and requirement for machines using Teflon™ PFA. Not only that but given the permanent place semiconductors have in the world there is also a high level of guarantee regarding the recurrence of these profits for the European economy. Semiconductors will be required in many industries from now onwards as technology develops and as such more material will be required to produce these semiconductors and therefore sales of Teflon™ PFA and other fluoropolymer materials which facilitate this will continue indefinitely. At the same time, given the levels of future investment the semiconductor industry is potentially set to make within Europe, will only be possible provided materials such as Teflon™ PFA are available within the continent. Therefore, on top of the profits which Chemours APM are generating from the European economy, Chemours APM supply of Teflon™ PFA is also exclusively allowing Europe to remain in contention to receive tens of billions of Euros of investment in new high skill jobs and production capacity.

7.3 Emissions

The inherent nature of fluoropolymers means they are not likely to release emissions due to their stability and inertness. Emissions may occur during processing and melting, however, emissions during use and end-of-life are not likely to occur. The large molecular weight of the fluoropolymers means it is unlikely to cross biological membranes. In addition, Teflon™ PFA is insoluble in water therefore there is no potential of toxicity to aquatic organisms. This section will look at emissions during the lifecycle of the product and what can be done to reduce emissions.

7.3.1 Emissions at the Dordrecht site

There are no emissions related to the manufacture of Teflon™ PFA at the Dordrecht site. See Section 3.1.1 for information on emissions abatement at Chemours' Dordrecht site and European facilities.

The investments Chemours has made is recognised by Dutch authorities who concluded "*no health risk is expected for people living in the vicinity of the Chemours Dordrecht plant due to exposure*"[122]. The additional measures being implemented to achieve their CRC 2030 goals will continue to lower emissions and exposure even further.

7.3.2 Lifecycle emissions of Perfluoro alkoxy

The potential for emissions is likely to occur during the manufacturing phase of the articles, i.e., during melting of the resins. According to one downstream user, the moulding and converting process takes place entirely within a closed system and releases of the material do not occur. The high value of the product is also an incentive to ensure that there is no waste.

As previously mentioned in Section 5.1, the residual monomer and polymerisation aid content for PFA are extremely low. This can be attributed to final processing steps implemented by manufacturers,

[122] National Institute for Public Health and the Environment, Ministry of Health, Welfare and Sport, Evaluation of substances used in the GenX technology by Chemours, Dordrecht, 2016.

such as washing and heating. These steps allow for the removal of residuals from the final commercial product[123].

The inert, resistant and insoluble nature of the polymer suggests emissions through chemical leaching are also not likely. Therefore, emissions of Teflon™ PFA during use are considered to be unlikely and have not been calculated.

7.3.3 Waste management and end of life

At the end of use, fluoropolymers could be disposed of in the following manners: landfill, incineration, or reuse/recycling.

7.3.3.1 Recycling

It is possible to recycle PFA to be used in lower grade applications (that do not require the high degree of purity that semiconductors need). As indicated by downstream users, moulders and converters may have their own in-house recycling programs. For example, the melt cakes used in process start-ups can be sold to a recycling company where it will then be ground down and re-granulated for use in low grade applications. Additionally, there may be PFA granules from tubing off-cuts. Users will have grinders and closed loop systems dedicated for PFA; this ensures there will be low PFA waste.

Due to the long lifetime of Teflon™ PFA there is only small volumes of waste coming out of fabrication plants and in some cases these components will be reused in lower grade applications, or where possible, in some fabrication equipment.

7.3.3.2 Incineration

The most commonly used method of disposal for Teflon™ PFA is incineration. At high enough temperatures set out in the Industrial Emissions Directive 2010/75/EU of at least 850°C-1100°C for at least two seconds, the C-F bond will be broken destroying the fluoropolymers and any residual fluoropolymers and substances that may form during thermal decomposition. In Europe, typically 80%

of fluoropolymers are sent to incineration[124].

7.3.3.3 Landfill

Fluoropolymers are extremely stable and will not degrade in the environment or release hazardous substances. Due to the properties presented in Section 5, it can be inferred that fluoropolymers sent to landfill will not break down or transform and will remain in a landfill unless otherwise removed, owing to their persistency. Additionally, landfills in Europe are required to be lined with HDPE thus reducing the potential for seepage into the local environment.

124 https://fluoropolymers.plasticseurope.org/application/files/5416/5104/8333/20211104_FP_RMOA_Final_3.pdf accessed November 2022

124 https://fluoropolymers.plasticseurope.org/application/files/5416/5104/8333/20211104_FP_RMOA_Final_3.pdf accessed November 2022

The structures built with the use of PFA in the semiconductor industry are expected to be in place for decades, and according to desk-based research, no structures in Europe are known to have been dismantled and sent to landfill.

7.4 Value of downstream markets

7.4.1 Semiconductors

In 2021 the global semiconductor market was €448.93 billion with a compound annual growth rate (CAGR) of 9.2% through 2029[125]. In 2019, however, due to the global Covid-19 pandemic, the industry suffered a decline in the market of 6.8% in 2020 compared to 2019[126]. The main driving factors in this growth is due to rising disposable income and the consumption of consumer electronics and the shift to home-based working during the pandemic has led to increased demand for personal computers[127].

More specifically, in 2020 the global automotive semiconductor market was worth €37.71 billion with CAGR of 11.8% through 2030[128]. It was observed that the demand for automotive semiconductor chips has increased by 50% since 2017 and is expected to continue increasing over the coming years[129]. The driving factors attributing to the growth in this sector is the electrification of vehicles and the increase in advanced driver assistance systems technologies[130].

In 2021, the global high-performance fluoropolymers market was valued at €3.67 billion and is expected to grow at a CAGR of 6.8% through 2026[131]. While PTFE dominated the market in 2020, PFA is expected to be the fastest growing fluoropolymer during this period[132]. The driving factors behind this growth vary depending on the sector. For example, lower emissions and increased fuel efficiency are driving factors in the automotive industry. The aerospace industry relies on their combined physiochemical properties to deliver the functionality needed. More specifically, Chemours Teflon™ PFA holds a 60% global market share and 34% European market share[133].

As seen in Figure 4-7 earlier, the semiconductor supply chain for semiconductor manufacturing after Chemours APM consists of three main market segments, moulders and converters, equipment manufacturers and fabrication plant owners. To value the entire downstream supply chain the RPA study team has evaluated and consulted with actors in each of these segments to determine an estimate for the value of these markets in terms of profits, employment, environmental and health impacts and innovation and investments.

7.4.1.1 Moulders and converters using Teflon™ PFA

Within the semiconductor supply chain, moulders and converters are responsible for manufacturing pipes, tubing and other components that will be used to manufacture equipment vital to the semiconductor manufacturing process. These companies are direct customers of Chemours APM and receive the Teflon™ PFA in its resin form. However, it is the semiconductor fabrication plants that dictate purity requirements. These players further down the supply chain will ask moulders and

125 https://www.fortunebusinessinsights.com/semiconductor-market-102365 accessed July 2022
126 https://www.fortunebusinessinsights.com/semiconductor-market-102365 accessed July 2022
127 https://www.fortunebusinessinsights.com/semiconductor-market-102365 accessed July 2022
128 https://www.alliedmarketresearch.com/automotive-semiconductor-market-A14477 accessed July 2022
129 https://www.eetimes.eu/a-look-at-the-european-semiconductor-industry/ accessed July 2022
130 https://www.alliedmarketresearch.com/automotive-semiconductor-market-A14477 accessed July 2022
131 https://www.marketsandmarkets.com/Market-Reports/fluor-polymer-market-497.html accessed July 2022
132 https://www.marketsandmarkets.com/Market-Reports/fluor-polymer-market-497.html accessed July 2022
133 Internal Communication with Chemours APM Division 2022

converters to prove the purity of their components, which can sometimes be done in house or is negotiated with the raw material supplier. Modern day semiconductor manufacturing has become so advanced and sophisticated that exceptionally pure and non-reactive materials are essential to enable continued advancements in semiconductor processing power and design as previously discussed which is why this industry is demanding only materials such as PFA and other fluoropolymer materials from moulders and converters. In short to meet the demands of their clients, moulders and converters must use PFA and other fluoropolymer materials.

During the consultation phase RPA received five responses from moulders and converters within the supply chain and within the EU. Estimations regarding the size of the market these respondents possessed were not possible and as such no wider market predictions or extrapolations regarding the Teflon™ PFA specific moulders and converters market have been made. The information presented below is therefore based solely on the responses RPA received, and these are presented as a minimum possible value estimation for the market. One company provided insufficient data in their response and was therefore not included in the below data amalgamation. Therefore, it can be assumed that the following figures will be a considerable underestimation of the true value of this supply chain segment.

Table 7-7 presents the lower and upper bound estimates for the volume of Teflon™ PFA used by European moulders and converters to produce components for use in semiconductor manufacturing processes, based on the information obtained during consultation. To protect the identity of the RPA consultation respondents the information for each responding company has been processed separately and then amalgamated together into a single total in a range and presented as such below.

Table 7-7: Estimated volume of Teflon™ PFA used by moulders and converters in Europe in tonnes

Year	Lower bound (tonnes)	Upper bound (tonnes)
2021	135	165
2022	151	185
2023	168	205
2024	184	225
2025	201	245
2026	217	265
2027	234	285
2028	250	305
2029	266	326
2030	283	346
2031	299	366
2032	316	386
2033	332	406
2034	349	426
2035	365	446
Assessment period total	2,910	3,557
Grand total	3,750	4,583

Source: RPA study team analysis

The moulders and converters who responded to the RPA consultation will, over the course of the assessment period, supply between 2,900 and 3,500 tonnes of Teflon™ PFA components for use in semiconductor manufacturing equipment. The maximum potential size of the market will be limited to the maximum volume of Teflon™ PFA Chemours can import into the European Union, which has been estimated in previous sections and outlined in Table 7-1 and this assumption can be made due to moulders and converters producing very little waste and few off cuts of PFA due to its high price point and cost for these companies.

The respondents to the RPA consultation had varying price ranges for their Teflon™ PFA products. These price ranges will not be disclosed for reasons of confidentiality and competition. Table 7-8 are the lower bound and upper bound estimates of revenue for the respondents to the RPA consultation. These revenue estimates were provided to RPA by each respondent respectively in their consultation questionnaires. From 2023 onwards they have been discounted at the rate of 4% to arrive at the present-day value. All individual company values were rounded to 3 significant figures before being amalgamated and presented in Table 7-8 which is why each row itself is not rounded to a set number of significant figures, the difference between the true and rounded figures below is also very low.

Table 7-8: Estimated revenue from sales of Teflon™ PFA equipment components for semiconductor manufacturing

Year	Lower bound (€)	Upper bound (€)
2021	96,750,000	118,250,000
2022	109,650,000	134,000,000
2023	119,720,000	146,300,000
2024	130,900,000	159,920,000
2025	143,400,000	175,270,000
2026	157,320,000	192,240,000
2027	172,870,000	211,340,000
2028	190,440,000	232,770,000
2029	210,240,000	257,040,000
2030	232,570,000	283,840,000
2031	257,240,000	313,790,000
2032	285,340,000	348,690,000
2033	316,890,000	387,830,000
2034	353,990,000	432,140,000
2035	394,840,000	481,710,000
Assessment period total	2,571,740,000	3,141,390,000
Grand total	3,172,160,000	3,875,130,000
Source: RPA study team analysis		

During the assessment period, the four consultation responses received by RPA **will generate between €2.5 and €3.2 billion in revenue**. The above estimate is a highly conservative under estimation of the true value of revenue being generated by the moulders and converters supply chain segment. It can be concluded however that this portion of the supply chain generates large returns for the European economy in terms of revenue given the substantial sums being generated by only a handful of companies within the supply chain segment. Total economic contribution to the European economy is however measured by profitability and not revenue generation. Respondents were asked to provide their profit margin in a 10% range (e.g., 0-10%, 11-20% etc.) to which the midpoint of those ranges was applied to those companies' revenues. In cases where a respondent had not provided a profit range for confidentiality reasons the RPA study team applied the Member State specific average operating profit metric from Eurostat for NACE classification C22.21. Table 7-9 presents the calculated combined profit generated by the known moulders and converters within Europe.

Table 7-9: Estimated profit from sales of Teflon™ PFA

Year	Lower bound (€)	Upper bound (€)
2021	9,232,000	11,283,000
2022	10,494,000	12,819,000
2023	11,484,000	14,040,000

Table 7-9: Estimated profit from sales of Teflon™ PFA		
Year	Lower bound (€)	Upper bound (€)
2024	12,589,000	15,388,000
2025	13,830,000	16,902,000
2026	15,208,000	18,595,000
2027	16,763,000	20,497,000
2028	18,516,000	22,640,000
2029	20,497,000	25,060,000
2030	22,730,000	27,730,000
2031	25,200,000	30,760,000
2032	28,020,000	34,230,000
2033	31,190,000	38,180,000
2034	34,910,000	42,570,000
2035	38,980,000	47,610,000
Assessment period total	252,014,000	307,872,000
Grand total	309,643,000	378,304,000
Source: RPA study team analysis		

The contacted **moulders and converters within Europe supplying Teflon™ PFA components for use in semiconductor wet processing equipment will contribute profits between €252 and €308 million over the assessment period.** Given the limited data used to calculate these profits and there still being a sizeable return to the economy, it can be concluded this segment of the supply chain has a significant impact on the European economy and will bring substantial value and benefits to Europe both strategically and financially under the continued use scenario.

7.4.1.2 Wet processing equipment containing Teflon™ PFA components

Wet processing equipment manufacturers have an important role in the semiconductor supply chain but are not direct customers of Chemours. These businesses utilise pipes, tubes, valves, and other components made from Teflon™ PFA, and other fluoropolymer materials, by moulders and converters and integrate them into equipment that are then used to manufacture semiconductor chips. Specially under consideration within this SEA is the use of PFA by equipment manufacturers to produce lithography machines. These machines are highly complex with thousands of parts and generate numerous highly skilled jobs and revenue for the European economy. This will be discussed further within this section.

Through Eurostat, the appropriate PRODCOM codes for equipment manufacturers were identified and that data was used to generate the figures presented in this section. The PRODCOM codes identified and used are as follows:

- **28.99.20.20** – Machines and apparatus used solely or principally for the manufacture of semiconductor boules or wafers
- **28.99.20.40** - Machines and apparatus for the manufacture of semiconductor devices or of electronic integrated circuits
- **28.99.51.00** – Parts and accessories of machines and apparatus used solely or principally for (a) the manufacture of semiconductor boules or wafers, semiconductor devices, electronic integrated circuits or flat panel displays, (b) the manufacture or repair of masks and reticles, (c) assembling semiconductor devices or electronic integrated circuits, and (d) lifting, handling, loading or unloading of boules, wafers, semiconductor devices, electronic integrated circuits and flat panel displays

Table 7-10 presents the volume, revenue, and profit of semiconductor manufacturing equipment in the European Union. Due to lack of responses in the consultation phase, these values are based solely on information through Eurostat using the PRODCOM codes previously mentioned. The volume laid out in the below table is based on the quantity of machines and apparatus solely for the manufacture of semiconductors. This excluded parts and accessories for the machines and is therefore based on PRODCOM codes 28.99.20.20 and 28.99.20.40. Also due to data limitations and a lack of consultation responses the below information is not specific to semiconductor manufacturing equipment made from Teflon™ PFA. The information provided below is therefore for all semiconductor manufacturing equipment. It should be noted however that while the below information does relate specifically to fluoropolymers the information is still valid for this SEA due to most of all semiconductor manufacturing equipment being made from fluoropolymer materials. Not only that but all pieces of manufacturing equipment made from fluoropolymers are vital to the production process of semiconductors and as such any disruption to one form of fluoropolymer or one piece of equipment would cripple the industry. As a result of this interconnected nature of both equipment and fluoropolymer materials in their production, the RPA study team has elected to look at the equipment manufacturing segment and the following fabrication plant segment collectively in relation to fluoropolymers instead of just PFA.

It can be seen in Table 7-10 the quantity of machines produced is estimated to increase steadily through to 2035. This is due to the demand for semiconductors increasing in line with European strategic goals to shift to a smarter digital society and establish a more secure localised supply chain as outlined in the European Chips act which is discussed more in section 7.8. **Over the assessment period it is estimated that 1 million machines for semiconductor manufacturing will be produced.**

Table 7-10: Estimated volume, revenue, and profit of semiconductor manufacturing equipment sales in Europe

Year	Volume (items)	Revenue (€)	Profit (€)
2021	67,700	22,500,000,000	2,820,000,000
2022	77,200	25,700,000,000	3,210,000,000
2023	79,700	25,500,000,000	3,190,000,000
2024	82,200	25,300,000,000	3,160,000,000
2025	84,900	25,100,000,000	3,140,000,000
2026	87,600	24,900,000,000	3,110,000,000
2027	90,400	24,700,000,000	3,090,000,000
2028	93,300	24,500,000,000	3,070,000,000
2029	96,300	24,300,000,000	3,040,000,000
2030	99,300	24,200,000,000	3,020,000,000
2031	103,000	24,000,000,000	3,000,000,000
2032	106,000	23,800,000,000	2,970,000,000
2033	109,000	23,600,000,000	2,950,000,000
2034	113,000	23,400,000,000	2,930,000,000
2035	116,000	23,200,000,000	2,900,000,000
Assessment period total	1,013,900	240,600,000,000	30,080,000,000
Grand total	1,405,600	364,700,000,000	45,600,000,000

Source: RPA study team analysis

The table above also presents the revenue generated from this industry, more specifically the three PRODCOM codes previously mentioned. The revenue generated from these machines is quite substantial due to the complexity of the machines as well as the price of materials used. From 2023 onwards they have been discounted at the rate of 4% to arrive at the present-day value. All values have been rounded to 3 significant figures apart from total rows. During the assessment period, **€240.6 billion will be generated in revenue from the sale of semiconductor manufacturing**

equipment. Showing the value and potential for this sector to grow and boost the European economy quite substantially. Total economic contribution to the European economy is however measured by profitability and not revenue generation. To estimate the profit generated by equipment manufacturers the RPA study team applied a profit margin of 12.5%, and this margin was extracted from Eurostat as the average operating margin for enterprises under NACE classicisation C28.99. Application of this margin results in **semiconductor equipment manufacturers contribute €30.1 billion in profit to the European economy over the assessment period.**

Due to the limited number of enterprises contacted during the consultation phase, the precise number of enterprises and employees within the semiconductor equipment manufacturing market segment was estimated by use of Eurostat data for NACE classification C28.99. This was done by first establishing the total number of enterprises which are operating under the classification C28.99. The study team then estimated that semiconductor equipment manufacturing accounted for 3% of the total gross revenue for NACE classification C28.99 and as such the study team has assumed that 3% of the total enterprises under this classification are manufacturing semiconductor equipment. This 3% figure was generated by taking the 2020 and 2021 estimated revenues and calculating their percentage portion of total gross revenue for C28.99 from Eurostat. This approach may produce a slight overestimate or underestimate as the relation between revenue generation and number of enterprises is not always perfectly linear. The results of these calculations can be found in Table 7-11. The number of equipment manufacturers and average number of employees presented in the table have been used to estimate the number of employees in this market segment which is presented in section 7.6.2.2. The average number of employees presented in the table has been extracted from Eurostat and where no average was provided the EU 27 average has been applied to them and these have been appended with an asterisk.

Table 7-11: Estimated number of enterprises manufacturing semiconductor manufacturing equipment in Europe

Member State	Total enterprises in C28.99	Total equipment manufacturers under C28.99	Average C28.99 employees per enterprise
Austria	259	8	49.2
Belgium	170	5	14.6
Bulgaria	189	6	10.3
Croatia	78	2	8.3
Cyprus	-	-	-
Czechia	519	16	19.4
Denmark	360	11	14.2
Estonia	53	2	26.8*
Finland	262	8	19
France	612	18	14.5
Germany	3,578	107	45.2
Greece	80	2	9.5
Hungary	360	11	15.4
Ireland	:	:	:
Italy	1,539	46	18.4
Latvia	21	1	16.2
Lithuania	22	1	16.1
Luxembourg	2	0	26.8*
Malta	-	-	-
Netherlands	666	20	32.7
Poland	826	25	13.9
Portugal	309	9	14.9

Table 7-11: Estimated number of enterprises manufacturing semiconductor manufacturing equipment in Europe			
Member State	Total enterprises in C28.99	Total equipment manufacturers under C28.99	Average C28.99 employees per enterprise
Romania	153	5	29.4
Slovakia	179	5	15
Slovenia	114	3	16.2
Spain	634	19	15.4
Sweden	490	15	12
Eu 27 Total	11,500	345	26.8
Source: RPA study team analysis *Data points with an asterisk indicate data was missing from Eurostat and the EU 27 average has been applied to them*			

Across the EU 27 it is estimated that a total of 11,500 enterprises are involved in the manufacture of special-purpose machinery**. Of these 11,500, it is estimated 345 of those enterprises are involved in the manufacture of semiconductor equipment.** The economic benefits and returns of this employment are estimated and presented in Section 7.6.2.2.

7.4.1.3 Fabrication plant owners

Fabrication plants are not direct customers of Chemours and are at the end of the supply chain manufacturing semiconductor chips using the lithography machines made by the wet processing equipment manufacturers and other equipment produced from fluoropolymers. The manufacturing process is complex and lengthy and requires the highest quality machines using the highest quality components to produce an extremely powerful chip to be used in an advanced technology.

Through Eurostat, the appropriate PRODCOM codes for fabrication plants were identified and that data was used to generate the figures presented in this section. The PRODCOM codes identified and used are as follows:

- **26.11.21.20** – Semiconductor diodes
- **26.11.21.80** – Semiconductor thyristors, diacs and triacs
- **26.11.22.20** - Semiconductor light emitting diodes (LEDs)
- **26.11.22.40** - Photosensitive semiconductor devices; solar cells, photo-diodes, photo-transistors, etc.
- **26.11.22.60** - Semiconductor devices (excluding photosensitive semiconductor devices, photovoltaic cells, thyristors, diacs and triacs, transistors, diodes, and light-emitting diodes)
- **26.11.30.03** - Multichip integrated circuits: processors and controllers, whether or not combined with memories, converters, logic circuits, amplifiers, clock and timing circuits, or other circuits
- **26.11.30.06** - Electronic integrated circuits (excluding multichip circuits): processors and controllers, whether or not combined with memories, converters, logic circuits, amplifiers, clock and timing circuits, or other circuits
- **26.11.30.23** - Multichip integrated circuits: memories
- **26.11.30.27** - Electronic integrated circuits (excluding multichip circuits): dynamic random-access memories (D-RAMs)
- **26.11.30.34** - Electronic integrated circuits (excluding multichip circuits): static random-access memories (S-RAMs), including cache random-access memories (cache-RAMs)
- **26.11.30.54** - Electronic integrated circuits (excluding multichip circuits): UV erasable, programmable, read only memories (EPROMs)

- **26.11.30.65** - Electronic integrated circuits (excluding multichip circuits): electrically erasable, programmable, read only memories (E^2PROMs), including flash E^2PROMs
- **26.11.30.67** - Electronic integrated circuits (excluding multichip circuits): other memories
- **26.11.30.80** - Electronic integrated circuits: amplifiers
- **26.11.30.91** - Other multichip integrated circuits n.e.c.
- **26.11.30.94** - Other electronic integrated circuits n.e.c.

Table 7-12 presents the volume, revenue, and profit of semiconductor chip manufacturers in the European Union. Due to a lack of responses in the consultation phase, these values are based solely on information through Eurostat using the PRODCOM codes previously mentioned. The volume laid out in the below table is based on the quantity of semiconductors chips, circuits, and other devices described by the above codes. The quantity of chips produced is estimated to increase steadily through to 2035 due to the demand for semiconductor chips increasing in line with European strategic goals to shift to a smarter digital society. **Over the assessment period it is estimated that just under 679 billion semiconductor chips and devices will be produced in Europe under the continued use scenario.**

Table 7-12: Estimated volume, revenue, and sales of semiconductor chips			
Year	**Volume**	**Revenue (€)**	**Profit (€)**
2021	45,400,000,000	21,700,000,000	3,100,000,000
2022	51,700,000,000	24,700,000,000	3,530,000,000
2023	53,400,000,000	24,500,000,000	3,500,000,000
2024	55,100,000,000	24,300,000,000	3,480,000,000
2025	56,900,000,000	24,100,000,000	3,450,000,000
2026	58,700,000,000	23,900,000,000	3,420,000,000
2027	60,500,000,000	23,800,000,000	3,400,000,000
2028	62,500,000,000	23,600,000,000	3,370,000,000
2029	64,500,000,000	23,400,000,000	3,350,000,000
2030	66,500,000,000	23,200,000,000	3,320,000,000
2031	68,700,000,000	23,000,000,000	3,290,000,000
2032	70,900,000,000	22,900,000,000	3,270,000,000
2033	73,100,000,000	22,700,000,000	3,240,000,000
2034	75,500,000,000	22,500,000,000	3,220,000,000
2035	77,900,000,000	22,300,000,000	3,190,000,000
Assessment period total	678,800,000,000	231,300,000,000	33,070,000,000
Grand total	941,300,000,000	350,600,000,000	50,130,000,000
Source: RPA study team analysis			

The table above also presents the revenue generated from the production of semiconductor chips. The revenue generated from these chips is quite substantial. This is due to the complexity and powerfulness of the chips as well as the price of materials used throughout the production process. The revenue presented in the table is a summation of the production value of the PRODCOM codes. that have been discounted at the rate of 4% from 2023 onwards to arrive at the present-day value. All values have been rounded to 3 significant figures apart from total rows. During the assessment period, **€231 billion will be generated in revenue from the sale of semiconductor chips.** Total economic contribution to the European economy is however measured by profitability and not revenue generation. A profit estimation was made by the RPA study team by applying the average operating margin of 14.3% for NACE classification C26.11. By applying this average European profit margin **over the assessment period semiconductor chips will contribute €33.1 billion in profit to European economy.**

Due to the limited number of enterprises contacted during the consultation phase, the precise number of enterprises and employees within the semiconductor equipment manufacturing market segment was estimated by use of Eurostat data for NACE classification C26.11. This was done by first establishing the total number of enterprises which are operating under the classification C26.11. Afterwards the study team estimated that semiconductor equipment manufacturing accounted for 5% of the total gross revenue for NACE classification C26.11 and as such the study team has assumed that 5% of the total enterprises under this classification are manufacturing semiconductor chips. This 5% figure was generated by taking the 2020 and 2021 estimated revenues and calculating their percentage portion of total gross revenue for C26.11 from Eurostat. This approach may produce a slight overestimate or underestimate as the relation between revenue generation and number of enterprises is not always perfectly linear. The results of these calculations can be found in the Table 7-13. The number of fabrication plants and average number of employees presented in the table have been used to estimate the number of employees in this market segment which is presented in section 7.6.2.3. The average number of employees presented in the table has been extracted from Eurostat and where no average was provided the EU 27 average has been applied to them and these have been marked with an asterisk.

Table 7-13: Estimated number of enterprises manufacturing semiconductors and semiconductor products in Europe			
Member State	Total enterprises in C26.11	Total fabrication plants under C26.11	Average C26.11 employees per enterprise
Austria	102	5	83.8
Belgium	105	5	29.4
Bulgaria	60	3	16.2
Croatia	70	4	8.3
Cyprus	0	0	8.9
Czechia	939	47	8
Denmark	46	2	13.8
Estonia	23	1	31.8*
Finland	134	7	12.6
France	276	14	82.5
Germany	1682	84	46.8
Greece	106	5	4.6
Hungary	227	11	47.3
Ireland	-	-	31.8
Italy	1002	50	25.5
Latvia	22	1	20.1
Lithuania	24	1	26.1
Luxembourg	0	0	31.8*
Malta	-	-	31.8*
Netherlands	325	16	18.3
Poland	535	27	25.7
Portugal	101	5	13.2
Romania	130	7	122.2
Slovakia	396	20	8.3
Slovenia	98	5	13.4
Spain	377	19	18.9
Sweden	245	12	8.9
EU 27 Total	7000	350	31.8
Source: RPA study team analysis *Note: Data points with an asterisk indicate data was missing from Eurostat and the EU 27 average has been applied to them*			

Across the EU 27 it is estimated that a total of 7,000 enterprises are involved in the manufacture of electronic components**.** Of these 7,000, based on the application of the above stated share of industries in scope of this SEA, **it is estimated 350 of those enterprises are involved in the manufacture of semiconductor chips, circuits, and other devices.**

7.4.1.4 Other market implications

The specific end use of semiconductor chips which is under review in this SEA work is the use of semiconductor chips in the automotive sector. Modern day cars, both electric and internal combustion engine, are highly advanced with many electronic systems requiring thousands of semiconductors per car. Put simply modern cars just cannot be manufactured without access to semiconductors. To that end, the RPA study team have used PRODCOM codes under the NACE classification of C29.10 to arrive at an estimate for the number of electric and internal combustion engine commuter vehicles manufactured within Europe. In 2021 an estimated 10.7 million vehicles were manufactured with a revenue value of €244 billion. To this revenue figure the study team applied the C29.10 EU27 average operating surplus percentage of 6.3% from Eurostat to estimate a profit of around €15.4 billion. Accounting for the market moving towards more electric vehicle production and less internal combustion engine vehicle production and economic headwinds the annual number of motor vehicles which will require and be dependent on semiconductors was estimated along with the estimated revenue and profit. These estimates can be found in the , all figures have been rounded to three significant figures and all revenue and profit values have been discounted from 2023 onwards at an annual rate of 4%.

Table 7-14: Estimated production revenue and profit from motor vehicle sales in Europe			
Year	**Production**	**Revenue (€)**	**Profit (€)**
2021	10,700,000	244,000,000,000	15,400,000,000
2022	10,200,000	239,000,000,000	15,100,000,000
2023	9,560,000	234,000,000,000	14,800,000,000
2024	9,180,000	234,000,000,000	14,700,000,000
2025	9,000,000	237,000,000,000	14,900,000,000
2026	9,020,000	243,000,000,000	15,300,000,000
2027	9,210,000	253,000,000,000	15,900,000,000
2028	9,570,000	267,000,000,000	16,800,000,000
2029	10,100,000	283,000,000,000	17,900,000,000
2030	10,800,000	303,000,000,000	19,100,000,000
2031	11,600,000	327,000,000,000	20,600,000,000
2032	12,500,000	353,000,000,000	22,200,000,000
2033	13,600,000	382,000,000,000	24,100,000,000
2034	14,800,000	414,000,000,000	26,100,000,000
2035	16,100,000	449,000,000,000	28,300,000,000
Assessment period total	117,300,000	3,274,000,000,000	206,300,000,000
Grand total	165,940,000	4,462,000,000,000	281,200,000,000
Source: RPA Study Team analysis			

Over the course of the assessment period under a continued use scenario which allows the manufacture of and access to semiconductors, just **over 117 million motor vehicles will be manufactured within Europe.** The manufacture and sale of these vehicles will generate the market segment revenues of over €3.2 trillion **resulting in profits of over €206 billion.** The value therefore of the automotive sector to the European economy is large and a continued use scenario allowing semiconductors to be accessed and manufactured would permit this market to continue to generate exceptional levels of value for the European economy.

The RPA study team have assumed that all motor vehicles and therefore all motor vehicle manufacturers are dependent on semiconductors. As such the study team extracted from Eurostat the number of enterprises under classification C29.10 and took the average number of employees per enterprise to estimate the number of employees whose jobs are dependent on semiconductors produced with PFA equipment (Table 7-15).

Table 7-15: Estimated total number of enterprises and average number of employees		
Member State	**Total enterprises in C29.10**	**Average C29.10 employees per enterprise**
Austria	13	1517
Belgium	54	307
Bulgaria	5	6.6
Croatia	25	16.2

Table 7-15: Estimated total number of enterprises and average number of employees		
Member State	Total enterprises in C29.10	Average C29.10 employees per enterprise
Cyprus	0	592.6*
Czechia	81	556.6
Denmark	21	592.6
Estonia	11	592.6
Finland	33	177.8
France	130	900.1
Germany	259	2240.4
Greece	16	5.2
Hungary	68	338
Ireland	24	6.7
Italy	91	685.5
Latvia	5	86
Lithuania	6	47
Luxembourg	0	592.6*
Malta	0	592.6*
Netherlands	144	96.2
Poland	151	256.5
Portugal	41	200.9
Romania	23	932.9
Slovakia	397	64.1
Slovenia	21	194.4
Spain	112	641.6
Sweden	159	435.2
EU 27 Total	1890	592.6

Source: Eurostat
Note: Data points with an asterisk indicate data was missing from Eurostat and the EU 27 average has been applied to them

shows that in total around 1,890 enterprises are estimated to be involved in the manufacture of motor vehicles and as such are reliant on access to semiconductors within Europe. The total number of employees and the value this employment brings to the European economy within this sector is discussed in section 7.6.2.4.

7.5 Health and environmental impacts

As determined in the hazard assessment, Teflon™ PFA is not a concern to human or environmental health.

7.5.1 Health impacts

Based on the information available and due to the fact that there is no production within the EU of Teflon™ PFA, health hazards are not of concern. Therefore, the health impacts under a continued use scenario have not been calculated.

7.5.2 Environmental impacts

Based on the information available, the environmental concerns for Teflon™ PFA relate to its persistency. Fluoropolymers can be landfilled at the end of life and because they are stable and won't break down in the environment, they are considered environmentally neutral[134].

7.6 Employment

7.6.1 Chemours APM

Chemours APM has an employment footprint across the Netherlands, Belgium, France, Spain, Germany, and Denmark. There is also employment in Switzerland but due to Switzerland being outside the EU27/EEA zone employment figures for this country have been excluded from consideration. The roles performed by these employees vary from direct hands-on roles such as manufacturing, packaging, and transporting products to more functionary roles such as sales teams, compliance, and HR. The Member States benefiting from this employment are the Netherlands, Belgium, France, Spain, Germany, and Denmark and across these nations APM employ a total of 629 full time equivalent employees each of whom are paid an average salary of €70,000. This high salary is due to the technical and specialist nature of APM's operations which makes the skillset of this workforce very high and their pay considerably above the standard European benchmark figure of €30,000. Employment is beneficial for any Member state or economy to experience, the RPA study team has conducted research to quantify, in a justifiable way, the extent of this benefit for each nation.

The RPA study team has first quantified how much of each employee's salary will be used to make tax and social security contributions. The study team has then determined how much of the employee's income will be removed from general money supply via savings (the household saving ratio) and subsequently how much disposable income each employee will have to drive economic activity and growth via consumption. These factors are reported in Table 7-16. All tax calculations have been estimated on a "most expensive" scenario whereby the highest possible tax bill for an individual has been estimated by assuming all individuals are unmarried and have no dependents. The tax income per person is therefore likely to be an overestimation of the true tax bills most of these individuals would face and subsequently national tax receipts would be lower. The household saving ratio is the percentage of a person's gross disposable income which is saved within a set period of a year, this value is typically reported by country quarterly but there are large variations in the frequency at which nations report this statistic. For reference the values reported below for the Netherlands relate to the saving ratio as of September 2021, the values for Belgium, Spain and Denmark refer to the rate as of December 2021 and for Germany and France the reported rate is from March 2022.

Table 7-16: Estimated economic contribution of employment from Chemours APM European operations

Member State	Number of Employees [1]	Average Salary (€) [1]	Tax income per person (€) [2]	Net pay (€)	Household saving ratio [3]	Disposable income per person (€)
Netherlands	464.9	70,000	22,178	47,822	16.31%	40,022
Belgium	76.2	70,000	30,719	39,281	12.50%	34,371
France	66.3	70,000	26,541	43,459	17.36%	35,915
Spain	15	70,000	22,418	47,582	13.81%	41,011
Germany	5.7	70,000	27,767	42,233	11.50%	37,376

134 https://fluoropolymers.plasticseurope.org/application/files/6216/3178/0517/Fluoropolymers_Safe_Hand_EN__June_2021.pdf

Table 7-16: Estimated economic contribution of employment from Chemours APM European operations						
Member State	Number of Employees [1]	Average Salary (€) [1]	Tax income per person (€) [2]	Net pay (€)	Household saving ratio [3]	Disposable income per person (€)
Denmark	1	70,000	30,674	39,326	8.17%	36,113

[1] *Source: Chemours APM consultation*
[2] *Source: https://salaryaftertax.com/ - for France, Spain, Belgium and Germany; https://www.icalculator.info/netherlands/salary-calculator/annual/2022.html - for the Netherlands; https://www.icalculator.info/denmark.html - for Denmark*
[3] *Source: https://tradingeconomics.com/country-list/personal-savings accessed 6th June 2022*

As can be seen from the above table Member States could be generating up to a maximum of between €22,000 and nearly €31,000 per employee because of Chemours APM operations. Consequently, European governments could receive tax receipts of up to a maximum of just over €14.9 million per year. This funding would be used to finance fiscal policy in Member States which would allow for economic growth through government expenditure and the government expenditure multiplier this multiplier however cannot currently be estimated for each Member State due to data constraints.

Likewise, after deducting the average household saving ratio, employees of APM have between 34,000 and €41,000 each to spend in disposable income per year. Theoretically not all this income would be truly disposable as each individual employee would have a basic level of consumption, they would have to spend to live, and some would be required to service household debt. However, whether this income was being spent on luxury items, servicing debt, or satisfying basic level consumption needs, consumption and economic activity would be taking place allowing economic growth to take place. In fact, per year Chemours APM employees through their disposable income would be able to contribute over €24.5 million in economic activity, which would bring the total yearly economic contribution of these employees to just over €39.4 million. This would also be subject to a separate consumption-based multiplier but once again due to data constraints and individual Member State complexities it is not currently possibly to accurately predict these multipliers but the returns to national and the wider European economy from Chemours APM employment is self-evident and substantial once multiplied. The total contributions made to each Member State's economy and the European economy have been summarised in Table 7-17.

Table 7-17: Estimated economic contributions of Chemours APM employees by Member State			
Member State	Total tax receipts (€)	Total disposable income (€)	Total
Netherlands	10,300,000	18,600,000	28,900,000
Belgium	2,340,000	2,620,000	4,960,000
France	1,760,000	2,380,000	4,140,000
Spain	336,000	615,000	951,000
Germany	158,000	213,000	371,000
Denmark	30,700	36,100	66,800
Total	14,900,000	24,500,000	39,400,000

Source: RPA study team analysis

Chemours APM employees are therefore able to make a significant annual contribution to the wider and national economies given their large average salary and the number of staff employed. The final form of analysis to assess the contribution of these employees by the RPA study team was to extrapolate these contributions across the duration of the assessment period and discount at the appropriate 4% rate. The results of this are found in Table 7-18.

Table 7-18: Estimated discounted annual estimate of economic contribution from Chemours APM employees	
Year	Economic contribution (€)
2022	39,400,000
2023	37,900,000
2024	36,400,000
2025	35,000,000
2026	33,700,000
2027	32,400,000
2028	31,100,000
2029	29,900,000
2030	28,800,000
2031	27,700,000
2032	26,600,000
2033	25,600,000
2034	24,600,000
2035	23,700,000
Assessment period total	284,100,000
Grand Total	432,800,000
Source: RPA study team analysis	

Therefore, as can be seen above over the course of the assessment period from 2026 to 2035 **the 629 full time equivalent positions related to Chemours APM operations will generate a total discounted contribution to the wider European economy of over €284 million.** Once again however it should be noted this value is likely to be considerably higher as these figures will be subject to government spending, money, and consumption multipliers but these multipliers cannot currently be accurately estimated. While the whole of the European economy benefits from this employment and these greater levels of spending the impacts are not evenly distributed. Countries such as the Netherlands, Belgium and France are in receipt of the majority of employment benefits from APM under the continued use scenario. This is not an issue as while some Member States are receiving a greater share of returns the whole economy is receiving economic contributions from this employment but it is also an indicator that under a non-use scenario the impacts of unemployment will not be evenly distributed and this is discussed more in Section 8.6.

7.6.2 Semiconductor industry and automotive

The semiconductor industry offers a significant amount of highly skilled jobs. According to SEMI, it is estimated that 250,000 people are employed directly because of semiconductor production, with an additional 2.5M jobs in the end-to-end electronic supply chain[135]. There's an additional 4,500 number of people directly employed because of the manufacture of fluoropolymers[136]. The use of Teflon™ PFA, and fluoropolymers in general, enable numerous other sectors generating associated employment. The increased demand of semiconductor chips recently would only continue to increase the amount of these highly skilled jobs that will become available.

135 https://www.semi.org/sites/semi.org/files/2020-12/SEMI%20Chemical%20Watch%20Presentation.pdf

136 https://fluoropolymers.plasticseurope.org/application/files/1216/5485/3500/Fluoropolymers_Market_Data_Update_-_Final_report_-_May_2022.pdf

7.6.2.1 *Moulders and converters*

The economic contributions from moulders and converters are based solely on the responses the RPA study team received during consultation. RPA received multiple responses from moulders and converters located in Germany and where possible total employees and average salaries have been added together. The average salary for Greece and the first line for Germany was extracted from Eurostat due to no salary information being provided. The two remaining salaries for Germany of €45,000 and €41,000 were derived using information obtained during consultation. The tax income, household saving ratio and disposable income were then calculated in the same manner as the previous calculations in this section and are summarised in Table 7-19.

Table 7-19: Estimated economic contributions of employment from moulders and converters within Europe

Member State	Total employees [1]	Average salary (€) [2]	Tax income per person (€) [3]	Net pay (€)	Household saving ratio [4]	Disposable income per person (€)
Austria	120	67,200	14,909	52,291	13.83%	45,059
Germany	300	58,100	21,949	36,151	11.50%	31,994
Germany	10	45,000	15,689	29,311	11.50%	25,940
Germany	39	41,000	13,865	27,135	11.50%	24,014
Total	469					

[1] Source: RPA downstream user consultation
[2] Source: Eurostat, and downstream user consultation
[3] Source: https://www.icalculator.info/european-union-tax-calculators.html and https://salaryaftertax.com/
[4] Source: https://tradingeconomics.com/country-list/personal-savings?continent=europe and https://www.ceicdata.com/en/countries

The individual data results in a **total annual contribution to the European economy from moulder and converter employees of just under €25.3 million.** This number is again a substantial underestimation of the true value benefiting the economy from employees in this sector. This underestimation is due to limited data collected during consultation and not being able to extract this information from Eurostat. Secondly, this value will not be the true benefit returned to the wider European economy due to multipliers on both government spending and consumption occurring. Due to reasons previously outline, these have not been estimated. Table 7-20 summarises the total benefits in terms of tax income and disposable income by Member State.

Table 7-20: Estimated economic contributions of moulders and converters employees by Member State

Member State	Total tax receipts (€)	Total disposable income (€)	Total (€)
Austria	1,790,000	5,410,000	7,200,000
Germany	6,580,000	9,600,000	16,180,000
Germany	157,000	259,000	416,000
Germany	541,000	937,000	1,478,000
Total	9,068,000	16,206,000	25,274,000

Source: RPA study team analysis

Table 7-21 presents the annual discounted economic contributions from the employees of contacted moulders and converters operating within Europe. The figures have been discounted post 2022 at the standard 4% discount rate with all figures also having been rounded to three significant figures.

Table 7-21: Estimated discounted estimates of economic contributions from moulders and converters employees within Europe	
Year	**Economic contribution (€)**
2022	25,300,000
2023	24,300,000
2024	23,400,000
2025	22,500,000
2026	21,600,000
2027	20,800,000
2028	20,000,000
2029	19,200,000
2030	18,500,000
2031	17,800,000
2032	17,100,000
2033	16,400,000
2034	15,800,000
2035	15,200,000
Assessment period total	182,400,000
Grand total	277,900,000
Source: RPA study team analysis	

Over the course of the assessment period, 2026 to 2035, **the known employees of moulders and converters operating within Europe will provide economic returns of over €182 million**. The true value of this will be much higher for the European economy once additional moulders and converters and economic multipliers have been considered.

7.6.2.2 Wet process equipment manufacturers

The economic contributions of persons employed by equipment manufacturers has been based solely on data obtained from Eurostat using the NACE code C28.99. The RPA study team assumed 3% equipment manufacturer enterprises share of this NACE code based on PRODCOM codes 28.99.20.20, 28.99.20.40 and 28.99.51.00. This allowed an estimate for the number of employees, as well as the average salary of employees per Member State. From this, the economic contributions could be estimated in the same manner as previously stated above. Data appended with an asterisk are where the European Union 27 average has been used, due to these countries reporting insufficient data to Eurostat. Table 7-22 presents the summarised economic contributions in terms of tax revenue and disposable income available for these employees by each Member State across Europe. It can be seen in Table 7-22 that there is an estimated total of 9,237 employees in this sector across the European Union.

Table 7-22: Estimated economic contribution of employment from semiconductor equipment manufacturers within Europe						
Member state	**Total Employees**	**Average salary (€) [1]**	**Individual tax income (€) [2]**	**Net pay (€)**	**Household saving ratio[3]**	**Individual disposable income (€)**
Austria	382	68,600	15,368	53,232	13.83%	45,870
Belgium	74	63,900	26,899	37,001	28.20%	26,567
Bulgaria	58	11,400	1,140	10,260	19.00%	8,311
Croatia	19	19,100	3,820	15,280	16.40%	12,774
Cyprus	-	-	-	-	18.00%	-
Czechia	302	23,500	3,525	19,975	16.77%	16,625
Denmark	153	68,700	30,093	38,607	21.24%	30,407

Table 7-22: Estimated economic contribution of employment from semiconductor equipment manufacturers within Europe						
Member state	Total Employees	Average salary (€) [1]	Individual tax income (€) [2]	Net pay (€)	Household saving ratio[3]	Individual disposable income (€)
Estonia	43*	55,500*	11,100	44,400	31.00%	30,636
Finland	149	57,500	20,247	37,253	26.20%	27,493
France	266	62,000	22,529	39,471	16.73%	32,868
Germany	4,852	58,800	22,172	36,628	11.50%	32,416
Greece	23	27,700	4,502	23,198	6.40%	21,713
Hungary	166	19,900	2,985	16,915	21.60%	13,261
Ireland	-	-	-	-	19.90%	-
Italy	850	54,400	20,092	34,308	12.60%	29,985
Latvia	10	22,400	4,552	17,848	20.60%	14,171
Lithuania	11	19,100	3,820	15,280	19.90%	12,239
Luxembourg	2 *	55,500*	15,872	39,628	55.00%	17,833
Malta	-	-	-	-	37.80%	-
Netherlands	653	92,600	32,233	60,367	15.02%	51,300
Poland	344	17,300	2,588	14,712	22.20%	11,446
Portugal	138	23,000	15,871	7,129	17.70%	5,867
Romania	135	14,800	1,480	13,320	19.50%	10,723
Slovakia	81	20,600	3,914	16,686	5.33%	15,797
Slovenia	55	33,900	8,587	25,313	11.40%	22,427
Spain	293	44,500	12,271	32,229	-0.79%	32,484
Sweden	176	61,900	19,808	42,092	19.78%	33,766
Total	9,237					

Sources :
[1] Eurostat,
https://ec.europa.eu/eurostat/databrowser/view/SBS_NA_CON_R2__custom_3183455/default/table?lang=en
[2]https://www.icalculator.info/european-union-tax-calculators.html and https://salaryaftertax.com/
[3]https://tradingeconomics.com/country-list/personal-savings?continent=europe and https://www.ceicdata.com/en/countries
Note: Data points with an asterisk indicate data was missing from Eurostat and the EU 27 average has been applied to them

The RPA study team have estimated that several EU Member States do not have employees working in the semiconductor manufacturing equipment sector, as such there will be no employee economic contributions from these nations. For each of the remaining Member States the total tax receipts and total disposable income provided per total of employees has been calculated and is presented in Table 7-23. **Employees from the semiconductor equipment manufacturing sector provide over €468 million in value to the European economy each year.** The level of employment and the value of this employment is substantial for the European economy demonstrating that supply chains within Europe utilising fluoropolymers and fluoropolymer products have additional supply chain segments which return incredible value for the European economy.

Table 7-23: Estimated economic contribution of semiconductor equipment manufacturers employees by Member State and totals			
Member State	Total tax receipts (€)	Total disposable income (€)	Total (€)
Austria	5,870,000	17,500,000	23,370,000
Belgium	2,000,000	1,980,000	3,980,000
Bulgaria	66,600	485,000	551,600
Croatia	74,200	248,000	322,200

Table 7-23: Estimated economic contribution of semiconductor equipment manufacturers employees by Member State and totals			
Member State	Total tax receipts (€)	Total disposable income (€)	Total (€)
Cyprus	-	-	-
Czechia	1,060,000	5,020,000	6,080,000
Denmark	4,620,000	4,660,000	9,280,000
Estonia	473,000	1,310,000	1,783,000
Finland	3,020,000	4,110,000	7,130,000
France	6,000,000	8,750,000	14,750,000
Germany	108,000,000	157,000,000	265,000,000
Greece	103,000	495,000	598,000
Hungary	496,000	2,210,000	2,706,000
Ireland	-	-	-
Italy	17,100,000	25,500,000	42,600,000
Latvia	46,500	145,000	191,500
Lithuania	40,600	130,000	170,600
Luxembourg	25,500	28,700	54,200
Malta	-	-	-
Netherlands	21,100,000	33,500,000	54,600,000
Poland	891,000	3,940,000	4,831,000
Portugal	2,190,000	810,000	3,000,000
Romania	200,000	1,450,000	1,650,000
Slovakia	315,000	1,270,000	1,585,000
Slovenia	476,000	1,240,000	1,716,000
Spain	3,590,000	9,510,000	13,100,000
Sweden	3,490,000	5,960,000	9,450,000
Total	181,247,400	287,251,700	468,499,100
Source: RPA study team analysis			

Table 7-24 presents the annual discounted economic contributions from the employees of contacted moulders and converters operating within Europe. The figures have been discounted post 2022 at the standard 4% discount rate with all figures also having been rounded to three significant figures.

Table 7-24: Estimated discounted estimates of economic contributions from semiconductor equipment manufacturers employees within Europe	
Year	Economic contribution (€)
2022	468,000,000
2023	450,000,000
2024	433,000,000
2025	416,000,000
2026	400,000,000
2027	385,000,000
2028	370,000,000
2029	356,000,000
2030	342,000,000
2031	329,000,000
2032	316,000,000
2033	304,000,000
2034	293,000,000
2035	281,000,000
Assessment period total	3,376,000,000
Grand total	5,143,000,000

Table 7-24: Estimated discounted estimates of economic contributions from semiconductor equipment manufacturers employees within Europe	
Year	Economic contribution (€)
Source: RPA study team analysis	

As seen from the Table above it can be seen that **the employees of semiconductor equipment manufacturing over the course of the assessment period will contribute just under €3.4 billion.** This is likely a substantial underestimation of the true return to the European economy because as previously mentioned no economic multipliers have been calculated and applied to the RPA study team model but also manufacturing semiconductor equipment is a highly skilled technical job. It is therefore not unreasonable to assume that many of the above estimated employees may be on a salary higher than that of the sectoral NACE average which will increase their economic contribution.

7.6.2.3 Fabrication plant owners

The economic contributions of persons employed by fabrication plants has been based solely on data obtained from Eurostat using the NACE code 26.11. The RPA study team assumed a 5% fabrication plant enterprise share of this NACE code based on PRODCOM codes 26.11.22.20, 26.11.22.40 and 26.11.22.60. This allowed an estimate for the number of employees, as well as the average salary of employees per Member State. From this, the economic contributions could be estimated in the same manner as previously stated above. Data appended with an asterisk are where the European Union 27 average has been used, due to these countries reporting insufficient data to Eurostat. Table 7-25, presents the summarised economic contributions in terms of tax revenue and disposable income available for these employees by each Member State across Europe. It can be seen in Table 7-25 that there is an estimated total of 10,695 employees in this sector across the European Union.

Table 7-25: Estimated economic contribution of employment from semiconductor manufacturing within Europe						
Member state	Employees	Average salary (€) [1]	Individual tax income (€) [2]	Net pay (€)	Household saving ratio [3]	Individual disposable income (€)
Austria	427	85,400	21,664	63,736	13.83%	54,921
Belgium	154	74,800	33,725	41,075	28.20%	29,492
Bulgaria	49	13,000	1,300	11,700	19.00%	9,477
Croatia	29	12,900	2,580	10,320	16.40%	8,628
Cyprus	0	-	-	-	18.00%	-
Czechia	376	21,700	5,642	16,058	16.77%	13,365
Denmark	32	68,900	30,180	38,720	21.24%	30,496
Estonia	37*	55,700*	11,140	44,560	31.00%	30,746
Finland	84	56,900	19,972	36,928	26.20%	27,253
France	1,139	73,400	28,246	45,154	16.73%	37,600
Germany	3,936	72,000	28,189	43,811	11.50%	38,773
Greece	24	32,600	26,448	6,152	6.40%	5,758
Hungary	537	15,700	2,355	13,345	21.60%	10,462
Ireland	0	-	-	-	19.90%	-
Italy	1,278	53,300	19,611	33,689	12.60%	29,444
Latvia	22	55,700*	12,211	43,489	20.60%	34,530
Lithuania	31	15,900	3,180	12,720	19.90%	10,189
Luxembourg	0	-	-	-	55.00%	-
Malta	0	-	-	-	37.80%	-
Netherlands	297	55,700*	16,878	38,822	15.02%	32,991
Poland	687	16,100	2,409	13,691	22.20%	10,652
Portugal	67	24,000	16,449	7,551	17.70%	6,214

Table 7-25: Estimated economic contribution of employment from semiconductor manufacturing within Europe						
Member state	Employees	Average salary (€) [1]	Individual tax income (€) [2]	Net pay (€)	Household saving ratio [3]	Individual disposable income (€)
Romania	794	55,700*	5,570	50,130	19.50%	40,355
Slovakia	164	18,000	3,420	14,580	5.33%	13,803
Slovenia	66	24,700	5,572	19,128	11.40%	16,947
Spain	356	40,600	10,692	29,908	-0.79%	30,144
Sweden	109	59,900	19,168	40,732	19.78%	32,675
Total	10,695					

Sources:
[1] *Eurostat,* *https://ec.europa.eu/eurostat/databrowser/view/SBS_NA_CON_R2__custom_3183455/default/table?lang=en*
[2] *https://www.icalculator.info/european-union-tax-calculators.html* and *https://salaryaftertax.com/*
[3] *https://tradingeconomics.com/country-list/personal-savings?continent=europe* and *https://www.ceicdata.com/en/countries*

The RPA study team have estimated that several EU Member States do not have employees working in the manufacture of semiconductors, as such there will be no employee economic contributions from these nations. For each of the remaining Member States the total tax receipts and total disposable income provided per total of employees has been calculated and is presented in Table 7-26. **The employees from fabrication plants provide over €555 million in value to the European economy each year.** The level of employment and the value of this employment is substantial for the European economy.

Table 7-26: Estimated economic contribution of semiconductor manufacturers employees by Member State and totals			
Member State	Total tax receipts (€)	Total disposable income (€)	Total (€)
Austria	9,260,000	23,500,000	32,760,000
Belgium	5,210,000	4,550,000	9,760,000
Bulgaria	63,200	461,000	524,200
Croatia	74,900	251,000	325,900
Cyprus	-	-	-
Czechia	2,120,000	5,020,000	7,140,000
Denmark	958,000	968,000	1,926,000
Estonia	407,000	1,120,000	1,527,000
Finland	1,690,000	2,300,000	3,990,000
France	32,200,000	42,800,000	75,000,000
Germany	111,000,000	153,000,000	264,000,000
Greece	645,000	140,000	785,000
Hungary	1,260,000	5,620,000	6,880,000
Ireland	-	-	-
Italy	25,100,000	37,600,000	62,700,000
Latvia	270,000	763,000	1,033,000
Lithuania	99,600	319,000	418,600
Luxembourg	-	-	-
Malta	-	-	-
Netherlands	5,020,000	9,810,000	14,830,000
Poland	1,660,000	7,320,000	8,980,000
Portugal	1,100,000	414,000	1,514,000
Romania	4,420,000	32,100,000	36,520,000

Table 7-26: Estimated economic contribution of semiconductor manufacturers employees by Member State and totals			
Member State	**Total tax receipts (€)**	**Total disposable income (€)**	**Total (€)**
Slovakia	562,000	2,270,000	2,832,000
Slovenia	366,000	1,110,000	1,476,000
Spain	3,810,000	10,700,000	14,510,000
Sweden	2,090,000	3,560,000	5,650,000
Total	209,385,700	345,696,000	555,081,700
Source: RPA study team analysis			

Table 7-27 presents the annual discounted economic contributions from the employees of contacted moulders and converters operating within Europe. The figures have been discounted post 2022 at the standard 4% discount rate with all figures also having been rounded to three significant figures.

Table 7-27: Estimated discounted estimates of economic contributions from semiconductor manufacturers employees within Europe	
Year	**Economic contribution (€)**
2022	555,000,000
2023	533,000,000
2024	513,000,000
2025	493,000,000
2026	474,000,000
2027	456,000,000
2028	438,000,000
2029	421,000,000
2030	405,000,000
2031	390,000,000
2032	375,000,000
2033	360,000,000
2034	346,000,000
2035	333,000,000
Assessment period total	3,998,000,000
Grand total	6,092,000,000
Source: RPA study team analysis	

As seen from the Table above **the employees of fabrication plant owners over the course of the assessment period will contribute just under €4 billion to the European economy.** This is likely a substantial underestimation of the true return to the European economy because as previously mentioned no economic multipliers have been calculated and applied to the RPA study team model but also manufacturing semiconductor equipment is a highly skilled technical job. It is therefore not unreasonable to assume that many of the above estimated employees may be on a salary higher than that of the sectoral NACE average which will increase their economic contribution.

Additionally, the investments made by Intel (discussed in Section 7.7) will create a significant number of jobs and boost the European semiconductor revenue. These investments in multiple European countries will create new high-paying jobs. Specifically in Germany the construction of a new fabrication plant will create 7,000 construction jobs and once complete 3,000 high tech jobs at Intel with tens of thousands of additional jobs across suppliers and partners. In Italy, the back-end manufacturing facilities will create 1,500 Intel jobs plus an additional 3,500 jobs across suppliers and partners, with operations starting between 2025 and 2027. In France, the new R&D hub will create 1,000 high tech jobs, with 450 jobs becoming available at the end of 2024. In summary, with Intel's long-established history in the EU for the last 30 years and its current employee count of 10,000 once complete Intel itself will be providing 26,000 jobs throughout Europe[137].

7.6.2.4 Other market implications

As previously mentioned, the semiconductor industry being able to sell semiconductors in Europe is critical to the continuation of the European automotive sector for both internal combustion engine and electric vehicles. Therefore the employment generated by this sector should also be considered and by using the information presented in Table 7-15 (Estimated total number of enterprises and average number of employees) the study team have been able to estimate the number of employees present within the NACE C29.10 classification across the whole EU27 and by each member state. This information is provided in Table 7-28.

Table 7-28: Estimated economic contribution of motor vehicle manufacturing employees within Europe

Member state	Employees	Average salary (€)	Individual tax income (€)	Net pay (€)	household saving ratio	Individual disposable income (€)
Austria	19,721	76,300	18,087	58,213	13.83%	50,162
Belgium	16,578	64,800	27,463	37,337	28.20%	26,808
Bulgaria	33	4,700	470	4,230	19.00%	3,426
Croatia	405	20,500	4,100	16,400	16.40%	13,710
Cyprus	-	77,100*	16,870	60,230	18.00%	49,389
Czechia	45,085	35,500	5,325	30,175	16.77%	25,115
Denmark	12,445	77,100*	33,772	43,328	21.24%	34,125
Estonia	6,519	77,100*	15,420	61,680	31.00%	42,559
Finland	5,867	44,500	12,196	32,305	26.20%	23,841
France	117,013	68,500	25,789	42,711	16.73%	35,565
Germany	580,264	96,400	40,008	56,392	11.50%	49,907
Greece	83	25,300	4,584	20,716	6.40%	19,390
Hungary	22,984	30,900	4,635	26,265	21.60%	20,592
Ireland	161	38,600	8,080	30,520	19.90%	24,447
Italy	62,381	54,800	20,266	34,534	12.60%	30,183
Latvia	430	77,100	17,133	59,967	20.60%	47,614
Lithuania	282	20,200	4,040	16,160	19.90%	12,944
Luxembourg	-	77,100*	19,675	57,425	55.00%	25,841
Malta	-	77,100*	18,170	58,930	37.80%	36,654
Netherlands	13,853	65,700	20,585	45,115	15.02%	38,339
Poland	38,732	26,200	3,488	22,712	22.20%	17,670
Portugal	8,237	33,700	11,737	21,963	17.70%	18,076
Romania	21,457	77,100*	7,710	69,390	19.50%	55,859
Slovakia	25,448	33,400	6,346	27,054	5.33%	25,612
Slovenia	4,082	77,100	24,490	52,610	11.40%	46,612
Spain	71,859	52,400	15,092	37,308	-0.79%	37,603
Sweden	69,197	80,600	25,792	54,808	19.78%	43,967
Total	1,143,113					

Source: RPA study team analysis
Data points with an asterisk indicate data was missing from Eurostat and the EU 27 average has been applied to them

[137] https://www.intel.com/content/www/us/en/newsroom/news/eu-news-2022-release.html#gs.b0i9g6 accessed July 2022

Over 1.14 million persons are estimated therefore to be employed within the manufacture of motor vehicles market. Following the same methodology as the previous calculation in this section the study team have calculated the total tax receipts, total disposable income, and total annual economic contribution these employees make. These estimates are presented in Table 7-29.

Table 7-29: Estimated economic contribution of motor vehicle manufacturing employees by Member State and total			
Member State	**Total tax receipts (€)**	**Total disposable income (€)**	**Total (€)**
Austria	357,000,000	989,000,000	1,346,000,000
Belgium	455,000,000	444,000,000	899,000,000
Bulgaria	15,500	113,000	128,500
Croatia	1,660,000	5,550,000	7,210,000
Cyprus	-	-	-
Czechia	240,000,000	1,130,000,000	1,370,000,000
Denmark	420,000,000	425,000,000	845,000,000
Estonia	101,000,000	277,000,000	378,000,000
Finland	71,600,000	140,000,000	211,600,000
France	3,020,000,000	4,160,000,000	7,180,000,000
Germany	23,200,000,000	29,000,000,000	52,200,000,000
Greece	381,000	1,610,000	1,991,000
Hungary	107,000,000	473,000,000	580,000,000
Ireland	1,300,000	3,930,000	5,230,000
Italy	1,260,000,000	1,880,000,000	3,140,000,000
Latvia	7,370,000	20,500,000	27,870,000
Lithuania	1,140,000	3,650,000	4,790,000
Luxembourg	-	-	-
Malta	-	-	-
Netherlands	285,000,000	531,000,000	816,000,000
Poland	135,000,000	684,000,000	819,000,000
Portugal	96,700,000	149,000,000	245,700,000
Romania	165,000,000	1,200,000,000	1,365,000,000
Slovakia	161,000,000	652,000,000	813,000,000
Slovenia	100,000,000	190,000,000	290,000,000
Spain	1,080,000,000	2,700,000,000	3,780,000,000
Sweden	1,780,000,000	3,040,000,000	4,820,000,000
Total	33,100,000,000	48,100,000,000	81,100,000,000
Source: RPA study team analysis			

The over 1.14 million staff employed by motor vehicle manufacturers are therefore estimates to make an annual contribution to the European economy to the tune of €81.1 billion. This value is so high due to the high wages of many workers throughout the European union and the volume of employees the market employs. At the same time however, this value is likely a substantial underestimation as this figure has not been subjected to government spending and consumption multipliers. These multipliers occur within the economy and will greatly increase the true value that these employees bring to the economy through their tax revenues and consumption spending. However due to data limitations it is not currently possible for these values to be estimated and applied to the prediction of economic returns. In Table 7-30 the annual contributions have been discounted at the 4% rate and expanded across the full assessment period.

Table 7-30: Estimated discounted economic contribution of motor vehicle manufacturing employees	
Year	**Economic contribution (€)**
2022	81,100,000,000
2023	78,000,000,000
2024	75,000,000,000
2025	72,100,000,000
2026	69,400,000,000
2027	66,700,000,000
2028	64,100,000,000
2029	61,700,000,000
2030	59,300,000,000
2031	57,000,000,000
2032	54,800,000,000
2033	52,700,000,000
2034	50,700,000,000
2035	48,700,000,000
Assessment period total	585,100,000,000
Grand total	891,300,000,000
Source: RPA study team analysis	

From the above table over the assessment period the employees of **motor vehicle manufacturers will make a total economic contribution of over €585 billion**. This economic contribution will also be spread across many Member States allowing for most of Europe to share and benefit from the employment generated by motor vehicle manufacturers.

7.7 Innovations and investments

Chemours APM is a global company meaning it has a global footprint for its research and development (R&D) and capital investment activities. Currently some R&D activities take place within Europe which are conducted by APM. Given that most of the business operations of the Chemours APM division are associated with fluoropolymers, most of their R&D spending is connected to fluoropolymers, with a total annual investment of €40.7 million being made by Chemours APM spread across two fronts. The first area of focus for Chemours APM's research and development spending is in the field of alternatives research. Specifically, APM take a proactive role in the development of alternative variants of fluoropolymer materials which deliver greater results in terms of purity than their current portfolio of goods. They also conduct extensive research and development into their manufacturing processes to further refine and develop alternative fluoropolymer materials but APM does not conduct research into alternatives to fluoropolymers. To this end during consultation and in their questionnaire response APM indicated they invest annually €13.1 million into R&D activities dedicated to exploring and assessing possible alternatives to fluoropolymer materials, such as replacing polymerisation aids in manufacturing processes. The second area of focus for research and development is the continued development of new manufacturing processes, products, and applications of existing fluoropolymer technologies to open new markets allow downstream supply chains to grow and to develop greater efficiencies in production. The annual value of these investments from APM amount to €27.6 million calculated by deducting €13.1 million from the total annual budget of €40.7 million. These investments have returned some positive results so far in terms of discovering viable alternatives to fluoropolymers. For example, a recent announcement from Chemours discussed the commercialisation of an alternative to fluorinated surfactants in one product line. Although this is not directly related to Teflon™ PFA, it is still a positive outcome to R&D investments made by Chemours. Under a non-use scenario these investments and research efforts would not continue due to there being no business portfolio present for Chemours APM to fund R&D activities. This is because all of Chemours APMs' products are fluoropolymers. The discounted annual value of this research and development spending is presented in Table 7-31.

Table 7-31: Estimated discounted annual R&D spending			
Year	Total fluoropolymer R&D (€)	Operational R&D (€)	Alternatives R&D (€)
2021	40,700,000	27,500,000	13,100,000
2022	39,100,000	26,500,000	12,600,000
2023	37,600,000	25,500,000	12,100,000
2024	36,100,000	24,500,000	11,700,000
2025	34,800,000	23,500,000	11,200,000
2026	33,400,000	22,600,000	10,800,000
2027	32,100,000	21,800,000	10,400,000
2028	30,900,000	20,900,000	9,970,000
2029	29,700,000	20,100,000	9,580,000
2030	28,600,000	19,300,000	9,220,000
2031	27,500,000	18,600,000	8,860,000
2032	26,400,000	17,900,000	8,520,000
2033	25,400,000	17,200,000	8,190,000
2034	24,400,000	16,500,000	7,880,000
2035	23,500,000	15,900,000	7,570,000
Assessment period total	281,900,000	190,800,000	90,990,000
Grand total	470,200,000	318,300,000	151,690,000
Source: RPA study team analysis			

After discounting at the 4% ECHA rate the total amount of **R&D investment Chemours APM will make in Europe over the course of the 2026-2035 assessment period stands at over €281 million with over €90.9 million of this being dedicated to the exploration of alternatives**.

7.7.1.1 Moulders and converters

Within the supply chain moulders and converters receive the Teflon™ PFA resin from Chemours and are responsible for forming various components that can be used within the semiconductor manufacturing process. During the hot processing of the resins, Teflon™ PFA is melted down at high temperatures and moulded to from these components. Specifications of the product typically come further down the supply chain and are fed back up to the chemical providers to produce high purity products. Therefore, it is not likely that moulders and converters within the supply chain will invest in R&D for alternatives to Teflon™ PFA. However, it is likely that they will do R&D to experiment with methods to increase purity and reduce contamination.

During consultation, the RPA study team received a few responses from moulders and converters within the supply that disclosed their R&D investments, equating to between hundreds of thousands and hundreds of millions of Euros. There was quite a large range between the two, however this is dependent on the types of projects the companies are involved in. The nature of the projects was not disclosed to the RPA team. However, it is likely these investments will investigate ways that material processing can be improved to align with mitigation efforts to control latent defects. Improving the consistency and quality control further down the semiconductor manufacturing supply chain.

7.7.1.2 Wet process equipment manufacturers

Within the supply chain wet processing equipment manufacturers will receive components from the moulders and converters and will integrate them into their machines. Teflon™ PFA will mostly be used in areas that are in direct contact with high purity process chemicals. These equipment manufacturers are likely to invest a lot of money into R&D to improve their machines to advance the technology of semiconductor chips. It is not likely their R&D investments will go into non-fluoropolymer alternatives.

During consultation, the RPA study team received little responses from wet processing equipment manufacturers on their investments. The figures received were in the billions, however, the scope of the investments could not be shared with RPA. Again, this is likely to be invested in advancing their machine technologies to keep up with chip advancements specified by fabrication plants further down the supply chain.

Global equipment market is approaching 150 billion US dollars, in 2022 the estimated year-on-year growth for wafter process equipment is 20.8%, with test and related equipment at 12.3% and assembly equipment having a year-on-year growth of 8.2%[138]. The established foothold of European based semiconductor equipment manufacturers will allow them to benefit greatly from this rapid expansion of fabrication plants causing new equipment to be required and current facilities being upgraded. The current share of the global market held by European industries cannot currently be determined based on data available to the RPA study team.

7.7.1.3 Fabrication plant owners

Fabrication plants are typically the players in the supply chain governing all technical requirements including cleanliness and purity for component materials. While these businesses will invest in R&D it is not necessarily targeted towards development of new materials or fluoropolymers in general. R&D is likely to be geared towards process improvements and advanced node structure with investments likely in the billions, according to downstream user consultation. As fabrication plants are generally specifying cleanliness and purity requirements, they are most likely the players in the supply chain governing R&D topics further upstream.

Presented at the SEMI West 2022 Market Symposium[139], it was stated that a total of 61 new fabrication facilities will begin construction across the globe from 2021 to 2023. Of these 61 facilities, 42 will be in Asia, 10 in North America and 9 in Europe. It can be seen from these numbers that an increase in Europe's fabrication facilities is needed to secure its supply in semiconductor chips and become a competitive player in this industry.

In early 2022, Intel announced plans to invest €80 billion into the European Union's semiconductor value chain over the coming decade[140]. The scope of these invests include everything from R&D to manufacturing and packaging technologies. An initial €17 billion will go towards a fabrication mega-site located in Germany, an R&D facility in France, and R&D, manufacturing and foundry services in Ireland, Italy, Poland, and Spain[118]. Once complete the total investments in Ireland will be €30 billion

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[138] Source: SEMI West 2022 Day 1 SEMI Market Symposium (agenda can be found here: https://www.semiconwest.org/programs/market-symposium)

[139] SEMI West 2022 Day 1 **SEMI Market Symposium**. Agenda can be found here: https://www.semiconwest.org/programs/market-symposium

[140] https://www.intel.com/content/www/us/en/newsroom/news/eu-news-2022-release.html#gs.b0i9g6 accessed July 2022

and in Italy investments will total €4.5 billion[118]. Additionally, in past two years Intel has spent more than €10 billion with European suppliers, and that spend is expected to double by 2026[118].

In July 2022, GlobalFoundries Inc. and ST Microelectronics announced a partnership in constructing a new 300 mm semiconductor manufacturing facility Crolles, France[141]. The aim is for the facility to hit full operating capacity by 2023 to produce 620,000 300 mm wafers per year. The companies will receive support from France due to the facilities contribution to the European Chips Act, the project is expected cost a total of $5.7 billion[142]. Additionally, ST Microelectronics has said it will continue its investments in its 300 mm manufacturing facility in Italy with full operating capacity to be available by 2025[143].

The development of these facilities in Europe will boost the European chip supply, playing into the EU Chips Act and establishing a more resilient supply chain of semiconductor chips. These investments are monumental for Europe and will support the green transition and the delivery of the European Green Deal[118].

7.7.1.4 Semiconductor industry

In addition to the sectors mentioned above, there are research and design facilities solely focused on advancing semiconductor technology located within Europe. These facilities may receive funding from the European Commission or invest in their projects with an annual R&D budget of up €500 million. The projects and research that takes place at these facilities helps achieve targets in projects such as Horizon 2020 and Horizon Europe. Semiconductors enable a smart, digital society and the research taking place at these institutes is at the forefront of Europe becoming climate neutral.

7.8 Wider implications: European strategic goals, consumers, and end-users

7.8.1 Teflon™ PFA

Not only does Europe want to reduce its dependency on Russian fossil fuels[144], but **The European Green Deal**[145] sets out actions to transform Europe into becoming the first climate neutral continent by 2050. Semiconductors enable low carbon and energy efficient solutions through optimisation of energy generation and usage in transportation, manufacturing, consumer products and services[146]. This also includes the decarbonisation of the transportation sector that represents 25% of the EU's total greenhouse gas emissions[147]. By 2030, the plan aims to reduce emissions from cars by 55% and

141 https://electronics360.globalspec.com/article/18357/gf-and-st-to-build-new-300-mm-fab-in-france accessed November 2022

142 https://siliconangle.com/2022/07/11/stmicro-globalfoundries-build-5-7b-semiconductor-fab-france/ accessed November 2022

143 https://electronics360.globalspec.com/article/18357/gf-and-st-to-build-new-300-mm-fab-in-france accessed November 2022

144 https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/repowereu-affordable-secure-and-sustainable-energy-europe_en accessed July 2022

145 https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en accessed July 2022

146 https://www.eusemiconductors.eu/esia Sept 2021 brochure "European Semiconductor Industry: A strong contributor to reducing Carbon Emissions".

147 https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/transport-and-green-deal_en accessed September 2022

by 2035 emissions from cars will reach zero[148], additionally **The Sustainable and Smart Mobility Strategy**[149] will aim to have 30 million zero-emission cars in operation by 2030. To achieve this an increase in electricity powered vehicles is expected. To achieve these goals the 27 EU Member States have approved the end of internal combustion engine vehicles by 2035, this will ban the sale of new petrol and diesel cars[150]. Semiconductors used in vehicle networks and sensors can increase the fuel efficiency of vehicles due to weight reduction by replacing older heavier mechanical systems with lighter tech-based systems[151]. Automated and Advanced Driver Assistance Systems powered by semiconductors can reduce emissions through cruise control and autonomous driving. In fact, autonomous driving can reduce fuel consumption by up to 45%[152] and would subsequently contribute to the UN social development goal of reducing fatalities from road traffic accidents.

However, to achieve this also means doubling the amount of semiconductor chips used in vehicles to operate these fully electric systems. A typical electric vehicle contains twice the number of semiconductor chips than internal combustion engine vehicles. As electric vehicles evolve and become smarter, they will require more chips. Changes in semiconductor innovation has enabled electric vehicles to have a longer battery life as well as decreasing the cost of the vehicle itself. Newer types of semiconductors, such as silicon carbide and gallium nitride, are cheaper than the traditional silicon semiconductor chips. They have also been shown to improve battery life.

An increase in electric vehicles would also mean an increase in charging stations to replenish a cars battery. Whether this is at a person's home, a store, or a rest stop along a motorway, semiconductor chips are essential to enable the fast charging of battery electric vehicles[153]. It was estimated in 2021 there were 376,000 publicly available electric vehicle charging stations in Europe. By 2025 it is estimated there will be 1.3 million and by 2030 it is estimated to grow to 2.9 million charging stations[154]. **The Sustainable and Smart Mobility Strategy** aims to install 3 million public charging points by 2030 to assist in boosting the uptake of zero-emission vehicles. Additionally, throughout Europe slow charging stations are gradually being replaced by ultra-fast chargers.

The global electric vehicle market was valued at $163 billion in 2020 and is expected to reach $823.75 billion by 2030, demonstrating a CAGR of 18.2% through the predicted period[155]. In Europe, the market share of battery electric vehicles is expected to be 60% in Western Europe by 2030, this is equivalent to 8.4 million vehicles[156]. This growth is attributed to many countries looking to phase out internal combustion engine vehicles by 2035, so that all new cars placed on the market will be electric.

Assisting **The European Green Deal** as well through smart electric grids that can reduce the CO_2 emissions in building. Semiconductors used for power management are made from silicon carbide and gallium nitride allowing the conversion of power to more efficient. Additionally, semiconductors

148 https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/delivering-european-green-deal_en#making-transport-sustainable-for-all accessed September 2022

149 https://transport.ec.europa.eu/transport-themes/mobility-strategy_en accessed September 2022

150 https://www.cecra.eu/_files/ugd/35e449_2c9a0d98bf8e489e825586259e0f1968.pdf accessed September 2022

151 https://www.eusemiconductors.eu/esia Sept 2021 brochure "European Semiconductor Industry: A strong contributor to reducing Carbon Emissions" accessed September 2022

152 https://www.eusemiconductors.eu/esia Sept 2021 brochure "European Semiconductor Industry: A strong contributor to reducing Carbon Emissions" accessed September 2022

153 https://www.sme.org/technologies/articles/2021/september/semiconductor-devices-for-automobiles/ accessed September 2022 accessed July 2022

154 https://www.virta.global/en/global-electric-vehicle-market accessed September 2022 accessed July 2022

155 https://www.alliedmarketresearch.com/electric-vehicle-market accessed July 2022

156 https://www.forbes.com/sites/neilwinton/2021/12/31/booming-electric-car-sales-in-europe-may-soon-face-a-reality-check accessed September 2022 accessed July 2022

can be used to lower the total energy consumption of a building by adapting the heating, ventilation, and air conditioning equipment to enable preference settings or sense human presence and activity[157].

Following the Covid-19 pandemic, the semiconductor industry experienced supply chain issues and increased demand for PCs leading to a global chip shortage[158]. Towards the end of 2020 as automobile production and demand increased the industry began to feel the impacts of the shortage, with multiple car manufacturers reporting up to 40% decreased production rates in 2021[159]. Additionally, the shift to more automated and electric vehicles has put a strain on the supply chain. However, this shortage is expected to resolve in late 2022.

The European Chips Act[160] is a strategy looking to increase Europe's current market share of semiconductors from 10% to 20% in 2030 to ensure the supply. This includes large investments in the development and manufacturing of systems and industrial production. As the world shifts to a more technological and digital era, the demand for semiconductor chips is expected to double by the end of the decade[161] and ensuring Europe has its own reliable supply chain will be vital not only to the automotive industry but many others.

7.9 Summary

The activities under review in this socio-economic analysis is the importation of Teflon™ PFA for sale into the semiconductor manufacturing supply chain, focussing on semiconductors in the automotive sector. This report has sought, where possible, to monetise and value the operations of both Chemours and the actors in these relevant supply chains.

The RPA study team have estimated that under the continued use scenario, over the course of the assessment period between the start of 2026 and the close of 2035, the European market for Teflon™ PFA will provide substantial wealth for the European economy. **Chemours APM will generate profits estimated between €117 and €353 million over the assessment period from the sale of Teflon™ PFA used in the semiconductor industry.** They will also generate additional profits of between €176 and €353 million from the sale of Teflon™ PFA for other uses. This is caused by continued strong growth in the demand for semiconductors and the materials required to manufacture them. This strong growth is being caused by initiatives such as the European Chips Act which aims to increase European manufacturing capacity for semiconductors and increase its footprint in the global semiconductor market. Similarly, an increase in production and demand for new high efficiency and electric vehicles, will require more semiconductors. These market shifts are being driven by programs such as the ban on new internal combustion engines in 2035 and the European objective to reduce emissions by 55% for cars by 2030. Teflon™ PFA is not manufactured or processed by Chemours in Europe, therefore there are no emissions at Chemours' sites in Europe in relation to Teflon™ PFA activities. In addition, none or very limited emissions during use are expected due to the closed systems used in the manufacture of articles. Teflon™ PFA is mostly recycled at the end of life, but some material is still placed into landfilled at the end of life. However, due to the longevity of the product, the fate at the end of life in Europe when used in semiconductor fabs is not known. In landfill, Teflon™ PFA would not degrade and leaching of monomers or polymerisation aid is not of concern due to the low presence (<1 ppm).

157 https://www.eusemiconductors.eu/esia Sept 2021 brochure "European Semiconductor Industry: A strong contributor to reducing Carbon Emissions" accessed September 2022

158 https://www.techradar.com/uk/news/global-chip-shortage accessed July 2022

159 https://www.jpmorgan.com/insights/research/supply-chain-chip-shortage accessed July 2022

160 https://ec.europa.eu/commission/presscorner/detail/en/ip_22_729 accessed July 2022

161 https://aeneas-office.org/2022/02/09/european-chips-act-proposals-in-detail/

The semiconductor supply chain assessed by the RPA study team consists of three market segments which were all assessed individually by the study team to determine the total value to the European economy. **The markets within this supply chain are estimated to generate profits over the course of the assessment period of around €63.4 billion.** This figure is also likely to be an underestimation of the true profits that will be generated by this industry due to the study teams use of average profit metric statistics from Eurostat and not true profit margins from actors within this supply chain. This SEA has also focussed on the use of semiconductors within the automotive industry and sought to quantify the benefit generated by this sector because of its' access to semiconductors. **The motor vehicle manufacturing market has been estimated to generate profits of over €206 billion over the assessment period** which again may be a slight underestimation in the true value returned by this sector given slight variances in profitability between actors in the market. It is assumed that European vehicle manufacturers will predominantly use European manufactured chips for a shorter more stable supply; and given the essentiality of chips in modern vehicles it can be assumed that 100% of this estimated income is dependent on the continued access to semiconductors and integrated circuits. **Therefore, the continued use scenario allows for economic benefits of €63.4 billion to be directly generated from the sale and use of Teflon™ PFA. This allows the automotive market to generate economic benefits of over €206 billion as a result of the use of semiconductors, whose manufacturing process is dependent on Teflon™ PFA.**

Teflon™ PFA has no known human health effects and no known environmental hazards and is not classified as PBT. It is however a persistent substance, and this level of persistency is evaluated in terms of emission levels. Due to no health and environmental hazards being present there are no associated health and environmental costs under the continued use scenario.

The presented markets are generators of substantial employment and employment value for the European economy. Chemours APM by the start of the assessment period will employ around 629 staff across the EU. The semiconductor industry is estimated to employ nearly 20,000 staff and finally the automotive sector employs over 1.14 million individuals across the continent. **Teflon™ PFA is therefore directly attributable to just under 21,000 jobs across Europe, with this set to grow substantially over the assessment period and it is a main contributing factor to a further 1.14 million jobs.**

At present Chemours APM have a diverse range of projects in their research and development portfolio across several sites within Europe. **APM over the assessment will spend nearly €91 million on fluoropolymer related alternative R&D**. It should be noted that this spending is not to develop alternatives to fluoropolymers but instead alternative forms of fluoropolymers. In addition to this they are also set to spend an additional €190 million on operational R&D to develop and improve their manufacturing processes and logistics chains. This level of spending is only possible under the continued use scenario as without the sale of fluoropolymers products such as Teflon™ PFA there would be no business operation to fund the projects they are conducting. Downstream users in the semiconductor supply chain and automotive sector are not spending R&D budgets on the development of new alternatives to fluoropolymers and Teflon™ PFA. They are however conducting operational R&D spending to again improve their processes and efficiency as best they can. In addition to this semiconductor manufacturers are planning to make investments worth tens to hundreds of billions of Euros into the establishment of new production capacity within Europe such as Intel's initial plans to invest over €80 billion across several Member States.

Finally, as well as generating substantial value in terms of profits generated and high levels of well-paid employment the Teflon™ PFA market and its downstream users are essential to the achievement of critical EU objectives and strategies. A total of five European objectives, directives and strategies were identified as being dependent on the Teflon™ PFA market in some capacity. Policies such as the

European Green Deal, sustainable and mart mobility strategy, fit-for-55, EU industrial strategy and the European Chips Act are dependent on semiconductors and therefore dependent on the supply of Teflon™ PFA. The European Chips Act and the EU industrial strategy are focused on the development and improvement of the semiconductor industry within Europe and access to Teflon™ PFA to produce manufacturing equipment under the continued use scenario is essential to this. Electric vehicles are even more dependent on semiconductors than internal combustion engine vehicles and as such due to electric vehicles being essential components to the success of the Green Deal, fit-for-55 strategy, and sustainable and smart mobility strategy these policies success is also highly dependent on continued access to semiconductors under the continued use scenario. Therefore, overall access to Teflon™ PFA under the continued use scenario will permit great value to be generated and distributed across Europe but also for key strategic aims to be achieved without harming the environment or human health.

8 Non-use scenario

8.1 Introduction

This section outlines the non-use scenario for the APM division of Chemours and its downstream users in relation to the import, export, sale, and use of fluoropolymers. There are many different forms a non-use or restriction scenario can take due to various conditions that can be laid out in a restriction proposal. These conditions can range from a total restriction on the manufacture and sale of a chemical product to limitations on the concentrations used during the manufacturing process or present in finished articles. The non-use scenario that has been assumed by the RPA study team is one of a total restriction (ban) on the import, manufacture, sale, and use of fluoropolymers within the EU27/EEA. It is therefore assumed for the purposes of this assessment that from the start of 2025 APM will have 6 months to phase out and cease their import, and manufacture of all fluoropolymer products in Europe with a further 6 months to sell all remaining stocks. This situation will also apply to the downstream customers of APM, who will also have 6 months to scale down and cease the purchase and use of fluoropolymers with a further 6 months to sell their remaining stocks of articles containing fluoropolymers. Therefore, the first year of no fluoropolymer related activities is assumed to be 2026 and this is the year for which first year losses are calculated and presented.

This non-use scenario was chosen due to it being the most extreme option possible under a REACH restriction. Therefore, utilisation of this scenario allows the RPA study team to present the worst-case scenario for both Chemours APM and the European economy. Other, less extreme, restriction situations may result in less damage being suffered by the European economy, but it should also be noted that many restriction conditions such as limits on permitted concentrations of fluoropolymers would also equate to de-facto ban on fluoropolymer usage within the EU27/EEA given the way in which the material is utilised. The results presented under this most extreme of restriction scenarios are therefore representative of the outcomes APM and the European economy would face under many different variations of restriction.

The non-use scenario will be the mirror image to the continued use scenario discussed in Section 6, thereby meaning this section will continue to focus on the import and sale of Teflon™ PFA for use within the manufacture of fluid handling/chemical distribution equipment used in the manufacture of semiconductors. The information presented in this section will be specific to the end uses of Teflon™ PFA supplied by APM but there will also be higher level generalisations and extrapolations to the wider context of these markets alongside discussion of impacts on other markets related to the in-scope markets.

The timeline for the assessment of the impacts suffered under the non-use scenario is a 10-year period from 2026 to 2035. This timeline has been used by the RPA study team due to the current lack of suitable and scalable alternatives to fluoropolymers in the applications being assessed and the time horizons that will be required to develop new materials. With regards to Teflon™ PFA, the same assessment period timeline of 10 years is also being applied to assess the impacts to the European economy of this sector not having access to fluoropolymers. However, it could be argued that an even longer timeframe could justifiably be applied to the semiconductor sector and semiconductor related uses of fluoropolymers. This is because the current processes of the sector are so dependent on fluoropolymers, like Teflon™ PFA, that a restriction on them would not just require manufacturing adjustments to be made but for the entire process of designing, and manufacturing semiconductors to be reinvented from the ground up. It has taken the industry upwards of 45 years to invent, develop, and continually improve the semiconductor manufacturing process, in which Teflon™ PFA is designed in as an integral part. Therefore, in theory given the lack of alternatives and the damning impacts a restriction would have on a highly IP protected and specialised industry, a timeframe of 40 to 50 years could justifiably be applied under ECHA SEAC restriction guidance[162][163]. To this end the losses related to Teflon™ PFA and the semiconductor industry presented in this assessment could be considered an underestimation by a factor of 4 to 5 times but the damages to the economy related to this sector within this assessment serve as a founded foundation for understanding the impacts Europe will face in the wake of a wide-ranging fluoropolymer restriction.

8.2 Import and profit losses

8.2.1 Teflon™ PFA import and profit losses

Under the assumed non-use scenario, the import of Teflon™ PFA for use within the semiconductor industry and all other uses will be reduced to zero tonnes per year. Therefore, meaning that over the assessment period instead of between 7,732 and 9,272 tonnes of Teflon™ PFA being imported for further use, nothing will be brought into the EU. Likewise, the size of the market these imports supply will be reduced to zero as the entire fluoropolymer market related to semiconductors will be wiped-out within Europe and no profits will be generated by Chemours APM to return to the economy. In fact, given that Chemours APM only deals in fluoropolymer materials a restriction of such a prohibitive nature would see the total closure of Chemours APM within Europe. As a result of this the volume, revenue and profit estimated and presented in section 7.2.1 above would all be lost under the non-use scenario.

Over the course of the assessment period therefore, under the non-use scenario the European economy will lose the semiconductor associated market with Teflon™ PFA causing a market value decline of between €169 and €508 million. The true losses that will be realised by the European economy and Chemours APM will come from the lost profits that will occur. Therefore, meaning the European economy and Chemours APM over the assessment period will suffer estimated losses of between €117 and €353 million. In addition to these losses related to Teflon™ PFA use in the semiconductor industry an extra €176 to €353 million in lost profits will also be inflicted on the European economy and Chemours APM once additional uses of Teflon™ PFA are accounted for. **A grand total of between €294 and €706 million in lost profits will be incurred as a direct result of a restriction being placed on Teflon™ PFA** which is a substantial number of lost profits for the European economy to suffer from just the prohibited sales of Teflon™ PFA which is at the very beginning of the supply chain. The additional implications of a restriction on the supply chain are discussed in more detail in section 8.4 but a restriction on Teflon™ PFA and fluoropolymers in general will result in the collapse of the semiconductor industry within Europe to the point that semiconductors would not be permitted to be manufactured within the EU27 which would have overwhelming negative implications for the continent as no technology would be able to function without semiconductor chips. The financial losses of Chemours APM are but the thin end of wedge with regards to the negative impacts a fluoropolymer restriction would have for Europe when considering the semiconductor industry.

8.3 Emissions

Because there are no viable alternative materials to replace Teflon™ PFA in the semiconductor manufacturing industry, it is difficult to determine what the waste management and end of life would like under a non-use scenario. It is estimated that components made from Teflon™ PFA will be phased out and replaced therefore these components are likely to be landfilled or incinerated. See Section

162 RDDS - Batch Process 0.9 (europa.eu) accessed July 2022

163 https://echa.europa.eu/documents/10162/0/afa_seac_surplus-loss_seac-52_en.pdf/5e24c796-d6fa-d8cc-882c-df887c6cf6be?t=1633422139138 accessed July 2022

8.5.2 for estimated environmental impacts under a non-use scenario in which alternative plastics are used.

Under a scenario where Teflon™ PFA can no longer be imported and used within Europe, no emissions are expected to take place from the use of PFA. Emissions from disposal of legacy products could still take place. It is not known what the regulatory constraints on these would be and emissions from legacy products are not assessed.

8.4 Value of downstream markets

In the event of a non-use scenario where Teflon™ PFA and fluoropolymers in general are restricted for use, not only would the semiconductor industry be greatly impacted but several businesses reliant on semiconductors would also be affected. It is well-known that any electronic device will use some sort of semiconductor chip, integrated circuit, or transistor, therefore it can be assumed that all electronic and technology sectors will be impacted to some degree. Fluoropolymers are a high value market, and due to their use in a wide variety of electronic components they enable around 50% of European Gross Domestic Product (GDP)[164]. **Therefore, it can be assumed that 50% of Europe's GDP will be affected if fluoropolymers are restricted.**

8.4.1 PFA in semiconductors

8.4.1.1 Moulders and converters

Based on information gathered during consultation, it can be concluded that in a non-use scenario, enterprises operating as moulders and converters using Teflon™ PFA would likely be forced to close their business. With no alternatives being available to replace Teflon™ PFA, there would likely be increased research into other materials. However, with no guarantee that these materials will be adequate for use in this industry it is expected that moulder and converter businesses would not be able to survive the research period. Additionally, if research was not able to find an alternative to continue generating ultra-pure components to be used in semiconductor manufacturing equipment, this market would no longer have a viable business and would be entirely removed from Europe. In the short term the number of components being manufactured in Europe and the profits and wealth generated by this section explained in Section 7.4.1.1 would be lost. That is, **the estimated revenue of between €2.6 and €3.1 billion and the related profits of between €252 and €308 million would be lost.**

8.4.1.2 Wet processing equipment manufacturers

All the players in the supply chain are reliant on one another and impacts on one market will be felt throughout the supply chain. Therefore, if moulders and converters were forced to shut down because businesses no longer received Teflon™ PFA resin to produce components needed in semiconductor process equipment, then it can be assumed equipment manufacturers would also likely close their businesses. While it was indicated by some downstream users that they would likely relocate their business outside Europe this would be costly and time consuming to build these large high-tech facilities. This portion of the market would be removed from Europe along with **the estimated revenue of €240.6 billion and the related profits of €30.1 billion would be lost from the European economy.**

164 https://www.semi.org/sites/semi.org/files/2020-12/SEMI%20Chemical%20Watch%20Presentation.pdf

8.4.1.3 Fabrication plant owners

Not only do fabrication plants produce chips enabling the use of modern technology, but they also provide significant amounts of highly skilled jobs and profits to the economy. Without the use of Teflon™ PFA semiconductor chips could no longer be manufactured. This will have large knock-on effects to other industries including automotive/transportation, communication, and clean energy to name a few. Some fabrication plants may be able to afford to continue doing research to develop a process where the same quality chips could be manufactured in another manner. However, this would be an extremely lengthy process and a positive outcome is not promised. Therefore, most fabrication plants would either shut down or relocate their business outside of Europe. Relocation would be extremely costly to a business; it is estimated to cost €15 billion to set up a new fabrication plant[165]. **Not only would this cost the European economy an estimated revenue of €231 billion and the related profits of €33.1 billion, but Europe's semiconductor chip share would decrease despite efforts to increase it to 20% global market share.**

8.4.1.4 Other market implications

The impact of the non-use scenario on the automotive industry is slightly more nuanced. When considering Teflon™ PFA alone in the context of the above outlined non-use scenario, the result of a restriction is the total collapse of the semiconductor manufacturing sector within Europe. This will mean that European car manufacturers will be fully reliant on chip imports and cannot rely on Europe's supply of semiconductor chips. This is because Teflon™ PFA is not present in the finished chip; and would not be subject to a restriction in Europe (when only considering Teflon™ PFA). Therefore, while the semiconductor manufacturing sector in Europe would collapse, the automotive sector would not be expected to suffer financial loses as they would be able to continue importing chips and manufacturing cars. Assuming that the global supply of chips is able to supply the European automotive sector, the move to 100% reliance on chip imports for the automotive sector, among others, would be highly damaging for Europe. This would cause a worsening of the European balance of payments (the difference between the value of European exports and imports). In addition, there would be substantial security concerns around the stability of global supply chains and political pressures around which nations would supply the European market. While the automotive sector would still contribute €206 billion in profits under the non-use scenario, when only consider Teflon™ PFA, the European economy would still face a substantial balance of trade and security difficulties.

However, the implications of a group restriction on fluoropolymers should also be considered for the semiconductor supply chain and European automotive industry. As previously mentioned, no Teflon™ PFA is present on a finished semiconductor chip, but during the consultation stage of this study it was gathered that many other fluoropolymers are used throughout the semiconductor supply chain. Some of these are present in the finished chips themselves and their packaging. Therefore, when considering a wider fluoropolymer restriction, as outlined in the introduction to this section, imports of semiconductors containing any fluoropolymers would become restricted. This could mean European car manufacturers would not be able to produce and sell vehicles in Europe. It can be concluded that a wider fluoropolymer ban would result in cessation of both the European semiconductor industry and automotive industry. The resulting unemployment and social costs of this are discussed later in section 8.6.2.4 but are considered to be substantial and damaging to the European economy. In terms of economic impacts however as presented in section 7.4.1.4 **a non-use scenario, when considering a wider fluoropolymer restriction, will result in over 117 million motor vehicles, both internal combustion engine and electric vehicles, no longer being manufactured within Europe.** The result of this would be a loss of over €3.2 trillion in profits **and produce economic**

[165] https://www.semi.org/sites/semi.org/files/2020-12/SEMI%20Chemical%20Watch%20Presentation.pdf

losses of over €206 billion. A total of 1,890 enterprises in Europe would also cease trading and close across the entire European Union.

8.5 Health and environmental impacts

8.5.1 Health impacts

Based on the information available and since there is no production within the EU of Teflon™ PFA, health hazards are not of concern. Therefore, the health impacts under a continued use scenario have not been calculated, thus no health impacts are expected also under a non-use scenario.

8.5.2 Environmental impacts

Based on the information available to date, the environmental concerns for Teflon™ PFA relate to its persistency. Therefore, the environmental impacts under a continued use scenario have not been calculated, thus no environmental impacts are expected also under a non-use scenario.

8.6 Unemployment

8.6.1 Chemours APM

As previously outlined in Section 7.6 by 2035, when a potential restriction may be adopted, there will be a total of 629 full time equivalent employees employed because of Chemours APMs fluoropolymer operations within the EU. These employees are located across Europe at several sites and during consultation with APM it was disclosed that all these staff would face redundancy in the event of a fluoropolymer restriction under REACH coming into effect. The SEAC guidance for assessing the cost and impact of unemployment is based on calculating the social cost of unemployment. This social cost is calculated according to the multiplication of the number of the employees who will lose their jobs, their average salary, and a ratio of social cost per job lost as calculated in Dubourg's (2016) paper. Table 8-1 presents this information and displays the calculated social cost of unemployment which will be suffered, due to a fluoropolymer restriction, by the European economy broken down by each separate Member State which will be affected. It should be noted that the figures presented in the final total social cost column have all been rounded to three significant figures for clarity.
also presents the same calculation but conducted instead using new social cost ratios which the RPA study team have recalculated using the same methodology of Duboug but utilising updated data sets and literature around recruitment costs.

Table 8-1: Estimated Chemours APM Social Cost of Unemployment – original social cost ratios

Country	Number of Employees	Average Salary (€)	Portion of workers being made redundant	Dubourg ratio of social cost per job lost	Total social cost of unemployment (€)
Netherlands	464.9	70,000	100%	2.35	76,500,000
Belgium	76.2	70,000	100%	3.03	16,200,000
France	66.3	70,000	100%	3.17	14,700,000
Spain	15	70,000	100%	2.80	2,940,000
Germany	5.7	70,000	100%	2.60	1,040,000
Denmark	1	70,000	100%	1.75	123,000
Source: APM personal communication 2022 and RPA study team analysis					

Table 8-2: Estimated Chemours APM Social Cost of Unemployment – new social cost ratios					
Country	Number of Employees	Average Salary (€)	Portion of workers being made redundant	Dubourg ratio of social cost per job lost	Total social cost of unemployment (€)
Netherlands	464.9	70,000	100%	3.16	103,000,000
Belgium	76.2	70,000	100%	3.86	20,600,000
France	66.3	70,000	100%	3.43	15,900,000
Spain	15	70,000	100%	3.83	4,020,000
Germany	5.7	70,000	100%	3.33	1,330,000
Denmark	1	70,000	100%	2.07	145,000
Source: APM personal communication 2022 and RPA study team analysis					

The unemployment generated from **cessation of Chemours APMs operations will generate total social costs in the order of over €111 million for the European economy** under original social cost ratios and €145 million under new social cost ratios. This is a considerable cost for the economy to suffer on top of the losses of output and profits from APM as outlined in previous sections. Not only that but some European nations will be more adversely affected than others. Member states such as Germany and Denmark will not see significant levels of unemployment with only 5.7 people and 1 person being made unemployed respectively. These low numbers of unemployment and low social costs will be easily absorbed by their respective economies and local communities. The Netherlands however will suffer much greater impacts because of a potential fluoropolymer restriction. Most of the APM staff on payroll are positioned within the Netherlands and losing 465 employees on an average wage of €70,000 will produce social costs of €76.5 million for the Dutch economy. These are heavy losses to incur and such a high quantity of people losing their jobs from a single site closing will also have resounding local implications. A high concentration of unemployment occurring at the Dordrecht site will most likely see economic scaring occur throughout the local economy as the level of consumption falls as wages are no longer paid which will result in a second wave of unemployment and substantial effort would need to be made at the macro level to prevent a substantial negative multiplier effect taking hold on unemployment in the region. It would therefore be very damaging and unfair in economic terms to implement a fluoropolymer restriction on Teflon™ PFA (given that is so adversely affects certain Member States over others.

8.6.2 Semiconductor industry and automotive

8.6.2.1 Moulders and converters

It was confirmed during consultation that moulders and converters within Europe supply various components made from Teflon™ PFA and other fluoropolymers to semiconductor equipment manufacturers for use in semiconductor chip manufacturing. Under a non-use scenario there would be a closure and complete loss of revenue for businesses solely reliant on fluoropolymers. There are currently no alternatives being considered and therefore RPA has assumed 100% unemployment for moulder and converter businesses using Teflon™ PFA. The RPA study team have used the previously stated known levels of employment within the moulders and converters market to calculate the social costs of the unemployment caused by moulders and converters ceasing operations.

Table 8-3: Estimated social cost of unemployment from semiconductor equipment manufacturers – original social cost factors					
Member State	Number of staff made unemployed	Average wage (€)	Portion of workers being made redundant	Social cost ratio of unemployment	Social cost of unemployment (€)
Austria	120	67,200	100%	2.41	19,400,000
Germany	300	58,100	100%	2.60	45,300,000
Germany	10	45,000	100%	2.60	1,170,000
Germany	39	41,000	100%	2.60	4,160,000
Total	469				70,030,000
Source: RPA study team analysis					

While this is considered an underestimation of the social costs of unemployment, based on the data above it can be assumed that Germany will largely feel the impacts accounting for €50.63 million of the total €70 million cost of unemployment.

Table 8-4: Estimated social cost of unemployment from semiconductor equipment manufacturers – new social cost factors					
Member State	Number of staff made unemployed	Average wage (€)	Portion of workers being made redundant	Social cost ratio of unemployment	Social cost of unemployment (€)
Austria	120	67,200	100%	3.16	25,400,000
Germany	300	58,100	100%	3.33	58,000,000
Germany	10	45,000	100%	3.33	1,500,000
Germany	39	41,000	100%	3.33	5,320,000
Total	469				90,220,000
Source: RPA study team analysis					

Table 8-3 above presents the information used to calculate the social cost of unemployment using the original 2016 Dubourg social cost ratios and Table 8-4 presents the same information but conducts the same calculation using RPA's update Dubourg social cost ratios. **These calculations show that under the original cost ratios the social cost of known moulders and converters unemployment is estimated to be just over €70 million.** This figure increases when the updated social cost ratios calculated by RPA are applied with the social cost of unemployment of moulders and converters rising to over €90 million.

8.6.2.2 Wet process equipment manufacturers

Although semiconductor equipment manufacturers are not direct users of Teflon™ PFA, without it there would not be a viable business model. Fluoropolymers, more specifically Teflon™ PFA, are critical to the manufacture of semiconductor equipment. While there are currently no viable alternatives on the market, the RPA study team has assumed either a business relocation outside Europe or business closure under a non-use scenario. The RPA study team used the previously used employment figures obtained through Eurostat to determine the social costs of unemployment of semiconductor equipment manufacturers ceasing operations. Data appended with an asterisk are where the European Union 27 average has been used, due to these countries reporting insufficient data to Eurostat.

Table 8-5: Estimated social cost of unemployment from semiconductor equipment manufacturers – original social cost factors				
Member State	Number of staff made unemployed	Average wage (€)	Social cost ratio of unemployment	Social cost of unemployment (€)
Austria	382	68,600	2.41	63,200,000
Belgium	74	63,900	3.03	14,400,000
Bulgaria	58	11,400	2.63	1,750,000
Croatia	19	19,100	2.76	1,020,000
Cyprus	-	-	2.07	0
Czechia	302	23,500	2.74	19,400,000
Denmark	153	68,700	1.75	18,400,000
Estonia	43		2.67	6,310,000
Finland	149	57,500	2.15	18,500,000
France	266	62,000	3.17	52,300,000
Germany	4,852	58,800	2.6	742,000,000
Greece	23	27,700	3.34	2,110,000
Hungary	166	19,900	2.75	9,100,000
Ireland	-	-	2.45	0
Italy	850	54,400	3.03	140,000,000
Latvia	10	22,400	2.54	581,000
Lithuania	11	19,100	2.75	558,000
Luxembourg	2		1.63	145,000
Malta	-	-	2.03	0
Netherlands	653	92,600	2.35	142,000,000
Poland	344	17,300	2.35	14,000,000
Portugal	138	23,000	2.83	8,990,000
Romania	135	14,800	2.39	4,770,000
Slovakia	81	20,600	3.51	5,820,000
Slovenia	55	33,900	2.47	4,640,000
Spain	293	44,500	2.8	36,500,000
Sweden	176	61,900	2.23	24,300,000
Total	9,235			1,330,000,000
Source: RPA study team analysis				

Table 8-5 above presents the information used to calculate the social cost of unemployment using the original 2016 Dubourg social cost ratios and Table 8-6 presents the same information but conducts the same calculation using RPA's update Dubourg social cost ratios. **These calculations show that under the original cost ratios the social cost of known semiconductor equipment manufacturer unemployment is estimated to be just over €1.3 billion.** Similarly, to moulders and converters, Germany will feel this impact greater than any other Member State accounting for €742 million of the social unemployment costs.

Table 8-6: Estimated social cost of unemployment from semiconductor equipment manufacturers – new social cost factors				
Member State	Number of staff made unemployed	Average wage (€)	Social cost ratio of unemployment	Social cost of unemployment (€)
Austria	382	68,600	3.2	82,800,000
Belgium	74	63,900	3.9	18,300,000
Bulgaria	58	11,400	3.5	2,330,000
Croatia	19	19,100	3.0	1,090,000
Cyprus	-	-	2.8	0
Czechia	302	23,500	3.1	22,200,000
Denmark	153	68,700	2.1	21,800,000

Table 8-6: Estimated social cost of unemployment from semiconductor equipment manufacturers – new social cost factors				
Member State	Number of staff made unemployed	Average wage (€)	Social cost ratio of unemployment	Social cost of unemployment (€)
Estonia	43	55,500*	3.0	7,000,000
Finland	149	57,500	2.8	23,700,000
France	266	62,000	3.4	56,600,000
Germany	4,852	58,800	3.3	950,000,000
Greece	23	27,700	4.5	2,820,000
Hungary	166	19,900	2.6	8,450,000
Ireland	-	-	2.6	0
Italy	850	54,400	4.6	213,000,000
Latvia	10	22,400	3.1	703,000
Lithuania	11	19,100	3.1	632,000
Luxembourg	2	55,500*	3.0	266,000
Malta	-	-	2.1	0
Netherlands	653	92,600	3.2	191,000,000
Poland	344	17,300	2.5	15,000,000
Portugal	138	23,000	3.6	11,600,000
Romania	135	14,800	4.1	8,150,000
Slovakia	81	20,600	4.0	6,620,000
Slovenia	55	33,900	3.2	6,000,000
Spain	293	44,500	3.8	50,000,000
Sweden	176	61,900	2.8	30,800,000
Total	9,237			1,730,000,000
Source: RPA study team analysis				

This figure increases when the updated social cost ratios calculated by RPA are applied with the social cost of unemployment of semiconductor equipment manufacturers rising to over €1.7 billion.

8.6.2.3 Fabrication plant owners

During consultation it was determined that without fluoropolymers or Teflon™ PFA the manufacture and production of semiconductor chips would not be possible. Due to no alternatives being available, it is determined that under a non-use scenario, fabrication plants would be forced to cease operations resulting in a complete shutdown of their business. The RPA study team used the previously used employment figures obtained through Eurostat to determine the social costs of unemployment of fabrication plants ceasing operations. Data appended with an asterisk are Data appended with an asterisk where the European Union 27 average has been used, due to these countries reporting insufficient data to Eurostat.

Table 8-7: Estimated social cost of unemployment from semiconductor manufacturers – original social cost factors				
Member State	Number of staff made unemployed	Average wage (€)	Social cost ratio of unemployment	Social cost of unemployment (€)
Austria	427	85,400	2.41	88,000,000
Belgium	154	74,800	3.03	35,000,000
Bulgaria	49	13,000	2.63	1,660,000
Croatia	29	12,900	2.76	1,030,000
Cyprus	0	-	2.07	0
Czechia	376	21,700	2.74	22,300,000
Denmark	32	68,900	1.75	3,830,000
Estonia	37*	55,700*	2.67	5,440,000

Table 8-7: Estimated social cost of unemployment from semiconductor manufacturers – original social cost factors				
Member State	**Number of staff made unemployed**	**Average wage (€)**	**Social cost ratio of unemployment**	**Social cost of unemployment (€)**
Finland	84	56,900	2.15	10,300,000
France	1,139	73,400	3.17	265,000,000
Germany	3,936	72,000	2.6	737,000,000
Greece	24	32,600	3.34	2,650,000
Hungary	537	15,700	2.75	23,200,000
Ireland	-	-	2.45	0
Italy	1,278	53,300	3.03	206,000,000
Latvia	22	55,700*	2.54	3,130,000
Lithuania	31	15,900	2.75	1,370,000
Luxembourg	0	-	1.63	0
Malta	-	-	2.03	0
Netherlands	297	55,700*	2.35	38,900,000
Poland	687	16,100	2.35	26,000,000
Portugal	67	24,000	2.83	4,530,000
Romania	794	55,700*	2.39	106,000,000
Slovakia	164	18,000	3.51	10,400,000
Slovenia	66	24,700	2.47	4,010,000
Spain	356	40,600	2.8	40,500,000
Sweden	109	59,900	2.23	14,600,000
Total	10,695			1,650,000,000
Source: RPA study team analysis				

Table 8-7 above presents the information used to calculate the social cost of unemployment using the original 2016 Dubourg social cost ratios and Table 8-8 presents the same information but conducts the same calculation using RPA's update Dubourg social cost ratios. **These calculations show that under the original cost ratios the social cost of known fabrication plant unemployment is estimated to be just over €1.6 billion.** As previously mentioned in the other two sectors, Germany will again be burdened from the shutdown of fabrication plants accounting for €737 million of the social unemployment costs.

Table 8-8: Estimated social cost of unemployment from semiconductor manufacturers – new social cost factors				
Member State	**Number of staff made unemployed**	**Average wage (€)**	**Social cost ratio of unemployment**	**Social cost of unemployment (€)**
Austria	427	85,400	3.2	115,000,000
Belgium	154	74,800	3.9	44,500,000
Bulgaria	49	13,000	3.5	2,210,000
Croatia	29	12,900	3.0	1,110,000
Cyprus	0	-	2.8	0
Czechia	376	21,700	3.1	25,500,000
Denmark	32	68,900	2.1	4,520,000
Estonia	37*	55,700*	3.0	6,030,000
Finland	84	56,900	2.8	13,200,000
France	1,139	73,400	3.4	286,000,000
Germany	3,936	72,000	3.3	943,000,000
Greece	24	32,600	4.5	3,540,000
Hungary	537	15,700	2.6	21,500,000
Ireland	-	-	2.6	0
Italy	1,278	53,300	4.6	313,000,000
Latvia	22	55,700*	3.1	3,790,000

Table 8-8: Estimated social cost of unemployment from semiconductor manufacturers – new social cost factors				
Member State	Number of staff made unemployed	Average wage (€)	Social cost ratio of unemployment	Social cost of unemployment (€)
Lithuania	31	15,900	3.1	1,550,000
Luxembourg	0	-	3.0	0
Malta	-	-	2.1	0
Netherlands	297	55,700*	3.2	52,400,000
Poland	687	16,100	2.5	27,800,000
Portugal	67	24,000	3.6	5,830,000
Romania	794	55,700*	4.1	181,000,000
Slovakia	164	18,000	4.0	11,800,000
Slovenia	66	24,700	3.2	5,180,000
Spain	356	40,600	3.8	55,400,000
Sweden	109	59,900	2.8	18,400,000
Total	10,695			2,140,000,000
Source: RPA study team analysis				

This figure increases when the updated social cost ratios calculated by RPA are applied with the social cost of unemployment of fabrication plant employees rising to over €2.1 billion.

8.6.2.4 Other market implications

As previously stated in section 8.4.1.4 finished semiconductors do not contain Teflon™ PFA and as such could continue to be imported into Europe. Thus, permitting the manufacture of internal combustion engine and electric vehicles to continue meaning there would be no loss of employment from the automotive sector. This would only be the case however when considering the impacts of a restriction on Teflon™ PFA in isolation from a wider fluoropolymer ban.

When considering the non-use scenario assumed under this SEA work in the context of a wider fluoropolymer ban however the impact on European automotive manufacturing employment is very different. The total cessation of the semiconductor manufacturing industry within Europe will leave motor vehicle manufacturers with no access to semiconductor chips. As a result of this the entire automotive sector in Europe would collapse as well as modern day vehicles cannot be produced without semiconductor chips which will lead to the total loss of all 1.14 million employees within this sector. The RPA have used these unemployment figures to calculate the social cost of unemployment to European society based on original Dubourg social cost ratios and new social cost ratios which were calculated by the study team using the same methodology as Dubourg from 2016. These calculations and their results are presented in the following two tables (Table 8-9 and Table 8-10).

Table 8-9: Estimated social cost of unemployment from motor vehicle manufacturers – original social cost factors					
Country	Number of employees	Average salary (€)	Portion of workers being made redundant	Dubourg ratio of social cost per job lost	Total social cost of unemployment (€)
Austria	19,721	76,300	100%	2.41	3,630,000,000
Belgium	16,578	64,800	100%	3.03	3,250,000,000
Bulgaria	33	4,700	100%	2.63	408,000
Croatia	405	20,500	100%	2.76	22,900,000
Cyprus	-	77,100	100%	2.07	-
Czechia	45,085	35,500	100%	2.74	4,390,000,000
Denmark	12,445	77,100	100%	1.75	1,680,000,000

Table 8-9: Estimated social cost of unemployment from motor vehicle manufacturers – original social cost factors					
Country	Number of employees	Average salary (€)	Portion of workers being made redundant	Dubourg ratio of social cost per job lost	Total social cost of unemployment (€)
Estonia	6,519	77,100	100%	2.67	1,340,000,000
Finland	5,867	44,500	100%	2.15	561,000,000
France	117,013	68,500	100%	3.17	25,400,000,000
Germany	580,264	96,400	100%	2.60	145,000,000,000
Greece	83	25,300	100%	3.34	7,030,000
Hungary	22,984	30,900	100%	2.75	1,950,000,000
Ireland	161	38,600	100%	2.45	15,200,000
Italy	62,381	54,800	100%	3.03	10,400,000,000
Latvia	430	77,100	100%	2.54	84,200,000
Lithuania	282	20,200	100%	2.75	15,700,000
Luxembourg	-	77,100	100%	1.63	-
Malta	-	77,100	100%	2.03	-
Netherlands	13,853	65,700	100%	2.35	2,140,000,000
Poland	38,732	26,200	100%	2.35	2,380,000,000
Portugal	8,237	33,700	100%	2.83	786,000,000
Romania	21,457	77,100	100%	2.39	3,950,000,000
Slovakia	25,448	33,400	100%	3.51	2,980,000,000
Slovenia	4,082	77,100	100%	2.47	777,000,000
Spain	71,859	52,400	100%	2.80	10,500,000,000
Sweden	69,197	80,600	100%	2.23	12,400,000,000
Total	1,143,113				233,659,438,000
Source: RPA study team analysis					

Table 8-10: Estimated social cost of unemployment from motor vehicle manufacturers – new social cost factors					
Country	Number of employees	Average salary (€)	Portion of workers being made redundant	Dubourg ratio of social cost per job lost	Total social cost of unemployment (€)
Austria	19,721	76,300	100%	3.16	4,750,000,000
Belgium	16,578	64,800	100%	3.86	4,140,000,000
Bulgaria	33	4,700	100%	3.50	543,000
Croatia	405	20,500	100%	2.95	24,500,000
Cyprus	-	77,100	100%	2.85	-
Czechia	45,085	35,500	100%	3.12	5,000,000,000
Denmark	12,445	77,100	100%	2.07	1,980,000,000
Estonia	6,519	77,100	100%	2.96	1,490,000,000
Finland	5,867	44,500	100%	2.76	720,000,000
France	117,013	68,500	100%	3.43	27,500,000,000
Germany	580,264	96,400	100%	3.33	186,000,000,000
Greece	83	25,300	100%	4.46	9,380,000
Hungary	22,984	30,900	100%	2.55	1,810,000,000
Ireland	161	38,600	100%	2.64	16,400,000
Italy	62,381	54,800	100%	4.60	15,700,000,000
Latvia	430	77,100	100%	3.07	102,000,000
Lithuania	282	20,200	100%	3.12	17,700,000
Luxembourg	-	77,100	100%	2.98	-

Table 8-10: Estimated social cost of unemployment from motor vehicle manufacturers – new social cost factors					
Country	Number of employees	Average salary (€)	Portion of workers being made redundant	Dubourg ratio of social cost per job lost	Total social cost of unemployment (€)
Malta	-	77,100	100%	2.09	-
Netherlands	13,853	65,700	100%	3.16	2,880,000,000
Poland	38,732	26,200	100%	2.51	2,550,000,000
Portugal	8,237	33,700	100%	3.64	1,010,000,000
Romania	21,457	77,100	100%	4.08	6,750,000,000
Slovakia	25,448	33,400	100%	3.99	3,390,000,000
Slovenia	4,082	77,100	100%	3.20	1,010,000,000
Spain	71,859	52,400	100%	3.83	14,400,000,000
Sweden	69,197	80,600	100%	2.82	15,700,000,000
Total	1,143,113				296,950,523,000
Source: RPA study team analysis					

As seen in the above tables under the non-use scenario only when considering a wider group restriction, the level of unemployment estimated to occur within the automotive sector is estimated to incur social costs of over €233 billion under original 2016 social cost ratios. Under the RPA updated social cost ratios however the social cost of unemployment under the non-use scenario increases to over €296 billion.

8.7 Innovation and investment losses

As referenced in Section 7.7 APM currently make substantial investments each year of €40.7 million into the development of their fluoropolymer businesses efficiency and alternative more advanced fluoropolymer materials. However, given that APM's product portfolio is fluoropolymers, a restriction being implemented would produce a scenario where all R&D activities within Europe conducted by APM would cease and investments would be moved to other areas of their global footprint. Therefore, reducing the annual level of investment made by APM into Europe for R&D to zero. These changes are compared to the continued use scenario over the assessment period in Table 8-11.

Table 8-11: Estimated discounted annual R&D spending lost under a non-use scenario			
Year	Total fluoropolymer R&D (€)	Operational R&D (€)	Alternatives R&D (€)
2026	- 33,400,000	- 22,600,000	- 10,800,000
2027	- 32,100,000	- 21,800,000	- 10,400,000
2028	- 30,900,000	- 20,900,000	- 9,970,000
2029	- 29,700,000	- 20,100,000	- 9,580,000
2030	- 28,600,000	- 19,300,000	- 9,220,000
2031	- 27,500,000	- 18,600,000	- 8,860,000
2032	- 26,400,000	- 17,900,000	- 8,520,000
2033	- 25,400,000	- 17,200,000	- 8,190,000
2034	- 24,400,000	- 16,500,000	- 7,880,000
2035	- 23,500,000	- 15,900,000	- 7,570,000
Assessment period total	- 281,900,000	- 190,800,000	- 90,990,000
Source: RPA study team analysis			

Europe would therefore lose out on over €281 million in investment and capital expenditure from APM as a direct result of a restriction being placed on fluoropolymers such as Teflon™ PFA within the EU. While this figure is a substantial amount of investment to lose over the course of the investment period there is a wider issue generated with regard to research and development. This being, the possible timeframes faced by the impacted industries using Teflon™ PFA, to develop and implement new materials and practices.

Under a total restriction scenario and if no derogation is granted for fluoropolymers to be used within the semiconductor industry, the EU27 will see the total withdrawal of the industry from the bloc. This will result in further substantial losses of R&D investment related to both fluoropolymers and semiconductor technology withdrawing from Europe, leaving the bloc without access to semiconductors. At the same time while these investments will be lost, the time scale that will be required to reinvent semiconductor technology that isn't reliant on fluoropolymers could take between 40 and 50 years, assuming alternatives were viable. Therefore, in terms of research and development of fluoropolymers within the semiconductor industry, it is not viable for fluoropolymers to be banned and then invest in alternatives given the length of the lead time required to develop and implement new semiconductor production technology.

8.7.1.1 Moulders and converters

During consultation bilateral interviews and discussions were held with key moulders and converters in the semiconductor supply chain. The identity of these enterprises cannot be disclosed for reasons of confidentiality. However, these organisations did disclose that, under a non-use scenario, it is most likely that moulders and converters would relocate their businesses outside Europe to continue supplying the rest of the world and simply cease their Europe oriented operations. This is because Europe is currently seen as the 4th priority geography in the semiconductor industry with China and Taiwan, North America and South Korea being viewed as more favourable investment areas for businesses at present. This would result in the loss of current investments made and being made in the semiconductor space within Europe, while at the same time also prohibiting new investment all together. Bilateral discussions with enterprises in the supply chain highlighted that due to the long lead times of investments in the semiconductor industry investment decisions from industry are quickly approaching finalisation stage. Thus a European climate that would attach strings to investment subsidies or create complex working conditions with a lack of access to necessary materials, the semiconductor industry may sacrifice Europe and focus on other markets. Therefore, not only will current and future investments be lost but the semiconductor industry will also pivot to other markets and not make investments to develop new materials and semiconductor manufacturing technologies in EU. A restriction would therefore lead to a loss of current and possible future investment in semiconductor technology, materials and manufacturing capacity in the EU.

8.7.1.2 Wet process equipment manufacturers

Like moulders and converters, under a non-use scenario, it is likely that wet process equipment manufacturers would relocate their businesses outside Europe or shut down. In the event of business closure, these companies would lose billions of Euros invested in the advancement of their equipment. Alternatively, setting up a new production factory outside Europe would be extremely costly and time consuming. The closure of some of these businesses that dominate the market for this equipment, will in turn have an impact on all players in the supply chain globally. If most machines and equipment are being exported outside Europe the effects of a business closure or relocation will be felt globally, potentially effecting the entire global semiconductor chip market.

8.7.1.3 Fabrication plant owners

RPA had limited feedback from fabrication plant owners, however, based on this information it can be concluded that if Teflon™ PFA or fluoropolymers in general becomes restricted in Europe it would not be possible to manufacture semiconductor chips. This would, therefore, result in business closure or relocation outside Europe. If alternative materials were used this could then require businesses to invest large resources to develop and advance a new manufacturing process to produce the quality of chips that is needed for today's technology. It is difficult to estimate how large the monetary impact a non-use scenario could have on the semiconductor industry. It can be estimated that this figure would be in the billions, based on figures from SEMI[166] initial capital investment of a fabrication plant would be upwards of €15 billion. Due to the complex and global supply chain, the shutdown of a fabrication plant could impact up to 16,000 suppliers globally.

8.8 Wider implications: European strategic goals, consumers, and end-users

The use of Teflon™ PFA allows for the production and manufacture of semiconductor chips to be used in several diverse sectors. Semiconductor chips allows for the digitalisation and autonomy of motor vehicles as well as numerous other sectors. A transition from internal combustion engine vehicles to battery electric vehicles is a critical part to achieve the goals set out in the EU green deal. The transportation sector accounts for 25% of the EU's greenhouse gas emissions. Without semiconductor chips, transportation methods will have no choice but to revert to alternative methods that aren't reliant on technology. This also applies to other modes of transportation such as trains and airplanes. Unfortunately, these methods will likely use more fossil fuels increasing the greenhouse gas emissions from this sector. It is likely that without semiconductor chips the EU will not be able to fulfil its goal as the first climate neutral continent by 2050.

In addition to this, the possibility of a restriction covering fluoropolymers used in the semiconductor industry will result in the European Chips Act being impossible to achieve. A restriction and heavy-handed forceful drive to develop new materials and manufacturing processes, just for the European market, according to industry sources, will create an intolerable level of strings being attached to government subsidy promised in the European Chips Act. As a result of this the semiconductor industry will sacrifice Europe as a global market and develop new manufacturing capacity in other geographical regions such as North America and South Korea. Therefore, the aims of the European Chips Act to encourage next generation chip manufacturing technologies and capacity to be brought to the European continent cannot be achieved in the event of a restriction. In addition, the continued uncertainty caused by the ongoing PFAS restriction process including fluoropolymers used in semiconductor production means Europe may miss the window of opportunity to secure investment in next generation semiconductor technology and fabrication plants. Therefore, even if a restriction is eventually deemed unnecessary for the semiconductor industry following the PFAS restriction consultation process, Europe will experience delays to secure investment in new production capacity being built in Europe. The semiconductor industry along the supply chain and throughout this consultation has been very clear that only a full and timely exemption of fluoropolymers from the PFAS restriction will allow investment which will achieve the goals of the European Chips Act.

Additionally, it is likely there will be a significant setback in technology advancements in Europe. Anything digital will require a semiconductor, and without Teflon™ PFA or fluoropolymers in general there will be no semiconductor production in Europe leaving Europe to rely on semiconductor imports. As previously stated, electronic components contribute about 50% of European GDP. This also means Europe would not be able to increase its global semiconductor market share from 10% to 20% by 2030 and as the world shifts to a digital era, Europe could get left behind having to rely on semiconductor imports and advance technology systems without the use of fluoropolymers.

[166] https://www.semi.org/sites/semi.org/files/2020-12/SEMI%20Chemical%20Watch%20Presentation.pdf

8.9 Summary

The non-use scenario that has been established by the RPA study team for the purpose of this assessment is one of a total ban on the import, manufacture, and use of all fluoropolymer substances within the EU, including articles containing fluoropolymers. The focus is specifically on the impacts of a restriction placed on the substance Teflon™ PFA supplied by the Chemours APM division. This is the most restrictive scenario and provides a worst-case scenario. Due to the way the Teflon™ PFA is used, a limit in formulation concentrations would also result in a *de-facto* ban.

The continued use and non-use scenarios have been compared based on a restriction timeline starting in 2025 with the effects not being felt until the start of 2026 and the assessment timeframe extending to the end of 2035. The assessment period has been chosen to reflect a potential date by when alternatives could be commercially available, however it is recognised that for semiconductors this period may be much longer and potentially as long as 50 years.

Under such a non-use scenario **Chemours APM will cease all their Teflon™ PFA related activities in Europe which will result in a loss of between €117 million and €353 million in profits** that would have been generated under the continued use scenario. They will also suffer a further €176 to €353 million in lost sales of Teflon™ PFA for other uses. Likewise, there will be significant disruption in the three downstream markets within the scope of this SEA. Within the semiconductor industry, due to a lack of alternatives, the development of the industry will be severed under the non-use scenario as will the viability of the automotive industry, that depends on the use of semiconductors.

The combined three semiconductor market segments assessed in this study, moulders and converters, wet process equipment manufacturers and fabrication plant owners, would suffer a combined loss of €63.4 billion, which is likely to be an underestimation. The motor vehicle industry when considering just a restriction on Teflon™ PFA will suffer no financial losses. However, under a wider fluoropolymer restriction the sector will suffer losses of over €206 billion. However, since all electronic devices use a form of semiconductor chip, integrated circuit, or transistor, it can be assumed that all electronic and technology sectors will be impacted to some degree. Fluoropolymers are used in a wide range of electronic components that enable around 50% of Europe's GDP[167]. Therefore, it can be assumed that 50% of Europe's GDP or €7.25 trillion (based on the EU 27 GDP for 2021[168]) will be lost if fluoropolymers are restricted.

In addition to substantial financial losses the European economy will also suffer significant levels of unemployment. Chemours APM ceasing their fluoropolymer operations will result in 629 Full Time Equivalent (FTE) individuals losing their job with a social cost to Europe of €111 million. The semiconductor supply chain will suffer unemployment in the region of just under 20,000 (FTE) workers with a social cost of just over €3 billion. The car manufacturers' market, which is highly dependent on semiconductors, will suffer over 1.14 million job losses costing over €233 billion in social costs but these job losses will only be realised under a wider fluoropolymer restriction and not when just considering Teflon™ PFA. Therefore, total social costs of unemployment under the non-use scenario restricting Teflon™ PFA are estimated to be around €3.1 billion rising to at least €236 billion when consider fluoropolymers in general. These jobs losses will occur across almost all Member States of the EU meaning the social impacts of this unemployment will therefore result in longer lasting social and financial scarring.

[167] https://www.semi.org/sites/semi.org/files/2020-12/SEMI%20Chemical%20Watch%20Presentation.pdf

[168] https://european-union.europa.eu/principles-countries-history/key-facts-and-figures/economy_en#:~:text=The%20European%20Union%20operates%20as,2021%20was%20%E2%82%AC%2014.5%20trillion.

Teflon™ PFA has no known health and environmental hazards, therefore there are no associated health and environmental benefits under a non-use scenario. Persistence is the property of concern, which is measured in terms of emissions. In the event of a non-use scenario, no emissions of Teflon™ PFA would occur.

Under the non-use scenario all current and future R&D plans of Chemours APM will be cancelled, which equates to over €281 million, set to be spent on alternative fluoropolymer development and process refinements, no longer being invested in Europe. In addition to the total loss of R&D spending from Chemours APM, a restriction would result in the semiconductor industry sacrificing the European market and moving investment plans and operations to outside Europe.

Under a non-use scenario some of Europe's most ambitious and strategic political and economic objectives will be near impossible to achieve. Policies such as the sustainable and smart mobility strategy, and Fit-for-55 will become much more difficult, if not impossible, to achieve due to a lack of access to electric vehicles and key industrial semiconductor components. The European Chips Act will be impossible to achieve without access to semiconductors which are manufactured with the use of Teflon™ PFA. In addition the continued uncertainty of regulation could result in Europe missing the window to secure next generation fabrication plant technology which it could use in the event of a restriction not being placed on fluoropolymers.

9 Conclusions

This socio-economic analysis has looked to assess and value the benefits and costs to the European economy and society under a continued and non-use scenario regarding the importation and use of Teflon™ PFA supplied by Advanced Performance Materials (APM) division of The Chemours Company. The entities under analysis within this work are the European operations of Chemours APM, the semiconductor manufacturing supply chain and the European automotive sector. For the actors in each of these respective supply chains and for APM's operations the RPA study team sought, where possible, to evaluate: the volume of product being manufactured/imported and sold, the revenue the market segment generates, profits earned on these revenues, the number of enterprises within the sector; the number of employees within the sector, the value of continued employment, the social cost of unemployment, levels of research and development, potential health risks and savings, levels of emissions, and possible environmental costs while also considering impacts to existing and future EU polices and European consumers.

The continued use and non-use scenarios of this assessment look at the period of 2026-2035 to maintain comparability between both scenarios while also accounting for the likely period it would take for new alternatives and products to enter the market after a potential restriction may have come into force. Over this period under the continued use scenario, Chemours APM is estimated to generate profits of between €294 and €353 million with €117 to €353 million coming from semiconductor related sales of Teflon™ PFA and €176 to €353 million from other sales of Teflon™ PFA. The semiconductor supply chain reliant on access to Teflon™ PFA is estimated to generate profits of over €63.4 billion. **The handling and sale of PFA reliant products for semiconductor manufacturing is therefore estimated to generate economic benefits of between €63.5 and €63.8 billion.** This essential supply chain subsequently permits the automotive sector to operate and generate profits of over €206 billion.

Under the non-use scenario the semiconductor industry and supply of Teflon™ PFA will be wiped out in Europe causing economic losses of between €63.5 and €63.8 billion. In addition to this, between Chemours APM and the semiconductor supply chain over 21,000 individuals will be made unemployment across the continent incurring additional social costs of over €3.2 billion. A restriction scenario confined to just Teflon™ PFA would not result in the automotive industry facing economic losses, due to a presumed shift to using imported chips. However, while imported chips allow manufacturing to continue, such a vast increase in the amount of imports into Europe would have negative implications for the European economy in terms of balance of trade and supply side security. However, if a wider fluoropolymer ban is considered the automotive sector would also cease to operate due to no access to semiconductor chips causing €206 billion in economic damage and causing over 1.14 million cases of unemployment incurring a social cost of over €236 billion. The widespread sale and use of Teflon™ PFA and Teflon™ PFA products also means all Member States of the European Union are impacted by these supply chains. All Member States can share in the financial and social benefits under the continued use scenario and similarly all Member States will suffer losses both financially and socially under the non-use scenario.

The positive continued use impacts and negative non-use impacts of Teflon™ PFA supplied by Chemours APM go beyond financial and employment. The effects are linked to several vital European security, social and environmental policies. Teflon™ PFA supplied by APM is a crucial component of vital societal functions, both for governments and citizens alike, and results under the continued use scenario the lofty ambitions of legislatures being achievable but unachievable under the non-use scenario.

The methods applied in this report are not without limitation and a certain level of assumptions and uncertainties. One area of ambiguity is the time at which many of these assessments were made was at a time before the global and European economy begun to suffer with rising inflation and international crises. A global or European economic slowdown may result in the benefits and the costs presented in this assessment to be overestimated, however, these variances do not diminish the underlying findings of this assessment with regards to how vital Teflon™ PFA is to the supply chains within the scope of this assessment. In short, the figures and findings of the above assessment indicate that Europe is substantially better off, financially, and socially, under a continued use scenario than under a non-use scenario provided by a restriction.

The full list of findings covered by this assessment can be found in the tables below. The tables present the scale of the benefits and/or costs of each area of discovery for both the continued use and non-use scenario with the differences and impacts discussed alongside them.

Table 9-1: Continued use vs Non-use scenario Cost/Benefit summary – Chemours APM			
Impact areas	**Continued-use scenario**	**Non-use scenario**	**Difference**
Substances in scope	Teflon™ PFA	None	Chemours APM would cease their European activities under a non-use scenario resulting in no products being supplied.
Volumes	7,732 – 9,278 tonnes (total) 3,093 – 4,639 tonnes (semiconductor) 4,639 tonnes (other)	0	Cessation of business activities will result in a total prevention of all tonnes of Teflon™ PFA from being imported into Europe.
Revenues	€422 million - €1.1 billion (total) €169 million - €508 million (semiconductor) €254 million - €508 million (other)	€0	Cessation of business activities under non-use will result in total loss of all revenues.
Profits	€294 million - €706 million (total) €117 million - €353 million (semiconductor) €176 million - €353 million (other)	€0	Cessation of business activities under non-use will result in total loss of all profits.
Emissions	0	0	No European based manufacturing results in 0 emissions under continued use and 0 emission reductions under non-use.
Health Impacts	0	0	Teflon™ PFA has no known hazards to harmful to human health, resulting in no human health costs under continued use and no health savings under non-use.
Environmental Impacts	0	0	Teflon™ PFA does not degrade during normal conditions of use, nor over time and is not PBT. It is persistent and environmental impacts are determined based on emissions, see above.
Employment	629 persons employed >€284 million employment value	629 persons unemployed €111 million social costs	Cessation of business activities results in total loss of employment preventing employment benefits being experienced and instead incurs social costs of between €111 and €145 million.
Innovation	€281 million (total) €91 million (alternatives) €190 million (operational)	0	Total assessment period R&D spending of €281 million will no longer proceed due to no business portfolio being present to fund research projects.
EU policies	European Green Deal Sustainable and smart mobility strategy Fit-for-55	European Green Deal	Under a non-use scenario only the Green Deal will continue to be achievable albeit very severely hampered, all other strategic objectives will be unachievable under a non-use scenario.

Table 9-1: Continued use vs Non-use scenario Cost/Benefit summary – Chemours APM			
Impact areas	**Continued-use scenario**	**Non-use scenario**	**Difference**
	EU industrial strategy European Chips Act		

Table 9-2: Continued use vs Non-use scenario Cost/Benefit summary – Semiconductor sector			
Impact areas	**Continued-use scenario**	**Non-use scenario**	**Difference**
Substances/products in scope	Teflon™ PFA moulded components Semiconductor manufacturing equipment Semiconductors	None	All downstream users would cease their European activities under a non-use scenario resulting in no products being supplied.
Volumes	2,910 – 3,557 tonnes of moulded components >1 million pieces of semiconductor manufacturing equipment >678 billion semiconductors	0	Cessation of business activities will result in a total prevention of all products from being manufactured and supplied in Europe.
Revenues	€474 billion - €476 billion	€0	Cessation of business activities under non-use will result in total loss of all revenues.
Profits	€63.4 billion	€0	Cessation of business activities under non-use will result in total loss of all profits.
Emissions	0	0	Teflon™ PFA is not emitted during the manufacturing stage of these products and no emissions will occur under a non-use scenario and emissions from legacy products has not been assessed.
Health Impacts	0	0	Teflon™ PFA is not hazardous at normal operating temperatures below 260 °C. No products pose human health risks resulting in no health costs under continued use and no health savings under non-use.
Environmental Impacts	0	0	Teflon™ PFA has no environmental hazards. It is persistent and environmental impacts are determined based on emissions. In these end products negligible emissions are assumed and once in landfill it is inert, and no leaching is expected. Therefore, there are no environmental costs under continued use and no environmental savings under non-use.

Table 9-2: Continued use vs Non-use scenario Cost/Benefit summary – Semiconductor sector			
Impact areas	**Continued-use scenario**	**Non-use scenario**	**Difference**
Employment	>21,000 persons employed >€7.84 billion employment value	>21,000 persons unemployed €3.16 billion social costs	All employees will be made redundant in the semiconductor and automotive industry under the non-use preventing employment benefits being experienced and incurring a social cost of between €236 and €302 billion.
Innovation	€0 alternatives spending €80 billion+ in planned semiconductor factory investment spending	0	No PFAS alternative R&D spending will be lost but over €80 billion in planned investment into new semiconductor fabrication plants will no longer proceed in Europe.
EU policies	European Green Deal Sustainable and smart mobility strategy Fit-for-55 EU industrial strategy European Chips Act	European Green Deal	Under a non-use scenario only the Green Deal will continue to be achievable albeit very severely hampered, all other strategic objectives will be unachievable under a non-use scenario.

Table 9-3: Continued use vs Non-use scenario Cost/Benefit summary – Automotive sector			
Impact areas	**Continued-use scenario**	**Non-use scenario**	**Difference**
Substances/products in scope	Internal combustion engine vehicles Electric vehicles	None	All downstream users would cease their European activities under a non-use scenario resulting in no products being supplied when all fluoropolymers are considered but not when only Teflon™ PFA.
Volumes	>117 million motor vehicles	>117 million motor vehicles (only PFA restricted) 0 (all fluoropolymers restricted)	Cessation of business activities will result in a total prevention of all products from being manufactured and supplied in Europe when all fluoropolymers are considered but not when only Teflon™ PFA.
Revenues	>€3.2 trillion	>€3.2 trillion (only PFA restricted) €0 (all fluoropolymers restricted)	Cessation of business activities under non-use will result in total loss of all revenues when all fluoropolymers are considered but not when only Teflon™ PFA.
Profits	>€206 billion	>€206 billion (only PFA restricted)	Cessation of business activities under non-use will result in total loss of all profits when all fluoropolymers are considered but not when only Teflon™ PFA.

Table 9-3: Continued use vs Non-use scenario Cost/Benefit summary – Automotive sector			
Impact areas	**Continued-use scenario**	**Non-use scenario**	**Difference**
		€0 (all fluoropolymers restricted)	
Emissions	0	0	Teflon™ PFA is not emitted during the manufacturing stage of these products and no emissions will occur under a non-use scenario and emissions from legacy products has not been assessed.
Health Impacts	0	0	Teflon™ PFA is not hazardous at normal operating temperatures below 260 °C. No products pose human health risks resulting in no health costs under continued use and no health savings under non-use.
Environmental Impacts	0	0	Teflon™ PFA has no environmental hazards. It is persistent and environmental impacts are determined based on emissions. In these end products negligible emissions are assumed and once in landfill it is inert, and no leaching is expected. Therefore, there are no environmental costs under continued use and no environmental savings under non-use.
Employment	>1.14 million persons employed >€585 billion employment value	0 persons unemployed (only PFA restricted) €0 social cost (only PFA restricted) >1.14 million persons unemployed (all fluoropolymers restricted) €236 billion social costs (all fluoropolymers restricted)	All employees will be made redundant in the semiconductor and automotive industry under the non-use preventing employment benefits being experienced and incurring a social cost of €236 billion. when all fluoropolymers are considered but not when only Teflon™ PFA.
Innovation	0	0	No PFAS alternative R&D spending takes place and so none will be lost from this sector.
EU policies	European Green Deal Sustainable and smart mobility strategy Fit-for-55	European Green Deal	Under a non-use scenario only the Green Deal will continue to be achievable albeit very severely hampered, all other strategic objectives will be unachievable under a non-use scenario.

Table 9-3: Continued use vs Non-use scenario Cost/Benefit summary – Automotive sector			
Impact areas	**Continued-use scenario**	**Non-use scenario**	**Difference**
	EU industrial strategy		

Annex 1 Uncertainties and assumptions

This section presents an overview of the limitations and uncertainties of this study and considers their potential impact on the conclusions. Table A1-9-4 provides a summarised overview of each element and assesses their significance for the results of this study.

Table A1-9-4: Uncertainties and limitations

Uncertainty and Limitation	Explanation	Under (-) or over (+) estimate	
		Cost	Benefits
Number of workers /companies	The number of enterprises with exposure and the number of exposed workers is challenging to calculate accurately. The number of workers is the primary determinant of the benefits and the number of companies the primary determinant of the costs. Both are related. The costs and benefits modelled under the use and non-use scenario may therefore be under- or overestimated.	++/--	++/--
Discount rate	The estimates in this report have all been modelled using a static discount rate of 4%. A declining discount rate allocates more weight to costs and benefits that occur after 20 years. Although the costs and benefits increase (due to the lower discounting effect), the cost-benefit ratio does not change. This further shows that the costs and benefits are generally equally distributed over time.	-/+	-/+
Positive bias in reported data	It is possible that there is some self-selection among companies that participated in the consultation for this study or provided data for the surveys of the industry associations. Worst-performing companies are less likely to be aware of PFAS in their products and be willing to contribute to the study. This may underestimate both costs and benefits and has not been further assessed.	-	-
Growth rates	The growth rates for Chemours APM operations and that of their downstream users were made and supplied to the RPA study team at a time before inflation begun to greatly accelerate. Since international crises have caused inflation to increase, spending to decline and economies to slow there is a high potential for the stated growth rates in this SEA to be above what will truly be experienced in the short term. This will likely only apply to the short term however with longer term projections likely to be unaffected. Slower true growth rates due to international economic issues may mean some of the short-term estimates within this SEA are unintentionally overestimated. The scale of this overestimation is hard to determine as this highly dependent on the scale and severity with which issues such as inflation and economic slowdown in Europe reach.	+?	+?
Profit margins of downstream users	The profit margins that have been applied to downstream users such as Li-ion battery	+/-	+/-

Table A1-9-4: Uncertainties and limitations			
Uncertainty and Limitation	Explanation	Under (-) or over (+) estimate	
		Cost	Benefits
	manufacturers are amalgamated industry average operating margins extracted from Eurostat. Given that these estimations account for many businesses, substances, and products out of scope of this SEA there is potential for estimates to be under or overestimated. In specific instances the above report has highlighted where it is believed underestimations or overestimations have been made.		
Tax contributions of employees	All tax calculations have been estimated on a "most expensive" scenario whereby the highest possible tax bill for an individual has been estimated by assuming all individuals are unmarried and have no dependents. The tax income per person is therefore likely to be an overestimation of the true tax bills most of these individuals would face and subsequently national tax receipts would be lower. However, the model the RPA study team have designed does not use multipliers and as such putting extra income under tax receipts or disposable income results in the same final employment benefit figure. Therefore, while tax receipts are overestimated the final benefit is not.	NA	+
Chemours and sector employment contributions	Once again however it should be noted this value is likely to be considerably higher as these figures will be subject to government spending, money, and consumption multipliers but these multipliers cannot currently be accurately estimated.	NA	--
Government spending multiplier and a consumption multiplier	All benefits of employment will have been underestimated due to no government spending or consumption multipliers being applied. These would naturally occur within an economic system and thus will grow the scale of the returns provided by employment but with them not being applied in the model of this SEA the presented benefits will be underestimated by large amounts.	NA	---
Source: RPA Study Team analysis			

Annex 2 Consultation Response Statistics

The number of consultation responses and interviews for the APM division are summarised within this Annex, a summary of responses can be seen in the Table A2-1. Questionnaires were constructed to target specific information for each player in the supply chain.

A total of three surveys were created to target: fabrication plant owners, equipment manufacturers and moulders and converters. Fifteen downstream user questionnaires were sent with responses from nine companies (including one industry association) covering all the supply chain actors investigated. RPA invited all companies to semi-structured interviews, unless they declined to participate in the survey, and conducted interviews with six companies, including a university conducting research and development in the field. The survey was sent in April 2022 and it was preceded by a workshop introducing the scope and purpose of the survey. Interviews were conducted in Q3 2022 and Q1 2023.

The table A2-1 presents a summary of all surveys and interviews.

Table A2-1: Consultation responses summary

	Surveys	Interviews
Total surveys/interview invitations sent	***14***	***13***
Fabrication plant	1	1
Chemical distribution & Processing[(a)]	2	2
Moulder & Converter	9	7
R&D Institute	0	1
Industry Association[(b)]	1	1
Equipment supplier	1	0
Total surveys/interviews conducted	***9***	***8***

Source: RPA study team analysis
Notes:
[(a)] *considered as an equipment manufacturer*
[(b)] *considered as a fabrication plant owner*

The topic has been important within the affected industries and corresponding industry associations and there have been several concurrent surveys running, which the study team believes hampered efforts in obtaining further data.

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