SUBMISSION DOCUMENT
FOR PUBLIC CONSULTATION

Potential restriction of the per- and polyfluoroalkyl substances (PFAS) related to precision polymeric parts and shapes used in high performance industrial operating environments

SUBSTANCES: per- and polyfluoroalkyl substances (PFAS)

FROM: DuPont

USE: In precision polymeric parts and shapes used in high performance industrial operating environments

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Submission document for public consultation of the potential restriction of the per- and polyfluoroalkyl substances (PFAS) related to precision polymeric parts and shapes used in high performance industrial operating environments - Kalrez® perfluoroelastomer parts and Vespel® parts and shapes

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The views expressed in this report are, unless otherwise stated, those of the authors and do not necessarily represent any official view of DuPont and/or any other organization mentioned in this report

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ABBREVIATIONS

BEVs Battery Electric Vehicles
CA Competent Authority
CLP Classification, Labelling and Packaging
CPI Chemical Processing Industry
CoF Coefficient of Friction
CVT Continuously Variable Transmission
EBIT Earnings Before Interest and Taxes
ECHA European Chemicals Agency
EEA European Economic Area
EGR Exhaust Gas Recirculation
EU European Union
EUR Euro (currency)
EV Electrical Vehicle
FCEV Fuel Cell Electric Vehicles
FFKM Perfluoroelastomers
FKM Fluoroelastomers
FTE Full Time Employee
FVMQ Fluorosilicone Rubber
GDP Gross Domestic Product
GVA Gross Value Added
H_2S Hydrogen Sulfide
HNBR Hydrogenated Nitrile Butadiene Rubber
ICE Internal Combustion Engine
IP Intellectual Property
IQ Installation Qualification
MST Manufacturing System Test
NBR Nitrile Butadiene Rubber
NPV Net Present Value
OECD Organization for Economic Co-operation and Development
OQ Operational Qualification
PFA Perfluoroalkoxy Polymer
PFAS Per- and Polyfluoroalkyl Substances
PHEVs Plug-in Hybrid Electric Vehicles
PMT Persistent, Mobile, and Toxic
PTFE Polytetrafluoroethylene
PQ Performance Qualification
PV Pressure-Velocity
RAC Committee for Risk Assessment
RGD Rapid Gas Decompression
R&D Research and Development
REACH Registration, Evaluation, Authorisation and Restriction of Chemicals
SEAC Committee for Socio-Economic Analysis
SVHC Substance of Very High Concern
VMQ Vinyl Methyl Silicone
VPvM Very Persistent and Very Mobile
wt% percentage by weight

1. SUMMARY

This section starts with a brief description of the regulatory **context and purpose** of the document. It then provides a **short summary of the relevant product lines** of DuPont – Kalrez® perfluoroelastomer parts and Vespel® parts and shapes and their main applications, followed by a short description of the **methodology** applied. It then concludes with the **important summary of the main findings, followed by the request of DuPont for derogations justified by the evidence in this document**.

This document is the **first submission** of DuPont within this Public Consultation. It **covers key topics** of interest, but for certain areas not all data has been collected yet (e.g., emissions). DuPont is working on the collection of this data, but this has not been finalized yet. **A response with further information regarding environmental, social, and business impacts, and if necessary, a more detailed description of the derogations requested will be provided in a second submission by DuPont that is planned within the timeline given.**

1.1. Purpose

On 13 January 2023, the Competent Authorities (CAs) of the Netherlands, Germany, Sweden, Denmark, and Norway submitted a joint proposal to ECHA for a broad restriction under REACH of a group of per- and polyfluorinated substances (PFAS) within the EU unless derogations are granted. The proposed restriction aims to limit the risks to the environment and human health from the manufacture and use of a wide range of PFAS due to their persistent, bioaccumulative and toxic (PBT) or very persistent and very bioaccumulative (vPvB) properties. All PFAS in scope of this restriction proposal are meant to be either persistent themselves or degrade to other persistent PFAS. The opinion-development phase at ECHA takes 12 to 15 months. After this, the proposal, and the opinions of RAC and SEAC are forwarded to the Commission for decision-making by the Commission with the Member States. The entry into force of a potential restriction is anticipated to take place in 2025 and become effective in 2026/2027.

PFAS are a group of more than 10,000 synthetic (i.e., man-made) chemicals. PFAS have been produced in large quantities and used in a variety of industrial, commercial, and consumer applications since the late 1940s.[1, 2, 3] In the proposed restriction, PFAS (Per- and Polyfluoroalkyl Substances) are defined as any substance containing at least one fully fluorinated methyl (CF_3-) or methylene (-CF_2-) carbon atom (without any hydrogen, chlorine, bromine, or iodine attached to it). The definition is based on Organisation for Economic Co-operation and Development (OECD) definition of PFAS[4] published in 2021 and covers over 10,000 PFAS, including some fully degradable subgroups, which would be restricted under the current draft Annex XV report unless a derogation is granted.

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1 Banks, R.E., Smart, B.E., Tatlow, J.C., 1994. Organofluorine chemistry: Principles and commercial applications. New York (NY): Plenum. 670 p. ISBN 978-1-4899-1202-2.

2 Kissa, E., 2001. Fluorinated Surfactants and Repellents, 2nd Edition, CRC Press. ISBN 9780824704728.

3 Buck, R.C., Franklin, J., Berger, U., Conder, J.M., Cousins, I.T., de Voogt, P., Jensen, A.A., Kannan, K., Mabury, S.A., van Leeuwen, S.P., 2011. Perfluoroalkyl and polyfluoroalkyl substances in the environment: Terminology, classification, and origins. *Integr. Environ. Assess. Manag.* 7, 513−541.

4 https://www.oecd.org/chemicalsafety/portal-perfluorinated-chemicals/terminology-per-and- polyfluoroalkyl-substances.pdf (Accessed in May 2023).

In this regard, the restriction proposal[5] highlights two potential restriction options (ROs) referred to as RO1 and RO2.

- RO1 entails a full ban on PFAS chemicals, covering their usage, manufacturing, and placing on the market in the EU with no derogations and a transition period of 18 months from the entry into force of the restriction.
- RO2 covers the same scope of restriction while introducing specific time-limited derogations. In addition to an 18-month transition period, it would allow for either 5- or 12-year derogation period, depending on the application.

1.2. Focus - Kalrez® perfluoroelastomer parts and Vespel® parts and shapes

This analysis focuses on the value of specific PFAS related to fluoropolymer-containing and/or based Vespel® parts and shapes and Kalrez® perfluoroelastomer parts in high performance operating environments for industrial use in the European Economic Area (EEA) market. It has been performed by EPPA[6] at the request of DuPont Specialty Products Operations Sàrl and its affiliates (DuPont), in view of providing regulators with strong evidence-based findings on the social and economic impacts that are expected to occur should these substances be restricted under REACH.

Fluoropolymers like PTFE, PFA, and FFKM are categorized as per- and polyfluoroalkyl substances (PFAS) according to the OECD definition. In the current EU REACH regulation, all polymers, including fluoropolymers, are exempted from the registration requirements. This exemption is based on the understanding that polymers generally have lower levels of toxicological concerns compared to non-polymeric substances. This is attributed to their high molecular weight, which restricts their ability to pass through biological membranes, resulting in a low potential for toxicity.[7] Fluoropolymers have unique physical and chemical properties that set them apart from other members of the PFAS family, resulting in specific toxicological and environmental characteristics. Fluoropolymers as a group have negligible residual monomer and oligomer content and low to no leachable content. With a number-average molecular weight well over 60,000 Da, fluoropolymers cannot cross cell membranes. It is also important to note that due to their high cost of manufacturing, fluoropolymer products often come with a higher cost compared to other alternatives. As a result, they are typically employed in situations where there are limited or no viable substitutes and alternatives available.[8]

Two of DuPont's product lines, Kalrez® perfluoroelastomer parts and Vespel® parts and shapes, heavily rely on specific substances within the scope of potential PFAS restriction proposal. More specifically:

[5] https://echa.europa.eu/documents/10162/f605d4b5-7c17-7414-8823-b49b9fd43aea (Accessed in May 2023).

[6] https://www.eppa.com/

[7] American Chemistry Council, Inc., 2022. New Study Demonstrates Vast Majority of Commercial Fluoropolymers Meet Criteria for Polymers of Low Concern Designation. Available at: https://www.americanchemistry.com/chemistry-in-america/news-trends/press-release/2022/new-study-demonstrates-vast-majority-of-commercial-fluoropolymers-meet-criteria-for-polymers-of-low-concern-designation (Accessed in July 2023).

[8] Henry, B. J., et al., 2018. A critical review of the application of polymer of low concern and regulatory criteria to fluoropolymers. *Integrated Environmental Assessment and Management, 14(3),* 316-33.

- **Kalrez® perfluoroelastomer parts** are engineered to deliver superior thermal stability, chemical resistance, and sealing effectiveness. The following fluoropolymers are being used in Kalrez® perfluoroelastomer parts:
    - Perfluoroelastomer (FFKM) is a rubbery fluoropolymer with a combination of thermal and chemical stability that is unmatched by any other elastomer. It constitutes the fundamental (50 – 97 %) constituent of all Kalrez® perfluoroelastomer parts.
    - Perfluoroalkoxy polymer (PFA) is another type of fluoropolymer which is used as a reinforcing filler within the FFKM polymer matrix in order to achieve the end user performance criteria while maintaining similar thermal and chemical resistance as the FFKM.
    - Polytetrafluoroethylene (PTFE) is another type of fluoropolymer which is used as a reinforcing filler within the FFKM polymer matrix in order to achieve the end user performance criteria while maintaining similar thermal and chemical resistance as the FFKM.
    - Fluoroelastomer (FKM) is another type of fluoropolymer which can be used in a composite layer form with FFKM for customer performance requirements.

    - Kalrez® perfluoroelastomer parts are used as sealing elements in the form of o-ring or custom seal geometries in various mechanical parts, shaft bearings, bushings, T-Seals, boots, chevron stacks, KVSP™ V-rings, packing systems, valves, pumps, wireline and drilling tools, mechanical seals in rotating equipment (e.g., pumps, mixers), compressors, filters, couplings, spraying heads, cleaning installations, dosing systems, sampling systems, filling equipment, centrifuges, instrumentation (e.g., level gauges, flowmeters, gas analysers, laboratory equipment), fuel burners, ozonators, bonded door, poppet valves, plasma chambers, isolation valves, wafer handling, viewports, gas line feeds, gas injection, and electrostatic chucks.
    - **The industries in which Kalrez® perfluoroelastomer parts are used are chemical processing (including processing in the pharmaceutical industry), transportation (including aerospace), semiconductor manufacturing, military and defence, petroleum and mining, and energy (i.e., hydrogen and natural gas)**. **The manufacturing of DuPont perfluoroelastomer polymer and Kalrez® finished parts occurs only outside of the EU.**

- **DuPont's Vespel® parts and shapes** exhibit exceptional temperature resistance, mechanical strength, chemical resistance, and resistance to wear. The following fluoropolymers are being used in Vespel® parts and shapes:
    - Polytetrafluoroethylene (PTFE) is being used as a polyimide processing aid for direct form parts, a fabric ingredient for various composite grades/parts, a filler for one grade, and external mould release for various composite parts.
    - Perfluoroalkoxy polymer (PFA) is another type of fluoropolymer which is compounded with carbon fibre for applications such as valves, pumps, fittings, and seals for oil and gas industry and for semiconductor, applications in wafer cleaning and resist stripping operations, as well as some flat panel display and dry plasma applications.

- Fluorinated polyimide resins (containing 6FTA/6FDA), e.g., NR-150 Resin (2016-76-0(6FTA)) and PMR-II-50 are high temperature resins formulated for composite systems.
- **The industries using Vespel® products are: chemical processing, transportation (including aerospace), semiconductor manufacturing, military and defence, petroleum and mining, energy (i.e. hydrogen and natural gas), and industrial manufacturing (such as automotive manufacturing, textile, glass handling, scientific laboratory instruments, and industrial welding/ plasma/ cutting tools). The manufacturing of Vespel® occurs both within and outside of the EU.**

As indicated above, while Vespel® parts and shapes and Kalrez® perfluoroelastomer parts are used in various high performance operating environments, this analysis will focus on the use of PFAS in the following industries:[9]

DuPont's products	Industry	PFAS use
Vespel®	- Transportation, including Aerospace - Petroleum and Mining - Chemical Processing - Semiconductor Manufacturing - Other Industrial Manufacturing - Energy - Military and Defence	- PTFE - PFA - NR-150 Resin (2016-76-0(6FTA)) - PMR II-50 Resin
Kalrez®	- Transportation, including Aerospace - Petroleum and Mining - Chemical Processing - Semiconductor Manufacturing - Other Industrial Manufacturing - Energy - Military and Defence	- FFKM - PTFE - PFA

1.3. Methodology

The assessment has been **conducted in accordance with the existing official guidance of ECHA under REACH**[10] and it is based on information and data gathered from DuPont as a manufacturer of:

- Vespel® parts and shapes that use PFAS in its manufacturing process and products, and
- Kalrez® perfluoroelastomer parts.

This analysis gathers technical and economic information to describe in both qualitative and (if feasible) quantitative terms, the (order of magnitude of) impacts to affected industries as well as to

[9] Thus, please note that this assessment provides a non-exhaustive overview of the applications of Vespel® parts and shapes and Kalrez® perfluoroelastomer parts in high demanding industrial operating environments. Applications are not limited to the discussed industries in this assessment.

[10] The ECHA Guideline for SEA for the restriction proposals is available at: https://echa.europa.eu/documents/10162/23036412/sea_restrictions_en.pdf/2d7c8e06-b5dd-40fc-b646-3467b5082a9d

the EEA supply chains and society that are expected from the ban of PFAS. In particular, this analysis covers the importance of the PFAS at the different stages of the manufacturing process of parts that are used in these industries previously mentioned. The report also covers an analysis of alternatives and shows the lack of availability of technologically suitable and economically viable alternatives, the technical difficulties associated with the substitution of PFAS via alternatives, the social and economic impacts from their restriction, and the broader impacts to society.

The assessments presented in this report are as close to real data or to perception of future changes as possible to have using conservative estimates, always putting the protection of human health and environment first.

1.4. Main findings

DuPont's commitment to research and development has led to the creation of high-performance materials, including their Vespel® parts and shapes and Kalrez® perfluoroelastomer parts product lines.

The proposed restriction on the use of PFAS, **would prohibit the manufacturing of Vespel® parts in the EEA and importing PFAS-containing Vespel® parts and shapes. The import of Kalrez® perfluoroelastomer parts in the EEA would also be prohibited.** The large number of EEA industries that rely on Vespel® parts and shapes and Kalrez® perfluoroelastomer parts in their industrial operating environments, such as **chemical processing (including processing in the pharmaceutical industry), transportation (including aerospace), semiconductor manufacturing, military and defence, petroleum and mining, energy (i.e. hydrogen and natural gas), and industrial manufacturing (such as automotive manufacturing, textile, glass handling, scientific laboratory instruments, and industrial welding/ plasma/ cutting tools)** would all be halted. **A full PFAS ban would eliminate the ability to supply into the market for these high performing materials within the EEA. This would have dire consequences on industrial operating environments that rely on these products.**

Industrial operating environments heavily rely on the use of Kalrez® perfluoroelastomer parts and Vespel® parts and shapes, which contain or depend on fluoropolymers such as FFKM, PTFE, FKM, and PFA.

Kalrez® perfluoroelastomer parts

- **Kalrez® perfluoroelastomer parts** are engineered to deliver superior thermal stability, chemical resistance, and sealing effectiveness.

- **The manufacturing of DuPont perfluoroelastomer polymer and Kalrez® finished parts occurs only outside of the EU.**

- The analysis of alternatives concludes that there are currently no technically suitable nor economically feasible alternatives readily available to substitute fluoropolymers such as PTFE, PFA, and FFKM while providing comparable product performance benefits.

- **For Kalrez® perfluoroelastomer parts, alternative materials do not offer the desired combination of thermal stability and chemical resistance for reliable sealing in critical dynamic and static applications. This then leads to issues such as leakage, process contamination and part failures.** In the case of in-kind alternatives (non-fluoropolymer elastomeric materials), their performance falls significantly behind the incumbent fluoropolymer. They are unable to meet the critical requirements of applications that demand high temperature and/or high chemical resistance. While not-in-kind alternatives may offer similar heat and chemical resistance (e.g., metal), they lack the level of elastic resistance (resilience) needed to properly seal in the demanding application, resulting in ineffective sealing, shorter life and an overall poor performance in the application . **This poses safety risks as well as environmental and health hazards due to equipment failure.** In addition, their much higher stiffness would require a complete redesign of the hardware, when possible, which translates into time, costs, and compromises to the overall integrity of the system.

- **Without any derogation related to FFKM (perfluoroelastomer) a PFAS restriction would result in a complete loss of sales and profits related to the import of Kalrez® perfluoroelastomer parts in the EEA due to the lack of suitable alternatives. For the past 50 years, there have been no new inventions or successful developments to replace FFKM.**

- **Without a long enough derogation related to fluorinated polymerization aids for FFKM, it would result in a complete restriction of FFKM. The current proposal is 6.5 years for fluorinated polymerization aids. If a suitable alternative for the fluorinated polymerization aids for Kalrez® perfluoroelastomer parts can even be found, the research and development (R&D) process for finding non-fluorinated polymerization aids for Kalrez® is estimated to take at least 15 years. The manufacturing sites for Kalrez® are located outside of the EU. Therefore, the primary impact of the potential EU PFAS restrictions would be discontinued use of Kalrez® perfluoroelastomer parts in EU industries that rely on these high performance perfluorinated elastomers today.**

Vespel® parts and shapes

- **DuPont's Vespel® parts and shapes** exhibit exceptional temperature resistance, mechanical strength, chemical resistance, and resistance to wear.

- **The manufacturing of Vespel® parts and shapes occurs both within and outside of the EEA.** Table 1 below presents the grade families of Vespel® parts and shapes, PFAS use as well as their relevant application examples (*please note that this table is a based on the Table 2-1 Grades of Vespel®, composition and applications from the Socio-Economic Impact Assessment for the use of PFAS within the Aerospace Supply Chain*).[11]

[11] RPA, 2023. Socio-Economic Impact Assessment for the use of PFAS within the Aerospace Supply Chain, report for DuPont Specialty Products USA, LLC, June 2023, Norwich, Norfolk, UK.

Table 1: Grade families of Vespel® parts and shapes, composition, and applications.

Vespel® grade family	Description (Mfg Process where PFAS used)	Applications	PFAS Functionality in parts
Vespel® CP	Composites with any 1 or more of the following uses: 1) PTFE reinforced fabrics 2) Fluorine containing polyimides 3) PTFE mould release	Aircraft wear strips and track liners used for low friction gliding in applications such as wing frame braking and engine nacelles. Used where high temperature prohibits use of oil lubrication, or where oil/grease lubrication would pick up dirt and form an abrasive mass. Aircraft bushings, bumpers, washers. Industrial applications include Wind Energy liners and spherical bearings in transportation (military and beyond)	Fabrics: Self-lubricating, low friction gliding, vibration resistance, chemical resistance to greases, fuels, and de-icing fluids. Used where high temperature prohibits use of oil lubrication, or where oil/grease lubrication would pick up dirt and form an abrasive mass. Fluorine containing polyimide resin: Hi temperature resin (the trifluoromethyl groups on the 6FTA monomer result in the classification of this polymer as a PFAS). External Mould Release: used where needed for part release; no part functionality.
Vespel® ASB*	Assembled parts consisting of fastened or bonded composites on metal components (e.g., wear strips on metal to make track liners)	Bonding composites for metallic structures	The composite part of the component will have the same functionality as Vespel® CP grades.
Vespel® SP, ST	Direct form polyimide-based parts and components 1) PTFE Processing aid or 2) Couple Grades (SP-211, SP-221) have Higher PTFE content ingredient	For lubricated and non-lubricated, low friction and wear applications. Valve seats, seals, bearings, washers, seal rings, business in aerospace, automotive, commercial off-road vehicles such as construction, farming, mining vehicles, industrial manufacturing including automotive, chemical processing, and other industrial processing equipment.	PTFE has no functionality in the final part; however, it is a critical processing aid lubricant. Without PTFE Vespel® direct form parts cannot be manufactured. In some grades (SP-211) a higher PTFE content provides low friction properties (per ASTM D6456-10[12] and SAE Aerospace Material Specifications (AMS) 3644G).
Vespel® SCP	Direct form polyimide-based parts and components with PTFE processing aid	Increased thermal oxidative resistance and mechanical properties over Vespel® SP. Improved chemical resistance and friction performance. Aerospace applications: Washers, bumpers, wear pads and bushings Transportation and Industrial uses where high temperature or	PTFE has no functionality in the final part; however, it is a critical processing aid lubricant. Without PTFE Vespel® direct form parts cannot be manufactured.

[12] Standard specification for finished parts made from polyimide resins. Available at: https://www.astm.org/d6456-10r18.html (Accessed in June 2023).

		increased performance over Vespel® SP is required.	
Vespel® CR	Carbon-fiber filled thermoplastic fluoropolymer, Perfluoroalkoxy polymer(PFA)	Oil and Gas: applications such as valves, pumps, fittings, and seals. Semiconductor manufacturing: applications in wafer cleaning and resist stripping some flat panel display and dry plasma applications. Performs in aggressive wet chemical / plasma conditions and elevated temperatures.	Chemical resistance and extended life for oil and gas, and wet processing in semiconductors. Good ultraviolet (UV) resistance in Flat Panel Display applications. In dry plasma applications, Vespel® CR-6110 has been used as a thermal insulator and bearing.
***Please note - Vespel® ASB grades consist of a metallic component and a Vespel® CP component.** Data based on *DuPont Vespel® S Line Design Handbook. Available at:* https://www.dupont.com/content/dam/dupont/amer/us/en/vespel/public/documents/en/DuPont%20Vespel%C2%AE%20S%20Line%20Design%20Handbook.pdf *(Accessed in July 2023).*			

Source: RPA, 2023[13]

- The analysis of alternatives concludes that there are currently no technically suitable nor economically feasible alternatives readily available to substitute fluoropolymers such as PTFE and PFA while providing comparable product performance benefits.
    - For Vespel® parts and shapes, projects have been initiated to develop alternatives to PFAS in products such as replacing the PTFE micropowder that is used in direct-form parts. In all other Vespel® products that use PFAS, the fluoropolymer constitutes a large fraction of a part or purchased component, and therefore no alternatives exist. **For Vespel® parts and shapes, several alternatives were considered. These included bronze, Isostatic Vespel® shapes, as well as thermoplastics like PEEK and PAI.** However, both bronze and thermoplastics were deemed technically unfeasible for various reasons. Bronze, requires a lubrication system, had a higher coefficient of friction, necessitated redesigning other engine components, and added weight. Thermoplastics were unsuitable due to their inability to operate within the required temperature range. Isostatic Vespel® shapes, on the other hand, showed potential to fulfil some technical criteria in specific applications. However, they would not meet all requirements, particularly in high-temperature environments, where dimensional tolerance and coefficient of thermal expansion are critical to operation.

- **Without any derogation related to PFAS used in Vespel® parts and shapes in the applications, the primary impact of the potential EU PFAS restrictions would be no importation of these products into the EU for the key industries. The industries these products support would not be able to continue operations. In the case of a complete shutdown of operations in the EEA, the Mechelen manufacturing facility would close.** As a result, during this period, the supply of Vespel® direct formed products to the industries currently served by Mechelen would cease completely.

13 RPA, 2023. Socio-Economic Impact Assessment for the use of PFAS within the Aerospace Supply Chain, report for DuPont Specialty Products USA, LLC, June 2023, Norwich, Norfolk, UK.

- As a result of the potential broad restriction for PFAS, the aerospace industry including commercial flights into and out of the EEA will cease due to the lack of ability to perform maintenance on aircraft, impacting travel and shipping, which will also impact industries that rely on air travel.

- Electric vehicles demand essential light weighting to maximize vehicle range. Using Vespel® bushings enables motor and drive systems that do not rely on heavy and resource intensive lubrication systems. A restriction on parts for electric vehicles could challenge the ability to achieve the Green Deal Initiatives.

- Vespel® CR products reduce environmental emissions in the chemical industry as well as the petroleum and mining industries. Where used, Vespel® parts and shapes increase the reliability and safety and lower the cost of ownership of industrial processes. Restricting the use of Vespel® products will reduce EEA competitiveness, and result in an increase in industrial accidents with corresponding loss of life and environmental pollution.

Currently, DuPont is still in the process of collecting and analysing data related to social, economic, and environmental impacts. Therefore, the total direct monetised impacts of the PFAS restriction will be addressed in the second submission to the public consultation that is planned within the timeline given by this public consultation.

- From an EEA macroeconomic standpoint, the broad restriction of critical fluoropolymers in the EEA will have deleterious impacts on the competitiveness of the EEA markets in the industrial operating environments, on competition in the EEA, on innovation, and on the overall EEA trade balance. A broad restriction of PFAS used in the production and manufacturing of Vespel® parts and shapes in the EEA would put the EU market at a disadvantage in competition with non-EEA markets, as EEA companies would no longer be able to provide the product to customers outside the EEA, while the rest of the world would have access to a wider portfolio of products and methods of manufacture. The 'wider economic impacts' section (4.3) provides a discussion on the wider macroeconomic impacts and consequences on EU society at large.

1.5. Derogations requested

The assessment presented in this document reasonably justifies the request for time-unlimited derogations for the use of specific fluoropolymers, including perfluoroelastomers, for critical industrial applications.

Based on the assessment presented below, DuPont requests the following:

- **A time-unlimited derogation (exemption from the proposed restriction) for fluoropolymers including FFKM (such as Kalrez® perfluoroelastomer parts), FKM, PTFE, and PFA in transportation (including aerospace), petroleum and mining, chemical processing, semiconductor manufacturing, military and defence, energy, and industrial manufacturing (such as automotive manufacturing, textile, glass handling, scientific laboratory instruments, and industrial welding/plasma/cutting tools),**
- a 15-year derogation for fluorinated polymerization aids for PTFE micro-powder as a user of PTFE micropowders with a review at 6 years after EiF to evaluate the research progress and extend the derogation, if necessary,
- a 15-year derogation for fluorinated polymerization aids for PFA as a user of PFA with a review at 6 years after EiF to evaluate the research progress and extend the derogation if necessary, and
- a 15-year derogation for fluorinated polymerization aids for FFKM with a review at 6 years after EiF to evaluate the research progress. This progress can be used to assess the societal value versus the risk and the progress toward finding alternatives to assess the likelihood of a needed extension beyond 15 years.

If the exemption for the use of fluoropolymers, including perfluoroelastomers, is granted for industrial uses, then DuPont fully supports annual reporting requirements via a site-specific management plan to manufacturers of fluoropolymers and articles which use fluoropolymers in the EU, and importers of articles which use fluoropolymers to gather data on the use of PFAS in industrial sectors and to monitor any developments/changes. DuPont agrees that the site-specific plan should include:

- Information on the identity of the substances and the products they are used in;
- A justification for the use;
- Details on the conditions of use and safe disposal.

DuPont agrees that the management plan shall be reviewed annually and kept available for inspection by enforcement authorities upon request.

2. LINK BETWEEN THIS DOCUMENT AND THE PUBLIC CONSULTATION QUESTIONS

The following overview **connects this document to the public consultation questions**. It shows the responses in the official sections of the public consultation system within the space given, and it guides interested parties towards the sections of this document where further detail can be found that did not fit into the text limitations given by the system.

Section I and Section II – personal information and organisation:
Response – this information will be provided in the system.
Section III – Non-confidential comments
Response – EPPA performed an analysis for DuPont on specific PFAS related to fluoropolymer containing and/or based Vespel® parts and shapes and Kalrez® perfluoroelastomer parts in high performance operating environments for industrial use in the European Economic Area (EEA) market. The purpose is to provide regulators with strong evidence-based findings on the anticipated societal and economic impacts that are expected to occur should these substances be restricted under REACH. The analysis is submitted as a public attachment that contains a detailed description of the aims and scope of the analysis, perspectives on alternatives, as well as impacts, plus a conclusion and the derogations justified by the analysis in this document. This is the first of two submissions within this Public Consultation for DuPont Kalrez® perfluoroelastomer parts and Vespel® parts and shapes. It covers key topics of interest, but for certain areas, not all data has been collected yet. DuPont is working to collect this data which will be provided in a second submission within the timeline given.
Specific information requests
Public consultation question 1 (Q1): Sectors and (sub-)uses: Please specify the sectors and (sub-)uses to which your comment applies according to the sectors and (sub-)uses identified in the Annex XV restriction report (Table 9). If your comment applies to several sectors and (sub-)uses, please make sure to specify all of them.
Response and link to further information in this document:
Q1: While DuPont Vespel® parts and shapes and Kalrez® perfluoroelastomer parts are used in various high performance operating environments, the analysis and this submission focuses on the use of PFAS in the following industries: Vespel® parts and shapes in transportation (including aerospace), petroleum and mining, chemical processing, semiconductor manufacturing, military and defence, energy, and industrial manufacturing (such as automotive manufacturing, textile, glass handling, scientific laboratory instruments, and industrial welding/plasma/cutting tools), Kalrez® perfluoroelastomer parts in transportation (including aerospace), petroleum and mining, chemical processing, semiconductor manufacturing, military and defence, and energy. Further details on these sectors and (sub-)uses will be found in the attached documents.
Public consultation question 2 (Q2): Emissions in the end-of-life phase: The environmental impact assessment does not cover emissions resulting from the end-of-life phase. To get a better understanding of the extent of the resulting underestimation, (sub-)use-specific information is requested on emissions across the different stages of the lifecycle of products, i.e., the manufacture phase, the use phase, and the end-of-life

phase. Please provide justifications for the representativeness of the provided information. In particular: Please provide, at the (sub-)use level, an indication of the share of emissions (as percentages) attributable to these three different stages. An indication of annual emission volumes in the end-of-life phase at sector or sub-sector level would also be appreciated. If possible, please provide for each (sub-)use what share of the waste (as percentages) is treated through incineration, landfilling and recycling. Please provide information to justify the estimates as well as information on the form of recycling referred to.
Response and link to further information in this document:
Q2: DuPont is working on the collection of this data. A response to this question will be provided in a second submission that is planned within the timeline given.
Public consultation question 3 (Q3): Emissions in the end-of-life phase: With respect to waste management options, additional information is requested on the effectiveness of incineration under normal operational conditions (for different waste types, e.g., hazardous, municipal) with respect to the destruction of PFAS and the prevention of PFAS emissions.
Response and link to further information in this document:
Q3: DuPont is working on the collection of this data. A response to this question will be provided in a second submission that is planned within the timeline given.
Public consultation question 4 (Q4): Impacts on the recycling industry: To get an understanding of the impacts of the proposed restriction on the recycling industry, information is requested on: The impacts that the concentration limits proposed in paragraph 2 of the proposed restriction entry text (see table starting on page 4 of the summary of the Annex XV restriction report) have on the technical and economic feasibility of recycling processes (together with a clear indication on the waste streams to which the described impacts relate). The measures that recyclers would need to take to achieve the proposed concentration limits. The costs associated with these measures.
Response and link to further information in this document:
Q4: Kalrez® perfluoroelastomer parts and Vespel® parts and shapes have long lifetimes and because they are used in industrial applications. Industrial companies are required to segregate and dispose of wastes according to EU plus local regulations. Due to potential cross contamination with the materials our products come into contact with, they are not recycled and therefore do not impact standard municipal recycling programs.
Public consultation question 5 (Q5): Proposed derogations – Tonnage and emissions: Paragraphs 5 and 6 of the proposed restriction entry text (see table starting on page 4 of the summary of the Annex XV restriction report) include several proposed derogations. For these proposed derogations, information is requested on the tonnage of PFAS used per year and the resulting emissions to the environment for the relevant use. Please provide justifications for the representativeness of the provided information.
Response and link to further information in this document:

Q5: DuPont is working on the collection of this data. A response to this question will be provided in a second submission within the given timeline.
Public consultation question 6 (Q6): Missing uses – Analysis of alternatives and socio-economic analysis: Several PFAS uses have not been covered in detail in the Annex XV restriction report (see uses highlighted in blue and orange in Table A.1 of Annex A of the Annex XV restriction report). In addition, some relevant uses may not have been identified yet. For such uses, specific information is requested on alternatives and socio-economic impacts, covering the following elements: The annual tonnage and emissions (at sub-sector level) and type of PFAS associated with the relevant use. The key functionalities provided by PFAS for the relevant use. The number of companies in the sector estimated to be affected by the restriction. The availability, technical and economic feasibility, hazards and risks of alternatives for the relevant use, including information on the extent (in terms of market shares) to which alternative-based products are already offered on the EU market and whether any shortages in the supply of relevant alternatives are expected. For cases in which alternatives are not yet available, information on the status of R&D processes for finding suitable alternatives, including the extent of R&D initiatives in terms of time and/or financial investments, the likelihood of successful completion, the time expected to be required for substitution (including any relevant certification or regulatory approvals) and the major challenges encountered with alternatives which were considered but subsequently disregarded. For cases in which substitution is technically and economically feasible but more time is required to substitute: the type and magnitude of costs (at company level and, if available, at sector level) associated with substitution (e.g., costs for new equipment or changes in operating costs); the time required for completing the substitution process (including any relevant certification or regulatory approvals); information on possible differences in functionality and the consequences for downstream users and consumers (e.g., estimations of expected early replacement needs or expected additional energy consumption); information on the benefits for alternative providers. For cases in which substitution is not technically or economically feasible, information on what the socio-economic impacts would be for companies, consumers, and other affected actors. If available, please provide the annual value of EU sales and profits of the relevant sector, and employment numbers for the sector.
Response and link to further information in this document:
Q6: Several key industrial applications have not been covered in the draft proposal. Examples include: Both Kalrez® perfluoroelastomer parts and Vespel® parts and shapes are used in the energy industry (incl. gas and hydrogen) and used in the petroleum and mining industry.

In the "Petroleum and Mining" use, the sub-uses of "gas" and "hydrogen" are not clearly called out and should be added. To support adding these (sub-)uses to Petroleum and Mining, relevant information is provided in the attached analysis document under the "Petroleum and Mining" use. While "Petroleum and Mining" covers a significant portion of the chemical processing industry, many other chemical processing industries (including semiconductor fabrications systems) rely on FFKM to reduce and prevent environmental emissions. Uses within the transportation industry outside of HVAC refrigerants, including critical aerospace engine components and safety systems are not included in the draft proposal. Military and defence and chemical processing applications were missed in the draft proposal. The aerospace industry is included in general transportation and the qualification time as well as technical feasibility of substitution differs from general transportation. DuPont performed a Socio-Economic Impact Assessment (SEA) for the use of PFAS within the Aerospace Supply Chain and will submit the SEA in another submission. Vespel® parts and shapes are used in a broad set of general industrial applications (like e.g., industrial manufacturing in industries such as automotive manufacturing, textile, glass handling, scientific laboratory instruments, and industrial welding/plasma/cutting tools), and these should be considered as well. The attachment to this submission will provide further evidence.
Public consultation question 7 (Q7): Potential derogations marked for reconsideration – Analysis of alternatives and socio-economic analysis: Paragraphs 5 and 6 of the proposed restriction entry text (see table starting on page 4 of the summary of the Annex XV restriction report) include several potential derogations for reconsideration after the consultation (in [square brackets]). These are uses of PFAS where the evidence underlying the assessment of the substitution potential was weak. The substitution potential is determined on the basis of i) whether technically and economically feasible alternatives have already been identified or alternative-based products are available on the market at the assumed entry into force of the proposed restriction, ii) whether known alternatives can be implemented before the transition period ends (taking into account time requirements for substitution and certification or regulatory approval), and iii) whether known alternatives are available in sufficient quantities on the market at the assumed entry into force to allow affected companies to substitute. A summary of the available evidence as well as the key aspects based on which a derogation is potentially warranted are presented in Table 8 in the Annex XV restriction report, with further details being provided in the respective sections in Annex E. To strengthen the justifications for a derogation for these uses, additional specific information is requested on alternatives and socio-economic impacts covering the elements described in points a) to g) in question 6 above.
Response and link to further information in this document:
Q7: General comments: Kalrez® perfluoroelastomer parts and Vespel® parts and shapes containing PFAS are widely used in high performance industrial operating environments such as transportation (including aerospace), petroleum and mining, chemical processing, semiconductor manufacturing, military and defence, energy, and industrial manufacturing (such as automotive manufacturing, textile, glass handling,

scientific laboratory instruments, and industrial welding/plasma/cutting tools), where components need to withstand the harsh operating environments and material performance is critical. These industries and uses would be heavily impacted and even disrupted in case of a restriction of the use. Industrial operating environments heavily rely on the use of FFKM (such as Kalrez® perfluoroelastomer parts) and Vespel® parts and shapes, which contain or depend on fluoropolymers such as PTFE and PFA. These materials are essential for high-demand applications due to their unique combination of properties.
The proposed restriction on PFAS substances would prohibit manufacturing of Vespel® parts and shapes in the EU and the import of PFAS-containing Vespel® parts and shapes and Kalrez® perfluoroelastomer parts in the EEA. The analysis of alternatives concludes that there are currently no technically suitable alternatives available to substitute fluoropolymers such as PTFE, PFA, FKM, and FFKM while providing comparable product performance. Thus, drastic impacts are expected. These include an increased risk of emissions of chemicals to the environment as well as increased worker exposure risk. For example, a heavy negative impact on the semiconductor manufacturing industry in the EU that the EU is trying to re-build further. Furthermore, drastic impacts on many industrial manufacturing process that can no longer be performed. The aerospace industry would have to cease assembly, manufacture, or repair of all commercial aircraft in the EU. There would also be a restriction on parts used in electric vehicles and renewable hydrogen applications. Vespel® parts and shapes and Kalrez® perfluoroelastomer parts support the military and defence industry as well.

Kalrez® perfluoroelastomer parts (FFKM):
For the past 50 years, there have been no new inventions or successful developments to replace FFKM.
Another aspect is the use of fluorinated polymerization aids for FFKM. If a suitable alternative for the polymerization aid can even be found, the research and development (R&D) process for finding non-PFAS alternatives to this polymerization aid for Kalrez® perfluoroelastomer parts is expected to take at least 15 years.
It should be noted that FFKM is only used where absolutely necessary and where the conditions do not allow any other material. This is because perfluoroelastomers are substantially (factor >10 vs closest elastomer) more expensive than alternative materials; therefore, it is only purchased for applications where no other elastomeric material can withstand the chemical and temperature environment. Substitution of FFKM therefore naturally takes place due to economic considerations alone where technically possible. This point has specifically been acknowledged by the dossier submitters.

Vespel® parts and shapes containing PFAS:

Fluoropolymers, such as PTFE, are critical ingredients when blended with other engineering plastics, and in the case of Vespel® parts and shapes act as an internal lubricant and/or physical property modifier for engineered components in transportation and other related uses. Alternatives have been explored but have not provided the performance characteristics required for the critical applications. The main obstacle encountered with many alternative materials is their inability to match the desired combination of chemical resistance, thermal stability, compliance, electrical resistance (including galvanic corrosion resistance), low friction, and/or tribological properties required for specific applications, resulting in premature failure. In the case of non-PFAS alternatives (non-fluoropolymers), their performance falls significantly behind the incumbent fluoropolymer. They are unable to meet the critical requirements of applications that demand both high temperature and high chemical resistance.

Projects have been initiated to develop alternatives to PFAS in products such as replacing the polymeric processing aid that is used for direct-form parts (one group of products in the portfolio). In all other Vespel® products that use PFAS, the fluoropolymer constitutes a large fraction of a part or purchased component, and therefore no alternatives exist.

The overall development timeline for substitution efforts – if alternatives can be found - spans several years, typically requiring 5 years for research and development for the exploratory phase of alternate material identification. Then, a qualification for all materials impacted occurs (additional 3 years) before customer qualification. After that, qualification with customers will vary with customer and application. Given the high cost of the materials in this marketspace, it is a market reality that it would have been replaced with cheaper materials that would match the requirements should such products already exist.

General conclusion and derogation request:

The timeframe for replacement is also dependent upon the degree on which the final product relies on the properties of PFAS. While it may be possible to develop replacements for polymeric processing aids within the 15-year R&D timeframe, certain products that derive their function from the unique properties of fluoropolymer PFAS as a major component will never be completely replaced. Very significant impacts have been identified as part of the analysis due to the majority of products relying on the function of fluoropolymers for applications.

Based on the assessment, DuPont requests the following:

- **A time-unlimited derogation (exemption from the proposed restriction) for fluoropolymers including FFKM (such as Kalrez® perfluoroelastomer parts), FKM, PTFE, and PFA in transportation (including aerospace), petroleum and mining, chemical processing, semiconductor manufacturing, military and defence, energy, and industrial manufacturing (such as automotive manufacturing, textile, glass handling, scientific laboratory instruments, and industrial welding/plasma/cutting tools),**
- a 15-year derogation for fluorinated polymerization aids for PTFE micro-powder as a user of PTFE micro-powders with a review at 6 years after EiF to evaluate the research progress and extend the derogation, if necessary,
- a 15-year derogation for fluorinated polymerization aids for PFA as a user of PFA with a review at 6 years after EiF to evaluate the research progress and extend the derogation if necessary, and
- a 15-year derogation for fluorinated polymerization aids for FFKM with a review at 6 years after EiF to evaluate the research progress. This progress can be used to assess the societal value versus the risk and the progress toward finding alternatives to assess the likelihood of a needed extension beyond 15 years.

The attachment to this submission will provide further evidence.

Public consultation question 8 (Q8):

Other identified uses – Analysis of alternatives and socio-economic analysis: Table 8 in the Annex XV restriction report provides a summary of the identified sectors and (sub-)uses of PFAS, their alternatives and the costs expected from a ban of PFAS. More details on the available evidence are provided in the respective sections in Annex E. For many of the (sub-)uses, the information on alternatives and socio-economic impacts was generic and mainly qualitative. In particular, evidence on alternatives was inconclusive for some applications falling under the following (sub-)uses: technical textiles, electronics, the energy sector, PTFE thread sealing tape, non-polymeric PFAS processing aids for production of acrylic foam tape, window film manufacturing, and lubricants not used under harsh conditions. More information is needed on alternatives and socio-economic impacts to conclude on substitution potential, proportionality, and the need for specific time-limited derogations. Therefore, specific information (if not already included in the Annex XV restriction report or covered in the questions above) is requested on alternatives and socio-economic impacts covering the elements listed in points a) to g) in question 6 above.
Response and link to further information in this document:
Q8: As the uses of the Kalrez® perfluoroelastomer parts and Vespel® parts and shapes span a wide variety of sectors and applications, the comment made in Q7 is relevant and applicable in this section in the same way.
Public consultation question 9 (Q9): Degradation potential of specific PFAS sub-groups: A few specific PFAS sub-groups are excluded from the scope of the restriction proposal because of a combination of key structural elements for which it can be expected that they will ultimately mineralize in the environment. RAC would appreciate to receive any further information that may be available regarding the potential degradation pathways, kinetics or produced metabolites in relevant environmental conditions and compartments for trifluoromethoxy, trifluoromethylamino- and difluoromethanedioxy-derivatives.
Response and link to further information in this document:
Q9: These sub-groups are outside of the scope of this response and this document, therefore no information related to Q9 will be provided here.
Public consultation question 10 (Q10): Analytical methods: Annex E of the Annex XV restriction report contains an assessment of the availability of analytical methods for PFAS. Analytical methods are rapidly evolving. Please provide any new or additional information on new developments in analytics not yet considered in the Annex XV restriction report.
Response and link to further information in this document:
Q10: Per Annex E, DuPont followed the analytical methods suggested. Total fluorine analysis was completed using combustion ion chromatography (CIC), and results were validated with matrix matched standards. The method was adequate to detect the total Fluorine content (not the amount of PFAS chemical).
Section IV and Section V – non-confidential and confidential attachments:
Response – these attachments will be provided in the system by attaching the non-confidential version of this document here.

3. AIMS AND SCOPE OF ANALYSIS

3.1. Purpose, scope, and methodology of this analysis under REACH

On 13 January 2023, the Competent Authorities (CAs) of the Netherlands, Germany, Sweden, Denmark, and Norway submitted a joint REACH restriction proposal for PFAS. In the proposed restriction, PFAS (Per- and Polyfluoroalkyl Substances) are defined as any substance containing at least one fully fluorinated methyl (CF_3-) or methylene (-CF_2-) carbon atom (without any hydrogen, chlorine, bromine, or iodine attached to it). The definition is based on OECD definition of PFAS published in 2021 and covers over 10,000 PFAS. The entry into force of a potential restriction is anticipated to take place in 2025 and become effective in 2026/2027).[14, 15, 16]

Fluoropolymers and fluorinated elastomers possess a combination of inherent physical properties that make them crucial in various industrial applications. They are highly valued for their ability to meet performance requirements related to safety, environmental performance, and efficiency of operations, especially in harsh conditions. These criteria include withstanding wide temperature fluctuations, broadest chemical resistance among polymers, reducing friction to minimize wear in moving parts, supporting lightweight design for enhanced fuel efficiency and increased loads, ensuring the proper functioning of safety equipment, as well as providing resistance to several types of radiation and preventing hazardous situations caused by fluid leaks.

Methodology

This analysis aims to identify and to assess in both qualitative and (when feasible) quantitative terms the socio-economic impacts that are expected to occur in case of a REACH restriction to this group of substances. **A detailed data gap analysis has been conducted** to gather information and data on PFAS in DuPont's Vespel® and Kalrez® product portfolio in the EEA that will be affected by a potential REACH restriction.

The assessment has been conducted in accordance with the existing official guidance from ECHA under REACH. ECHA has developed a solid methodology for conducting socio-economic assessments in the context of the REACH Regulation, with the support of a dedicated committee (SEAC). More specifically, this methodology is consistently applied for REACH applications for authorization of Substances of Very High Concern (SVHC), and REACH restrictions with a view of forecasting through the SEAC the impacts of the different regulatory options.

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[14] Banks, R.E., Smart, B.E., Tatlow, J.C., 1994. Organofluorine chemistry: Principles and commercial applications. New York (NY): Plenum. 670 p. ISBN 978-1-4899-1202-2.

[15] Kissa, E., 2001. Fluorinated Surfactants and Repellents, 2nd Edition, CRC Press. ISBN 9780824704728.

[16] Buck, R.C., Franklin, J., Berger, U., Conder, J.M., Cousins, I.T., de Voogt, P., Jensen, A.A., Kannan, K., Mabury, S.A., van Leeuwen, S.P., 2011. Perfluoroalkyl and polyfluoroalkyl substances in the environment: Terminology, classification, and origins. *Integr. Environ. Assess. Manag.* 7, 513−541.

From a geographical perspective, this analysis focuses on the European Economic Area (EEA) territory, comprising the European Union (EU-27), Iceland, Liechtenstein, and Norway. For assessing the producers' surplus (one part of the economic impacts), it has been decided to use **a 4-year time horizon**, which is the time period suggested by SEAC when there is no suitable alternative available in general (SAGA).[17, 18]

The socio-economic costs of a complete ban (REACH restriction) will be included in the second submission.

3.2. DuPont Vespel® parts and shapes and Kalrez® perfluoroelastomer parts

DuPont's history of innovation in materials science has enabled the company to assist customers in developing solutions that effectively address the most pressing challenges in their respective industries. Vespel® parts and shapes were first introduced in the 1960s and Kalrez® perfluoroelastomer parts (FFKM) in 1972. DuPont's supports its customers for these products by a wide range of comprehensive testing capabilities.[19] **These testing capabilities play a crucial role in enabling customers to meet the rigorous industry standards pertaining to reliability, safety, traceability, and efficiency**. This is particularly significant in critical applications that involve operating in demanding high-temperature environments combined with harsh chemicals and/or high pressure, such as those prevalent in the oil and gas, transportation, aerospace, chemical as well as industrial processing, and semiconductor manufacturing industry.[20]

Vespel® parts and shapes

Vespel® parts and shapes are a family of high-performance materials manufactured by DuPont that have a proven track record of outperforming other engineering materials since 1965. They perform in extreme conditions, such as temperature extremes, high friction, and heavy loads. **Vespel® parts and shapes products find widespread use in demanding industrial operating environments such as the aerospace, transportation including on-road automotive as well as commercial/off-road vehicles such as farming, construction, mining, and military vehicles, semiconductor manufacturing and testing, the petroleum and mining industry, industrial manufacturing including industries such as automotive manufacturing, chemical processing, textile, glass handling and industrial welding/plasma/cutting tools**.

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17 https://echa.europa.eu/documents/10162/13637/ec_note_suitable_alternative_in_general.pdf/5d0f551b-92b5-3157-8fdf-f2507cf071c1

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

19 DuPont, 2022. DuPont™ Kalrez® perfluoroelastomer parts and Vespel® parts and shapes. Polymeric solutions for exceptional valve sealing performance in extreme environments. Available at: https://www.dupont.com/content/dam/dupont/amer/us/en/kalrez/public/documents/en/DuPont%20Kalrez%20and%20Vespel%20Parts%20-%20Polymeric%20solutions%20for%20valve%20sealing%20-%20KZE-A40130-00-A1122.FinalRev.pdf Accessed in July 2023).

20 DuPont, 2022. DuPont™ Kalrez® and Vespel® Parts. Polymeric solutions for exceptional valve sealing performance in extreme environments. Available at: https://www.dupont.com/content/dam/dupont/amer/us/en/kalrez/public/documents/en/DuPont%20Kalrez%20and%20Vespel%20Parts%20-%20Polymeric%20solutions%20for%20valve%20sealing%20-%20KZE-A40130-00-A1122.FinalRev.pdf (Accessed in June 2023).

The product portfolio of Vespel® parts and shapes, is a large offering of parts that withstand extreme operating environments**.** The Vespel® parts and shapes portfolio offer a diverse range of properties. **Over the past 50 years, this portfolio has expanded to include various grades, each with its own unique characteristics achieved through different types and levels of fillers and manufacturing methods**.

DuPont's Vespel® parts and shapes provide a combination of the physical properties common among engineered plastics, metals, and ceramics. These properties include proven performance when used continuously in air up to 300 °C and for short excursions to as high as 550 °C, low wear and friction at high pressures and velocities (lubricated or unlubricated), creep resistance, strength and impact resistance, chemical resistance, and machinability.[21] **These properties make Vespel® parts and shapes crucial for use in high performance operating industrial applications, which require high stability along with durable, long-lasting properties**. Table 1 in Annex I provides a non-exhaustive list of examples of Vespel® grades and their corresponding properties.

Figure 1: DuPont Vespel® parts and shapes.

Source: DuPont, 2023
(https://www.dupont.com/content/dam/dupont/amer/us/en/vespel/public/documents/en/DuPont%20Vespel%20Parts%20for%20Automotive%20Applications%20-%20VPE-A40093-00-A0323.FinalRev.pdf)

Vespel® products are available and offered either as a shape, a near net shape, and/or as a finished part, as illustrated in Figure 1. Custom polyimide direct formed parts (DF/DF2) are engineering solutions manufactured by DuPont for high-volume solutions. In general, polyimide direct form parts use PTFE micropowder in the manufacturing process. These parts require minimal machining steps, resulting in lower costs per part than the shapes offering, and less material scrap or waste. Composite

[21] DuPont, 2022. DuPont™ Vespel® SP-1 for ball valve seats. Electronics & Industrial Kalrez® - Vespel® EMEA. Available at: https://www.dupont.com/content/dam/dupont/amer/us/en/vespel/public/documents/en/DuPont%20Vespel%20SP-1%20for%20ball%20valve%20seats%20-%20VPE-A40079-00-0922%20-%20EXTERNAL%20VERSION.pdf (Accessed in June 2023).

and assembly parts are designed to be used as produced. These products can include one or more of the following PFAS uses: PTFE reinforced fabrics, Fluorine containing polyimides, and/or a PTFE mould release. Chemical- and creep-resistant (CR) shapes, which use PFA, can be machined to final specification downstream.

Kalrez® perfluoroelastomer parts

Kalrez® perfluoroelastomer parts are manufactured by DuPont outside the EEA for sealing applications, particularly in O-ring shapes. The base polymer is composed of a copolymer product of tetrafluoroethylene, a perfluorinated ether, and a cure site monomer. FFKM is known for its ability to provide highly resistant seals and cleanliness in extreme temperature and chemical environments.

Kalrez® perfluoroelastomer parts are specifically designed to provide sealing solutions in demanding applications such as transportation (including aerospace), petroleum and mining, chemical processing (including pharmaceutical industry), semiconductor manufacturing, military and defence, energy.[22] These products offer enhanced stability, resistance, and reliable sealing capabilities. **They resist more than 1,800 different chemicals while offering high temperature stability**. The Kalrez® product portfolio encompasses a wide range of properties, with a non-exhaustive list of products and their properties provided in Table 2 in Annex I.[23]

Kalrez® perfluoroelastomer parts are used as sealing elements in the form of o-ring or custom seal geometries in various mechanical parts, shaft bearings, bushings, T-Seals, boots, chevron stacks, KVSP V-rings, packing systems, valves, pumps, wireline and drilling tools, mechanical seals in rotating equipment (e.g., pumps, mixers), compressors, filters, couplings, spraying heads, cleaning installations, dosing systems, sampling systems, filling equipment, centrifuges, instrumentation (e.g., level gauges, flowmeters, gas analysers, laboratory equipment), fuel burners, ozonators, bonded door, poppet valves, plasma chambers, isolation valves, wafer handling, viewports, gas line feeds, gas injection, and electrostatic chucks.[24,25] **The versatility of Kalrez® perfluoroelastomer parts allows for customized geometries to meet specific sealing requirements**. This results in a diverse range of seal types such as T-seals, packers, S-seals, V-rings, Chevron stacks, boots, X-rings, tri-lobes, electrostatic chucks, protective seals, bonded doors, and metal bondings. Figure 2 illustrates Kalrez® **perfluoro**elastomer parts.

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22 DuPont, 2023. Kalrez®. Available at: https://www.dupont.com/kalrez.html (Accessed in June 2023).

23 DuPont, 2022. DuPont™ Kalrez® and Vespel® Parts. Polymeric solutions for exceptional valve sealing performance in extreme environments. Available at: https://www.dupont.com/content/dam/dupont/amer/us/en/kalrez/public/documents/en/DuPont%E2%84%A2%20Kalre%C2%AE%20and%20Vespel%C2%AE%20-%20Polymeric%20Solutions%20for%20Valve%20Sealing%20in%20Extreme%20Environments.pdf (Accessed in June 2023).

24 DuPont, 2023. DuPont™ Kalrez® Perfluoroelastomer Parts in energy and oil & gas – Product selector guide. Available at: https://www.dupont.com/content/dam/dupont/amer/us/en/kalrez/public/documents/en/DuPont%20Kalrez%20Oil%20and%20Gas%20Product%20Selector%20Guide%20-%20KZE-A40128-00-B0123.FINALREV.pdf https://www.dupont.com/content/dam/dupont/amer/us/en/kalrez/public/documents/en/DuPont Kalrez Oil and Gas Product Selector Guide - KZE-A40128-00-B0123.FINALREV.pdf (Accessed in June 2023).

25 DuPont, 2023. Kalrez® Perfluoroelastomers for Oil & Gas. Available at: https://www.dupont.com/kalrez/oil-and-gas.html (Accessed in June 2023).

Figure 2: Kalrez® perfluoroelastomer parts.

Source: DuPont, 2023

The suitability of each seal type varies depending on the specific grade used. An overview of the suitability per application can be found in Table 3 in Annex I.

3.3. Use of Vespel® parts and shapes and Kalrez® perfluoroelastomer parts in high performance industrial operating environments

Kalrez® perfluoroelastomer parts and Vespel® parts and shapes are widely used in a broad variety of high-performance operating environments for industrial applications. More specifically, both products are used in transportation (including aerospace), petroleum and mining, chemical processing, semiconductor manufacturing, military and defence, energy, and industrial manufacturing (such as automotive manufacturing, textile, glass handling, scientific laboratory instruments, and industrial welding/plasma/cutting tools). Vespel® parts and shapes are also used in industrial manufacturing (such as automotive manufacturing, textile, glass handling, scientific laboratory instruments, and industrial welding/plasma/cutting tools). This section will provide an overview of the specificities of each industry and their use of DuPont's products.

3.3.1. Petroleum and Mining industry and its use of Vespel® parts and shapes and Kalrez® perfluoroelastomer parts

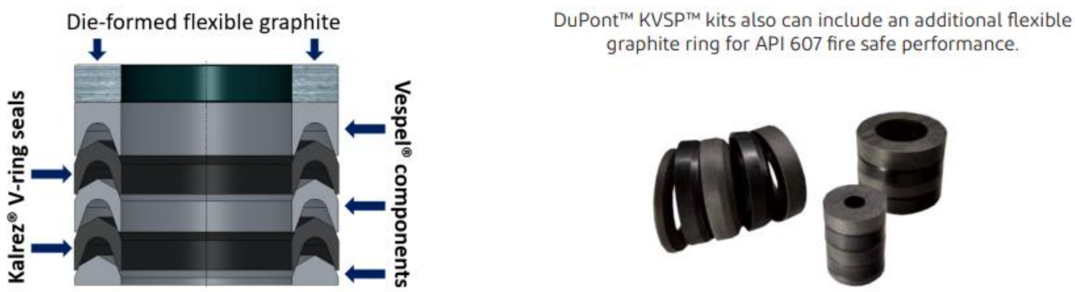
Petroleum and mining are essential industries that play a vital role in shaping and driving the EU society by providing energy resources that are critical for economic advancements, transportation, and the overall functioning of modern society today and for a significant number of years still to come.[26] Universal access to affordable, sustainable, and dependable energy resources stands as the

[26] OECD, 2011. The Economic Significance of Natural Resources: Key Points for Reformers in Eastern Europe, Caucasus, and Central Asia. Available at: https://www.oecd.org/env/outreach/2011_AB_Economic%20significance%20of%20NR%20in%20EECCA_ENG.pdf (Accessed in June 2023)

seventh Sustainable Development Goal outlined by the United Nations, highlighting the significance of this aspect for societal well-being.[27]

DuPont™ Kalrez® Valve Stem Packing (KVSP™), is a combination of chemically-resistant DuPont™ Kalrez® perfluoroelastomer parts and DuPont™ Vespel® V-rings that can reduce stem-based fugitive emissions and improve process control throughout the lifespan of the valve. Fugitive emissions remain a concern for many industries due to their potential to create environmental harm and incur economic costs. KVSP™ has the ability to significantly reduce stem-based fugitive emissions of methane and can also be used for handling other gasses including hydrogen. KVSP™ systems provide performance that approaches zero leakage. This is verified using EPA Method 21 for the determination of leakage of hydrocarbon-based volatile organic compounds (VOCs). KVSP™ requires smaller valve actuators than those required for graphite packing because it requires less compressive force and has much lower valve stem friction, leading to significant cost savings. DuPont™ Kalrez® KVSP™ is used both in the chemical and petroleum industries.[28]

Figure 3: DuPont™ Kalrez® Valve Stem Packing (KVSP™).



Source: DuPont, 2022 (https://www.dupont.com/content/dam/dupont/amer/us/en/kalrez/public/documents/en/DuPont%E2%84%A2%20KVSP%E2%84%A2%20-%20Reducing%20Fugitive%20Emissions.pdf)

Additional Vespel® applications:

Figure 4: Ball valve with Vespel® seats.

Source: DuPont, 2022 (https://www.dupont.com/content/dam/dupont/amer/us/en/vespel/public/documents/en/DuPont%20Vespel%20SP-1%20for%20ball%20valve%20seats%20-%20VPE-A40079-00-0922%20-%20EXTERNAL%20VERSION.pdf)

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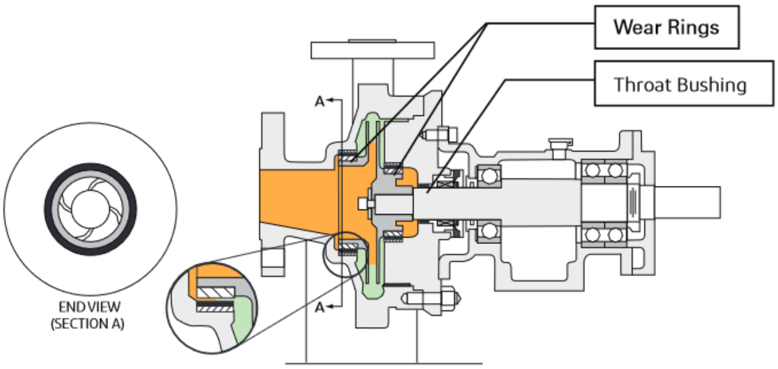
[27] United nations, 2023. Sustainable Development goals. Available at: https://sdgs.un.org/goals/goal7 (Accessed in June 2023).

[28] DuPont, 2022. DuPont™ Kalrez® Valve Stem Packing (KVSP™): Reducing Fugitive Emissions. Available at: https://www.dupont.com/content/dam/dupont/amer/us/en/kalrez/public/documents/en/DuPont%E2%84%A2%20KVSP%E2%84%A2%20-%20Reducing%20Fugitive%20Emissions.pdf (Accessed in June 2023).

Vespel® parts and shapes are used in the oil industry in valve seats for ball valves, which play a critical role in facilitating the smooth flow of high-pressure liquids and gases while minimizing any loss in pressure.[29] The properties of Vespel® valve seats include resistance to wear, creep, deformation under sustained stress, and impact. Moreover, the valve enables ease of machining to precise tolerances, the ability to withstand high pressures of up to 3000 psi (20.7 MPa), and a broad operational temperature range. Figure 4 illustrates a ball valve with Vespel® seats, in which the black Vespel® seats facilitating the smooth flow of high-pressure liquids.

Figure 5: Vespel® product applications in pumps.



Source: DuPont, 2022 (https://www.dupont.com/content/dam/dupont/amer/us/en/vespel/public/documents/en/Vespel%20CR-6100%20Wear%20Components%20for%20Fire%20Water%20Pumps%20in%20Offshore%20Oil%20Recovery%20Platforms%20-%20K22693.FinalRev.pdf)

Wear rings are a critical part of a pump that reduces the leakage of fluid from high pressure zones to lower pressure zones. Since these wear rings are designed to reduce leakage within a pump, excessive wear on these parts can lead to leakage, increased emissions, and decreased efficiency of the pumps. **Vespel® CR parts, such as wear rings and throat bushings, are used in the wear components of firewater pumps found on offshore oil recovery platforms, as illustrated in Figure 5.**[30] Vespel® CR-6100 parts, which contain 80 wt% PFA/20 wt% carbon fibre, reduce leakage by maintaining tight clearances over longer amounts of time due to their excellent wear and friction properties in extreme conditions. Depending on the industrial application, leaking in pumps and other industrial equipment can cause safety concerns for those operating the equipment and the surrounding environment, and it can also lead to increased fugitive emissions. Vespel® CR-6100 is a critical material for wear parts within industrial pump applications. In the context of offshore oil production facilities, ensuring safety and reliability at all times is of great importance, and the firewater pumps play a vital role in the safety systems. These pumps need to be ready to promptly start and operate at maximum capacity when

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[29] DuPont, 2022. DuPont™ Vespel® SP-1 for ball valve seats. Electronics & Industrial Kalrez® - Vespel® EMEA. Available at: https://www.dupont.com/content/dam/dupont/amer/us/en/vespel/public/documents/en/DuPont%20Vespel%20SP-1%20for%20ball%20valve%20seats%20-%20VPE-A40079-00-0922%20-%20EXTERNAL%20VERSION.pdf (Accessed in June 2023).

[30] DuPont, 2022. DuPont™ Vespel® Pump Reliability Technology. Vespel® CR-6100 wear components for fire pumps in offshore oil recovery platforms. Available at: https://www.dupont.com/content/dam/dupont/amer/us/en/vespel/public/documents/en/Vespel%20CR-6100%20Wear%20Components%20for%20Fire%20Water%20Pumps%20in%20Offshore%20Oil%20Recovery%20Platforms%20-%20K22693.FinalRev.pdf (Accessed in June 2023).

the alarm is triggered, even after long periods of inactivity. Lengthy periods of inactivity or standby can cause corrosion in metallic wear components due to exposure to seawater. The pumps must operate continuously under highly demanding conditions while supplying pressurized seawater to the fire sprinkler and hose systems on the platform. **Vespel® CR bowl wear rings and column bushings exhibit resilience to run-dry operations, ultimately enhancing reliability and reducing maintenance expenditures.** Pumps handling harsh chemicals are equipped with a mechanical seal, a device that ensures the sealing between the rotating shaft and the body of the pump, Vespel® parts are a key component in this sub-assembly to ensure no leakage and reliable operation of the mechanical seal. Vespel® CR can help reduce pump seizures and can lower vibration. This increases longevity of pumps and can avoid breakdown of critical operating equipment for a wide range of industrial applications. It also helps avoid metal to metal contact within pumps that can be a great source of wear.

The Vespel® CR line can be fabricated into a large number of parts such as throttle bushings, vertical pump shaft bearing, agitator bushings, API separator bearings, gear pump bearings, centrifugal compressor labyrinth seals, reciprocating compressor valve plates, and pump wear rings.

Vespel® parts and shapes are being used to meet the most stringent sealing requirements in hydrogen applications,[31, 32] thanks to its unique blend of thermal, mechanical, and tribological properties. Both SCP and CR products in Vespel® parts and shapes are being deployed as hydrogen use grows. Given the current environmental challenges linked to greenhouse gas emissions, hydrogen has the potential to become an important source of clean energy. Hydrogen has the benefit of only generating water as a by-product when combusted for energy and can be used in applications such as power generation, and as a substitute for fossil fuels for heating. Safety in sealing is key for storage, transportation and usage.

Additional Kalrez® perfluoroelastomer parts applications:

Rapid Gas Decompression (RGD) resistance is a critical property required in various components used in the oil and gas industry, such as seals, gaskets, O-rings, and other elastomeric articles. RGD occurs when gas is dissolved in an elastomer under high pressure, and subsequently, the pressure is suddenly relieved. When these materials are used in applications where they come into contact with pressurized gases, they can experience gas decompression effects, which can lead to dimensional changes, loss of mechanical properties, and potential failure. **Kalrez® perfluoroelastomer parts exhibit resistance to Rapid Gas Decompression (RGD)** and can withstand the most challenging environments, including Arctic surface conditions, as well as high downhole temperatures and pressures.[33] This makes Kalrez® perfluoroelastomer parts reliable both above and below ground. Oil refineries, which are often located in regions with cold climates, play a vital role in the transformation and refinement of crude oil into various products. **To meet the demanding temperature**

[31] DuPont, 2023, Hydrogen Valves.Available at: https://www.dupont.com/vespel/hydrogen-valves.html#:~:text=DuPont%E2%84%A2%20Vespel%C2%AE%20hydrogen,103%20MPa%20(15%2C000%20psi).&text=Vespel%20parts%20are%20suitable%20for,C%20(%2D423%20%C2%B0F) (Accessed in June 2023).

[32] See references to Vespel® in hydrogen service in EP1493962 B1, and DE602004001720 D1.

[33] DuPont, 2023. DuPont™ Kalrez® Rapid Gas Decompression Testing. Available at: https://www.dupont.com/knowledge/kalrez-rapid-gas-decompression-testing.html (Accessed in June 2023).

requirements in these environments, Kalrez® perfluoroelastomer parts have been formulated accordingly.[34]

According to the report by Wood Environment & Infrastructure Solutions UK Limited[35] which examined the use of PFAS in the petroleum and mining sector, including fluoropolymers, a wide range of fluoroplastics and fluoroelastomers are identified as being used in the oil and gas industry. The most common use for these materials in this sector is in the components of the equipment and piping used in extraction, transport and storage of petroleum resources.

Amine units are widely used in oil refineries and natural gas plants to eliminate sour gases such as hydrogen sulfide (H_2S) from product streams, a process known as sweetening.[36] However, the concentrations of alkylamines present in the aqueous solutions used for this purpose can cause elastomers to undergo swelling and lose their desired mechanical properties. This can result in the extrusion of the seal beyond its intended position, deformation of the fluid film in mechanical seals, increased leakage, and heightened operating torque in valves. **One of the specific Kalrez® grades, Kalrez® Spectrum™ 6380, offers resistance to amines and strong oxidizers, resulting in reduced leakage and extended mean time between repairs.**

To achieve the 2050 Net Zero Emissions target, it is crucial to reduce methane emissions from fossil fuel operations by 74% by 2030. DuPont offers a valve stem packing,[37] which can minimize stem-related fugitive emissions of methane. This Kalrez® valve stem packing not only contributes by reducing methane leakage but also demonstrates its suitability for handling other gases, including hydrogen. **By relying on this Kalrez® perfluoroelastomer part, the oil and gas industry can make significant progress in addressing methane emissions and contributing to a more sustainable energy future.**

The oil and gas industry, particularly pipeline systems, face risks such as environmental disasters, fluid loss, and contamination. **Considering the severe consequences of a pipeline system failure, industries often rely on DuPont's Kalrez® perfluoroelastomer parts and Vespel® parts and shapes product portfolios to mitigate these risks**.

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34 DuPont, 2022. DuPont™ Kalrez® OG193 Perfluoroelastomer Parts. Available at: https://www.dupont.com/content/dam/dupont/amer/us/en/kalrez/public/documents/en/KZE-A40087-00-B0921_DuPont-Kalrez-OG193-Brochure-Letter_digital.pdf (Accessed in June 2023).

35 Wood Environment & Infrastructure Solutions UK Limited, 2021. PFAS in mining and petroleum industry – use, emissions and alternatives. Available at: https://www.miljodirektoratet.no/sharepoint/downloaditem/?id=01FM3LD2R3K5XU7HZ275GJ7NKF3DGGZ576 (Accessed in July 2023).

36 DuPont, 2022. DuPont™ Kalrez® Spectrum™ 6380 Perfluoroelastomer parts for amine units in oil refineries/gas plants. Available at: https://www.dupont.com/content/dam/dupont/amer/us/en/kalrez/public/documents/en/DuPont%E2%84%A2%20Kalrez%C2%AE%206380%20Perfluroelastomer%20Parts%20for%20Amine%20Units%20in%20Oil%20RefineriesGas%20Plants.pdf (Accessed in June 2023).

37 See Figure 3 for more detailed information.

Hydrogen is anticipated to play a significant role in the heating and transportation sector.[38] However, the widespread adoption of hydrogen as an alternative energy source poses challenge. Hydrogen is typically stored and transported either in its cryogenic liquid form at extremely low temperatures or as a compressed gas under high pressures. **In this context, Vespel® parts and shapes propose low hydrogen permeability and robust physical properties that render them well-suited for hydrogen sealing applications.**

3.3.2. Semiconductor Manufacturing industry and its use of Kalrez® perfluoroelastomer parts and Vespel® parts and shapes

The EEA semiconductor manufacturing industry has increasingly emphasised the importance of increasing investments that reduce supply chain dependence on manufacturing in other regions and the importance of increasing investments within the EU. This is echoed by the European Chips Act, which aims to enhance the EU's competitiveness and resilience in semiconductor technologies and application. The act is also designed to facilitate the digital and green transition. As recognised by the European Commission,[39] chips are strategic assets for crucial industrial value chains. Semiconductor chips are essential components of various digital products, ranging from computers, medical equipment, communications, energy, and industrial automation. **The semiconductor manufacturing industry heavily relies on Kalrez® perfluoroelastomer parts due to their high performance in demanding operating environments. In this context, a restriction on PFAS and more specifically on FFKM would be a significant step back for innovation and competitiveness in the EEA semiconductors industry.**

In the semiconductors industry, PFAS is used in different segments of the manufacturing process for different sealing performances (such as high thermal stability, chemical resistance, good vacuum performance, plasma resistance, no elemental contamination, acid and solvent resistance, some high pH chemical resistance, low outgassing and permeation, and abrasion resistance).

With the ongoing digital transformation, new markets for the chip industry are emerging, such as the Internet of Things, 5G, highly automated cars, cloud computing, connectivity, space, and defence applications. Currently, the EU owns approximately 10% of the global microchips market share but is heavily dependent on suppliers outside the region Industry expectations that the demand for chips will double by 2030, combined with the recent global semiconductor shortages which forced multi-sectoral factory closures, **reflect the growing importance of semiconductors for the EU industry and society**. The European Chips Act will address shortages and the EU's technological leadership and

[38] DuPont, 2022. DuPont™ Kalrez® and Vespel® Parts for Hydrogen Energy. Available at: https://www.dupont.com/content/dam/dupont/amer/us/en/vespel/public/documents/en/DuPont%E2%84%A2%20Vespel%C2%AE%20Parts%20for%20Hydrogen%20Energy.pdf (Accessed in June 2023).

[39] European Commission, 2022. European Chips Act. Available at: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/european-chips-act_en (Accessed in June 2023).

mobilise more than 43 billion EUR of public and private measures to prepare, forecast, and respond to future supply chain disruptions.[40, 41]

Kalrez® perfluoroelastomer parts advance the semiconductor manufacturing processes in various segments. **Kalrez® perfluoroelastomer parts help DuPont's customers to reduce maintenance, reduce operating costs, and improve safety**.[42] Because of the purity of Kalrez® perfluoroelastomer parts, contamination is reduced, resulting in a higher wafer yield. Reducing contamination from particulates, outgassing, and extractables caused by seal deterioration are all critical goals for semiconductor fabricators.[43,44]

In semiconductor applications, Kalrez® perfluoroelastomer parts are generally used in:

- **Plasma processing environments**: where high-endurance and robust seal materials like dry etching, lid seals, centre rings, and wafer support are required, particularly in the presence of oxygen and fluorine radicals[45,46];
- **Thermal processes**: for sealing solutions in high-temperature environments such as wafer processing, chemical vapor deposition, atomic layer deposition, low-pressure chemical vapor deposition, oxidation, and diffusion processes[47];
- **Sub-fab seals**: used to prevent leakage and exhaust in piping and pumps that support foreline and wafer processing[48];
- **Back-end solutions**: critical for precision testing, wafer handling, packaging, and inspection processes to ensure the delivery of high-quality chips[49];
- **Wet processes**: employed in wafer processing environments, photolithography, copper plating, and etching, offering resistance to acid- and amine-based strippers.[50]

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40 European Commission. European Chips Act. Available at: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/european-chips-act_en (Accessed in June 2023).

41 European Union, 2022. European Chips Act Fact Sheet. Available at: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/european-chips-act_en (Accessed in June 2023).

42 DuPont, 2023. Semiconductor Manufacturing. Available at: https://www.dupont.com/kalrez/semiconductor-manufacturing.html https://www.dupont.com/kalrez/semiconductor-manufacturing.html (Accessed in June 2023).

43 DuPont, 2011. DuPont™ Kalrez® Perfluoroelastomer parts. Proven reliability in aggressive wafer processing environments. Available at: https://www.dupont.com/content/dam/dupont/amer/us/en/kalrez/public/documents/en/Semiconductor_Seals_Brochure.pdf (Accessed in June 2023).

44 Kalrez® 0090 shows the highest TOTAL GS EP PVV 142 (Rev.5) certification rating and is therefore TOTAL qualified. In the test, the material was tested in its resistance to rapid gas decompression or explosion decompression concerning O-rings used in industrial valve industry. Source: https://o-ring.info/catalog/datasheets/kalrezr-0090/kalrez-0090.pdf

45 DuPont, 2023. Plasma Process. Available at: https://www.dupont.com/kalrez/plasma-process.html (Accessed in June 2023).

46 DuPont, 2017. DuPont™ Kalrez® 9500 for semiconductor SACVD and FCVD applications. Available at: https://www.dupont.com/content/dam/dupont/amer/us/en/kalrez/public/documents/en/Kalrez_9500.pdf (Accessed in June 2023).

47 DuPont, 2023. Thermal Process. Available at: https://www.dupont.com/kalrez/thermal-process.html (Accessed in June 2023).

48 DuPont, 2023. Kalrez® Sub-Fab Seals. Available at: https://www.dupont.com/kalrez/sub-fab.html (Accessed in June 2023).

49 DuPont, 2023. Vespel® Back-End. Available at: https://www.dupont.com/vespel/back-end.html (Accessed in June 2023).

50 DuPont, 2023. Kalrez® Wet-Process. Available at: https://www.dupont.com/kalrez/wet-process.html (Accessed in June 2023).

Kalrez®' perfluoroelastomer parts versatility allows for customization to meet the specific needs and requirements of semiconductor manufacturers. DuPont works closely with customers to develop sealing materials that precisely align with their unique manufacturing demands. **This adaptability ensures that Kalrez® perfluoroelastomer parts effectively addresses the challenges faced by semiconductor fabricators, enabling them to enhance their processes and achieve higher levels of productivity and reliability**.

Figure 6: Photovoltaic product selector guide in silicon wafer-based cell manufacturing processes.

Source: DuPont, 2023 (https://www.dupont.com/content/dam/dupont/amer/us/en/kalrez/public/documents/en/Kalrez-Perfluoroelastomer_Parts_For_Photovoltaic_Manufacturing_Processes.pdf)

Photovoltaic cell manufacturing involves the use of aggressive chemicals and operating under severe conditions, including high temperatures and reactive plasma.[51] The versatility of Kalrez® perfluoroelastomer parts may be illustrated in the wide range of applications of Kalrez® perfluoroelastomer parts in photovoltaic manufacturing processes. For feedstock production and abatement systems, Figure 6 shows which Kalrez® products are generally used in silicon wafer-based cell manufacturing processes.[52] In almost all steps of silicon wafer-based cell manufacturing processes, different grades of Kalrez® perfluoroelastomer parts are used and recommended for use. For instance, one of the grades is used specifically for edge isolation, ARC coatings, and PV cell manufacturing processes requiring resistance to fluorine-based plasma, including amorphous/microcrystalline silicon thin film deposition**. Kalrez®** perfluoroelastomer parts' **resistance to chemicals has been proven to withstand the demanding environments encountered in semiconductor manufacturing industry.**

<u>Vespel® parts and shapes</u>

DuPont™ Vespel® CR-6110 shapes are a carbon-fibre filled thermoplastic perfluoropolymer (PFA) that have demonstrated outstanding performance in aggressive wet chemical/plasma conditions and at elevated temperatures. Customers report improved preventative maintenance cycles by switching to Vespel® CR-6110 in wafer holding/processing, and cleaning and resist stripping operations. In dry plasma applications, Vespel® CR-6110 is also used as a thermal insulator and bearing in semiconductor processing.

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[51] DuPont, 2010. Perfluoroelastomer and fluoroelastomer seals for photovoltaic cell manufacturing processes. Available at: https://www.dupont.com/content/dam/dupont/amer/us/en/kalrez/public/documents/en/Perfluoroelastomer_and_Fluoroelastomer_Seals_for_Photovoltaic_Cell_Manufacturing_Processes.pdf (Accessed in June 2023).

[52] DuPont, 2012. DuPont™ Kalrez® Perfluoroelastomer parts for photovoltaic manufacturing processes. Available at: https://www.dupont.com/content/dam/dupont/amer/us/en/kalrez/public/documents/en/Kalrez-Perfluoroelastomer_Parts_For_Photovoltaic_Manufacturing_Processes.pdf (Accessed in June 2023).

3.3.3. Chemical processing industry and industrial manufacturing uses of Kalrez® perfluoroelastomer parts and Vespel® parts and shapes

Applications in this section include chemical processing and industrial manufacturing (such as automotive manufacturing, textile, glass handling, scientific laboratory instruments, and industrial welding/plasma/cutting tools). DuPont's Kalrez® perfluoroelastomer parts are widely used in the Chemical Processing Industry (CPI) due to their thermal and chemical resistance. Kalrez® perfluoroelastomer parts find applications in mechanical seals, valves, pumps, filters, O-rings, and custom parts. The broad chemical compatibility of Kalrez® perfluoroelastomer parts make them a reliable choice for handling aggressive chemicals and demanding process conditions. Moreover, the ability of Kalrez® **perfluoroelastomer** parts to withstand a wide range of temperatures, from low (-42°C) to elevated levels, further enhance their suitability for CPI applications. **Original equipment manufacturers, chemical processing plants, and refineries rely on Kalrez® perfluoroelastomer parts to ensure reliable and long-lasting sealing solutions, while minimizing downtime and optimizing operational efficiency in chemical processes.**[53]

The chemical processing industry holds a significant position in the global economy, with its contributions exerting a substantial impact on various aspects of industrial production. According to Eurostat, in the EU, the chemical industry accounted for approximately 7% of the EU-27's Gross Value Added (GVA) in recent years. In 2019, the chemical sector employed around 1.2 million people across the EU member states. **The industry encompasses diverse activities, including the production of chemicals, pharmaceuticals, plastics, and other chemical-based products**. These products serve as essential inputs for numerous downstream industries across different sectors of the economy, such as agriculture, construction, automotive, and healthcare.

The chemical sector (including pharmaceuticals, rubber, and plastics) is the largest sector in the EU27 manufacturing industry, accounting for 17.7% of added value (2020 figures). Chemicals is the second largest sector in employment (3.4 million people), contributing 12.3% of EU27 manufacturing employment. The sector generates an even greater number of indirect jobs – up to three times higher than through direct employment.[54, 55]

[53] DuPont, 2023. Kalrez® perfluoroelastomer parts. Available at: https://www.dupont.com/kalrez.html (Accessed in June 2023).

[54] Eurostat, 2023. Production and international trade in chemicals. Available at: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Production_and_international_trade_in_chemicals (Accessed in June 2023).

[55] Cefic, 2023. Our contribution to EU27 industry. Available at: https://cefic.org/a-pillar-of-the-european-economy/facts-and-figures-of-the-european-chemical-industry/our-contribution-to-eu-industry/#h-chemicals-is-the-leading-sector-accounting-for-17-7-of-eu27-manufacturing-added-value (Accessed in June 2023),

Figure 7: Kalrez® perfluoroelastomer parts /Vespel® valve stem packing.

Source: DuPont, 2023 (https://www.dupont.com/knowledge/kalrez-kvsp-valve-stem-packing.html)

In the chemical processing industry, the applications of Kalrez® perfluoroelastomer parts are highly varied. For instance, in chemical plants, Kalrez® valve seals are frequently used to prevent leaks. These control valve gland seals must be extremely effective.[56] Kalrez® valve stem packings are resistant to 60% pentane/40% butane, hexane, acetone, and acid water. They have outperformed the incumbent solutions and resulted in no identified gland leaks in the valves after extensive testing. Figure 7 illustrates the functioning of Kalrez® in a valve seal.

Another application of Kalrez® perfluoroelastomer parts in the chemical processing industry is in chemical reactors. Chemical reactors are systems that use chemical reaction to transform raw materials into new products. **Since these raw materials are often aggressive and are continuously rotated by a stirrer, the seals need to be reliable and safe**.[57] The reactors are cleaned sometimes as much as 3 times a year, typically with demanding cleaning processes.

[56] DuPont, 2022. DuPont™ Kalrez® Valve Stem Packing (KVSP™) Valve sealing in chemical plants. Available at: https://www.dupont.com/content/dam/dupont/amer/us/en/kalrez/public/documents/en/DuPont%E2%84%A2%20Kalrez%C2%AE%20and%20Vespel%C2%AE%20-%20Polymeric%20Solutions%20for%20Valve%20Sealing%20in%20Extreme%20Environments.pdf (Accessed in June 2023).

[57] DuPont, 2022. Dupont™ Kalrez® Spectrum™ 7375 Perfluoroelastomer parts for mechanical seals in a chemical reactor. Available at: https://www.dupont.com/content/dam/dupont/amer/us/en/kalrez/public/documents/en/DuPont%E2%84%A2%20Kalrez%C2%AE%207375%20Perfluroelastomer%20Parts%20for%20Mechanical%20Seals%20in%20a%20Chemical%20Reactor.pdf (Accessed in June 2023).

In chemical environments, ball valves are primarily used for shutting off feeds of both gases and liquids. Figure 8 shows how the Kalrez® perfluoroelastomer parts are placed in the ball valves. The sealing materials in these environments are crucial, and Kalrez® perfluoroelastomer parts have been exceeding performance requirements of 24 months, resulting in significant cost savings by reducing maintenance and associated shutdowns as well as reducing the human exposure and leaks.[58] The Kalrez® perfluoroelastomer parts exhibit very little or no seal degradation.[59]

Figure 8: Kalrez® O-ring in ball valves.

Source: DuPont, 2022 (https://www.dupont.com/content/dam/dupont/amer/us/en/kalrez/public/documents/en/DuPont%E2%84%A2%20Kalrez%C2%AE%200090%20Perfluroelastomer%20Parts%20for%20Ball%20Valves%20in%20Refineries.pdf)

Kalrez® O-rings also find application in the production of pharmaceutical glass containers. The manufacturing process for these tubes involves heating, bending, and cutting long glass tubes using specialized equipment. When subjected to high temperatures, metal O-rings can potentially harm the glass. Consequently, Kalrez® O-rings are used to prevent any damage during the manufacturing process. **As the tubes are rotated by a stainless-steel wheel, a Kalrez® O-ring is positioned on the outside to ensure there is no direct contact between the wheel and the glass tube.**

Operations in the chemical processing industry require excellent sealing performance. **Given the catastrophic consequences of a fault in a sealing system, industries frequently rely on DuPont's Kalrez® products.**

<u>Vespel® parts and shapes</u>

The Vespel® business offers a PFA/carbon fibre composite, CR-6100, for aggressive chemical environments. Formulated to match the coefficient of thermal expansion of steel in the xy plane, this

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[58] DuPont, 2022. DuPontTM Kalrez® 0090 Perfluoroelastomer parts for ball valves in refineries. Available at: https://www.dupont.com/content/dam/dupont/amer/us/en/kalrez/public/documents/en/DuPont%E2%84%A2%20Kalrez%C2%AE%200090%20Perfluroelastomer%20Parts%20for%20Ball%20Valves%20in%20Refineries.pdf (Accessed in June 2023).

[59] NORSOK is a series of standards developed by the Norwegian petroleum industry for oil and gas companies. Their main objectives are to ensure safety, enhance value, and promote cost-effectiveness in petroleum industry developments and operations. These standards are designed to replace individual oil company specifications and also serve as reference points in governmental regulations.

composite delivers exceptional performance up to 260°C. The PFA provides lubrication to pump even under dry conditions. Vespel® CR-6100 can even handle sulfuric acid/hydrogen peroxide mixtures that quickly degrade most other substances. While primarily used for petroleum refining and petrochemicals, it is also used in applications for power generation, pulp and paper manufacturing, fertilizer manufacturing, and general chemical manufacturing. Vespel® CR-6100 improves the safety, life, and efficiency of centrifugal pumps. We estimate that due to this efficiency improvement 6.5 billion kilowatt-hours per year are currently being saved across EMEA, resulting in lower CO_2 emissions.

Ball valve seats and seals are used to achieve bubble-tight closure in high chemical hazard and extreme temperature processes. Typically for valves that need to seal at high temperatures and high pressures, metal seated valves are used consisting of a tungsten carbide (to 260 °C) or chromium carbide (> 260 °C) coating on the ball and seats. Because the compressive modulus of metals is very high (> 500GPa), it is less compliant and cannot make an effective seal and make the valve "bubble tight." Due to creep, many polymers become difficult to use much above their glass transition temperature at higher pressure classes. Typical benefits observed using Vespel® parts and shapes as valve seat material can include: increased life and reliability of equipment, lower fugitive emissions, reduced operation downtime, less frequent maintenance, reduced overall operation cost, and lower operating torque.

Vespel® parts are used in glass handling industry with typical applications including take-out inserts, sweep-out fingers, stacker and transfer pads, guides and dead plate, as Vespel® parts are an excellent choice for hot glass handling components. These parts use PTFE in the manufacturing process. DuPont™ Vespel® parts and shapes increases plant reliability and lowers operation costs by delivering extended life and less glass checking compared with conventional glass handling technology. [60]

Many analytical instruments require a number of components that need high performance properties that can only be met by Vespel® materials.[61] From oven components and column ferrules in gas chromatographs, to electrical insulators in mass spectroscopy detectors Vespel® parts and shapes is used in extreme conditions to seal, insulate, and protect a variety of components for sensitive equipment. Vespel® parts and shapes not only survive high temperatures but performs well in applications where thermal cycling would damage other components.

Vespel® bushings are used in a variety in industries such as in the textile machines, insulating parts in welding torchers (welding tools are then used in multiple industries that use welding such as construction, transportation, etc.).

[60] DuPont, 2009. DuPont™ Vespel® Glass Handling Technology Innovation for the glass industry. Available at: https://www.dupont.com/content/dam/dupont/amer/us/en/vespel/public/documents/en/K22677-1_Vespel_Glass_Handling_Brochure.pdf (Accessed in June 2023).

[61] DuPont, 2007, DuPont™ Vespel® Insulator Solutions. Available at: https://d2zo35mdb530wx.cloudfront.net/_legacy/UCPthyssenkruppBAMXNA/assets.files/tkmna_com/products/collateral/plastics/dupont-vespel/vespel_insulatorsolutions.pdf (Accessed in June 2023).

3.3.4. Transportation and aerospace industry and their use of Vespel® parts and shapes and Kalrez® perfluoroelastomer parts

DuPont's Vespel® parts and shapes are widely used in the transportation industry due to their heat resistance, wear resistance, and low-friction properties. These characteristics make them suitable material for automotive and aerospace applications, where they are commonly utilized as washers, bushings, and seal rings. This section provides an overview of the transportation sector's reliance on Vespel® and Kalrez® products, highlighting their significant and widespread role in this industry.

The transportation industry plays a fundamental role in the EU society, making multidimensional contributions that impact various aspects of society. Transportation is a cornerstone of the EU integration and is fundamental for facilitating the free movement of individuals, services, and goods.[62] By facilitating such movement, the transportation sector enhances accessibility, mobility, social activities, cultural activities, economic activities, and trade, thereby fostering economic growth and development.[63] It has also been shown that economic opportunities are, to an increasing extent, linked to individuals' mobility. As a result, **the transportation sector plays a crucial role in driving economic progress and ensuring the efficient functioning of modern society, both at an individual and global level.** [64]

Figure 9 illustrates how the transportation industry has seen tremendous growth over the past two decades.[65] Passenger transportation, including passenger cars, motorcycles, buses, trams, metros, railways, intra-EU air, and intra-EU sea transportation, has experienced significant expansion. Additionally, the transportation of goods via road, rail, inland waterways, oil pipelines, intra-EU air, and intra-EU sea transportation has witnessed substantial growth. This growth in the reliance on transportation aligns with the overall increase in Gross Domestic Product (GDP). **This bidirectional relationship between economic growth and infrastructure has also been found in research**.[66]

62 European Commission, Directorate-General for Mobility and Transport, 2022. EU transport in figures – Statistical pocketbook 2022, Publications Office of the European Union. Available at: https://data.europa.eu/doi/10.2832/216553 (Accessed in June 2023).

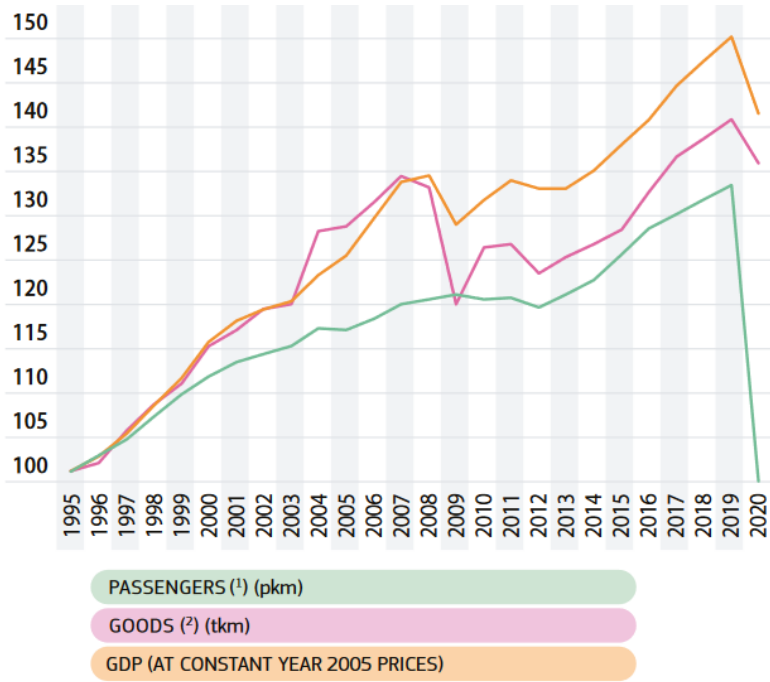
63 Rodrigue, J.P., 2020. The Geography of Transport Systems. Available at: https://doi.org/10.4324/9780429346323 (Accessed in June 2023).

64 Ibid.

65 European Commission, Directorate-General for Mobility and Transport, 2022. EU transport in figures – Statistical pocketbook 2022, Publications Office of the European Union. Available at: https://data.europa.eu/doi/10.2832/216553 (Accessed in June 2023).

66 Mohmand, Y. T. et al., 2021. Investigating the causal relationship between transport infrastructure, economic growth and transport emissions in Pakistan. Research in Transportation Economics. Available at: https://doi.org/10.1016/j.retrec.2020.100972 (Accessed in June 2023).

Figure 9: Passenger, goods, GDP 1995 – 2020 (Year 1995 = 100)



Source: European Commission, DG Mobility and Transport, 2022 (https://data.europa.eu/doi/10.2832/216553)
NB: (1) Passenger cars, powered two-wheelers, busses & coaches, tram & metro, railways, intra-EU air, intra-EU sail – ***pkm: passengers per kilometre****; (2) Road, rail, inland waterways, oil pipelines, intra-EU air, intra-EU sea –* ***tkm: tonnes per kilometre***
The y-axis (green line) represents the number of passengers indicated in pkm, the y-axis (pink line) represents the amount of goods that were transferred in tkm and the y-axis (orange line) represents the GDP (index with 1995 as the base year).

The transportation industry holds significant importance for the EU and global economy, with the transportation services sector contributing approximately 5% of the EU-27's Gross Value Added (GVA) in 2020, amounting to around 555 billion EUR.[67] In 2019, 5,237,100 individuals were employed in road transportation in the EEA.[68]

Road applications: Automotive industry

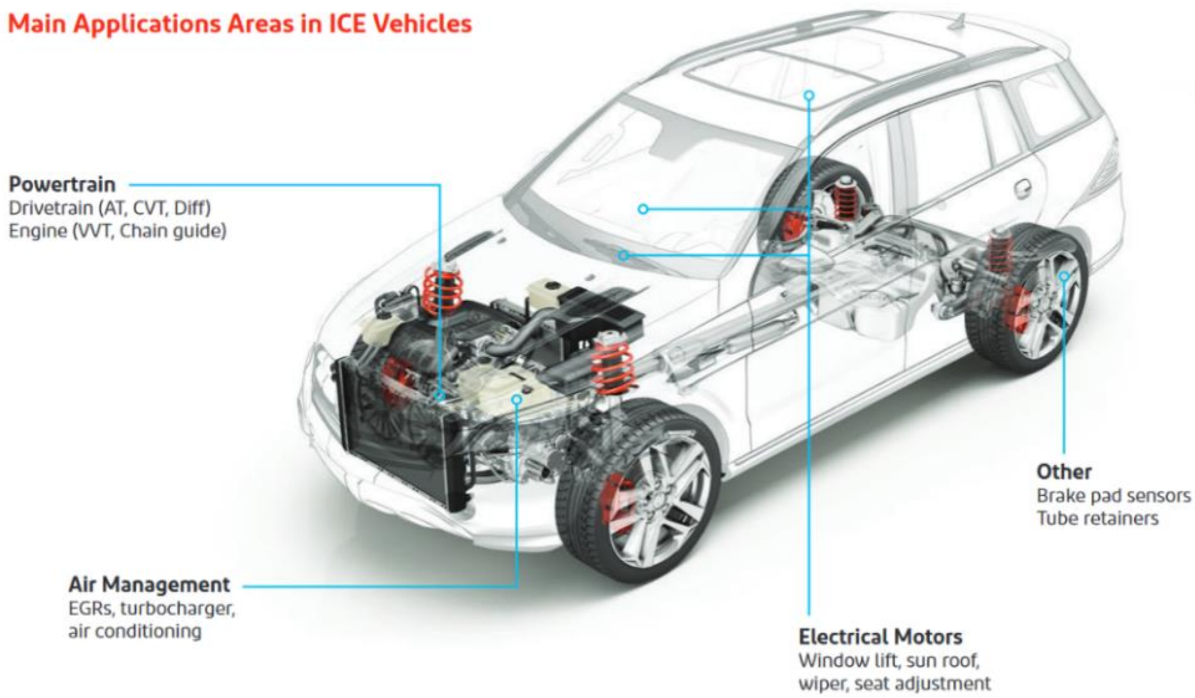
Vespel® parts and shapes have diverse applications in the automotive industry, including Internal Combustion Engine (ICE), Electrical Vehicle (EV) systems, driveline components, engine components, powersports vehicles, and turbochargers.[69] Please refer to Table 4 in Annex I for an overview of Vespel® products that are used in the automotive industry, highlighting the heterogeneity

[67] European Commission, Directorate-General for Mobility and Transport, 2022. EU transport in figures – Statistical pocketbook 2022, Publications Office of the European Union. Available at: https://data.europa.eu/doi/10.2832/216553 (Accessed in June 2023).
[68] European Commission, Directorate-General for Mobility and Transport, 2022. *EU transport in figures – Statistical pocketbook 2022*, Publications Office of the European Union, https://data.europa.eu/doi/10.2832/216553
[69] DuPont, 2023. DuPont Automotive applications. Available at: https://www.dupont.com/vespel/automotive.html (Accessed in June 2023).

in shapes and properties per Vespel® component.[70] This section will provide a non-exhaustive overview of the use of Vespel® parts and shapes products in the automotive industry.

The automotive industry utilizes Vespel® parts and shapes for various purposes, such as in the ICE vehicle's air management system, in brake pad sensors, and in powertrains. ICE applications rely on the combustion of fuel-air mixtures.[71] For these applications, Vespel® components offer advantages such as the absence of heat exchanges in the working fluid stream. Some key application areas in ICE vehicles are also illustrated in Figure 10.

Figure 10: Main application areas for Vespel ® parts in ICE vehicles.



Source: DuPont, 2022 (https://www.dupont.com/content/dam/dupont/amer/us/en/vespel/public/documents/en/DuPont%20Vespel%20Parts%20for%20Automotive%20Applications%20-%20VPE-A40093-00-A0323.FinalRev.pdf)

Automotive gearboxes and transmissions require lubrication to reduce friction and heat generated by metallic gears. However, some applications, like the wastegate, operate without lubrication. In both cases, **materials used must meet specific requirements for low wear rates and durability, delivering both low Coefficient of Friction (CoF) and survivability in high Pressure-Velocity (PV) conditions.**[72] **High temperature resistance is crucial, especially for automotive ICE powertrain applications**. While

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[70] DuPont, 2022. DuPont™ Vespel® Parts and Shapes for Automotive Applications (xEV & ICE). Available at: https://www.dupont.com/content/dam/dupont/amer/us/en/vespel/public/documents/en/DuPont%20Vespel%20Parts%20for%20Automotive%20Applications%20-%20VPE-A40093-00-A0323.FinalRev.pdf (Accessed in June 2023).

[71] Taylor, C. F., 1985. Internal Combustion Engine in Theory and Practice. MIT press. Available at: https://ftp.idu.ac.id/wp-content/uploads/ebook/tdg/ADVANCED%20ENGINE%20TECHNOLOGY%20AND%20PERFORMANCE/The%20Internal-Combustion%20Engine%20in%20Theory%20and%20Practice.%20Vol.%20I_%20Thermodynamics,%20Fluid%20Flow,%20Performance%20(%20PDFDrive%20).pdf (Accessed in June 2023).

[72] DuPont, 2022. DuPont™ Vespel® Parts and Shapes for Automotive Applications (xEV & ICE). Available at: https://www.dupont.com/content/dam/dupont/amer/us/en/vespel/public/documents/en/DuPont%20Vespel%20Parts%20for%20Automotive%20Applications%20-%20VPE-A40093-00-A0323.FinalRev.pdf (Accessed in June 2023).

a well-lubricated engine typically reaches temperatures of 90°C to 105°C, a non-lubricated turbocharger wastegate can exceed 300°C. Vespel® SP resin materials possess high temperature resistance, withstanding continuous use temperatures up to 260°C and even tolerating excursions beyond 350°C. Due to this high temperature resistance and inability to melt, they are a reliable choice for automotive applications. The bushings in the actuator must be able to perform at these elevated temperatures, delivering smooth operations and guiding the connecting rod within the wastegate actuator to ensure control of the turbocharger at variable pressures and speeds.[73]

Vespel® parts and shapes are also used as components in automotive turbochargers and Exhaust Gas Recirculation (EGR) systems.[74] The bushings and washers resist the high temperatures that are required in the turbocharging applications, contributing to increased fuel efficiency and reduced emissions.

As the automotive industry continues to transition towards electrification to reduce carbon emissions, there is an increasing demand for innovative materials.[75] For road transportation, there also is a short-term trend expected to move to electric and hydrogen hybrids, with a dual cell for road transportation. **DuPont's Vespel® parts and shapes are used in EVs, including Plug-in Hybrid Electric Vehicles (PHEVs), Battery Electric Vehicles (BEVs), and Fuel Cell Electric Vehicles (FCEVs).**[76] These components are primarily used in transmissions, differentials, and motors in the form of wear rings, hydrogen gas seals, bushings, thrust washers, and thrust plugs (see Figure 11). The thrust plugs, which are made with Vespel® parts and shapes, allow for application of the right amount of friction for smooth opening and closing, as well as keeping windows in place when partially opened. Moreover, they improve the service life of door slide motors, actuator bushings, cooling fan boxes, and gear boxes for adjusting steering and seating position. **For EV battery cells, Vespel® parts and shapes are generally used in the form of terminal seals, isolation rings, and spacers**.[77]

[73] DuPont, 2023. DuPont™ Vespel® SP-21 Guide Bushings for Turbocharger Wastegate Actuators – Case Study. Available at: https://www.dupont.com/knowledge/vespel-actuator-guide-bushings.html (Accessed in May 2023).

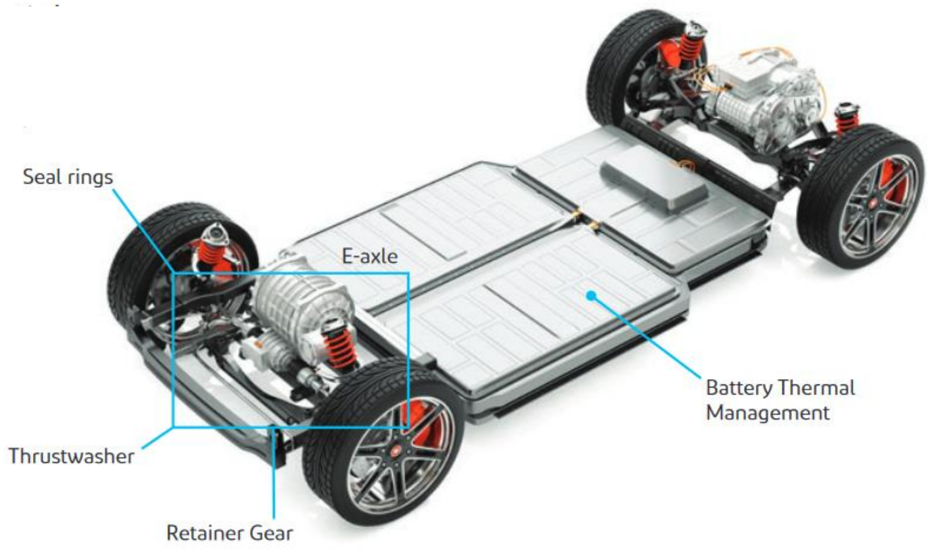
[74] DuPont, 2023. DuPont™ Vespel® Turbochargers. Available at: https://www.dupont.com/vespel/turbochargers-egr.html (Accessed in June 2023).

[75] DuPont, 2022. DuPont™ Vespel® Parts and Shapes for Automotive Applications (xEV & ICE). Available at: https://www.dupont.com/content/dam/dupont/amer/us/en/vespel/public/documents/en/DuPont%20Vespel%20Parts%20for%20Automotive%20Applications%20-%20VPE-A40093-00-A0323.FinalRev.pdf (Accessed in June 2023).

[76] DuPont, 2022. DuPont™ Vespel® Parts and Shapes for Electrical Vehicle Applications (PHEV, BEV, FCEV). Available at: https://www.dupont.com/content/dam/dupont/amer/us/en/vespel/public/documents/en/DuPont%20Vespel%20Parts%20and%20Shapes%20in%20Electrical%20Vehicles%20-%20sell%20sheet%20-%20VPE-A40075-00-A0422-FinalRev.pdf (Accessed in June 2023).

[77] DuPont, 2023. DuPont™ Vespel® for EV Battery Cell Thermal Management Applications. Available at: https://www.dupont.com/content/dam/dupont/amer/us/en/vespel/public/documents/en/Vespel-For-EV-Battery-Cell-Thermal%20Management-Application-Profile-VPE-A40071-00-A0921.FinalRev.pdf (Accessed in June 2023).

Figure 11: Illustration of Vespel® parts that are used in Electrical Vehicle Applications.



Source: DuPont, 2022 (https://www.dupont.com/content/dam/dupont/amer/us/en/vespel/public/documents/en/DuPont%20Vespel%20Parts%20and%20Shapes%20in%20Electrical%20Vehicles%20-%20sell%20sheet%20-%20VPE-A40075-00-A0422-FinalRev.pdf)

Thrust washers (see Figure 12) play a crucial role in e-axles, differentials, torque vectoring, and disconnect systems. Thrust washers are designed to absorb axial forces, act as spacers between rotating and stationary components, prevent wear, minimize seizing and torque loss, and withstand high pressure and velocity.[78] Because electric motors can generate higher torque than ICEs vehicle designs can simplify transmission systems, but at the cost of putting more force on the drive components. **Vespel® thrust washers have already demonstrated their performance in various heavy-duty applications, including tractor (farming, construction), truck (primarily industrial use trucks such as those used in mining and construction), and car transmissions**. They can operate in normal oil mist environments, reaching PVs (pressure-velocity) of up to 40 millipascal-seconds (mPa·s) and speeds of 7,000 revolutions per minute (rpm).[79] Light weighting is key to extending the range of electric vehicles. Using high performance bearing and thrust washers such as Vespel® parts and shapes, significant design simplifications and weight reduction can be achieved by eliminating complex oil lubrication systems. **The flexibility of Vespel® parts allows for optimized designs by adjusting the contact area, both externally and internally, based on known loading and speed conditions**.

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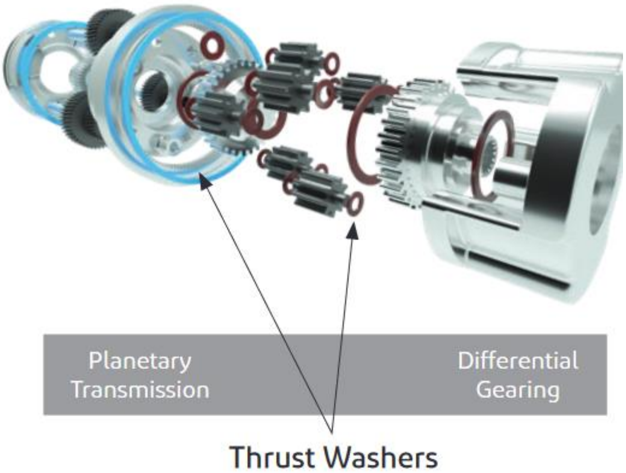
[78] DuPont, 2022. DuPont™ Vespel® Parts and Shapes for Electrical Vehicle Applications (PHEV, BEV, FCEV). Available at: https://www.dupont.com/content/dam/dupont/amer/us/en/vespel/public/documents/en/DuPont%20Vespel%20Parts%20and%20Shapes%20in%20Electrical%20Vehicles%20-%20sell%20sheet%20-%20VPE-A40075-00-A0422-FinalRev.pdf (Accessed in June 2023).

[79] DuPont, 1997. DuPont™ Automotive Vespel®. Available at: https://www.dupont.com/content/dam/dupont/amer/us/en/vespel/public/documents/en/vesautoe.pdf (Accessed in June 2023).

Figure 12: Illustration of thrust washers.



Source: DuPont, 2022
(https://www.dupont.com/content/dam/dupont/amer/us/en/vespel/public/documents/en/DuPont%20Vespel%20Parts%20and%20Shapes%20in%20Electrical%20Vehicles%20-%20sell%20sheet%20-%20VPE-A40075-00-A0422-FinalRev.pdf)

Other important applications of Vespel® parts and shapes that are used in the ground transport applications are: [80, 81]

- **Seal rings**. These rings work dynamically to provide a seal between the shaft and the housing at specific pressures and speeds. Lifetime, minimization of leakage, and reliability are critical factors in seal ring design, as they directly affect shifting operations. Seal rings are used in tractor and other earth moving equipment transmissions, passenger car automatic gearboxes, and automotive continuously variable transmissions;
- **Valve seats**. These reduce oil leakages within the transmission;
- **Thrust plugs**. These directly fit into the rotor shaft, are specifically used in applications like windscreen wipers, window lifts, sunroofs, and seat adjustments. These parts are designed to withstand axial loads while resisting creep and wear even in dirty environments;
- **Wear pads**. These Vespel® parts and shapes are installed in the metallic support of brake pads. They thermally and electrically insulate the wire connecting the brake wear warning light. These wear pads must provide low and consistent wear rates without melting or depositing any film on the disc. Manual transmissions in on road and off-road vehicles use shift fork wear pads to prevent metal to metal contact.
- **Bushings, washers, ball bearing cages, insulations, and thrust plugs**. These are generally used within electrical motors. These components must withstand axial and radial loads coupled with high speeds.

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[80] DuPont, 1997. DuPont™ Automotive Vespel®. Available at: https://www.dupont.com/content/dam/dupont/amer/us/en/vespel/public/documents/en/vesautoe.pdf (Accessed in June 2023).

[81] DuPont, 2022. DuPont™ Vespel® Parts and Shapes in Internal Combustion Engine Applications. Available at: https://www.dupont.com/content/dam/dupont/amer/us/en/vespel/public/documents/en/DuPont%20Vespel%20Parts%20and%20Shapes%20in%20Internal%20Combustion%20Engine%20Applications%20-%20sell%20sheet%20-%20VPE-A40076-00-A0422-FinalRev.pdf (Accessed in June 2023).

- **Military ground vehicles also utilize Vespel® for bearings, bushings, washers, seal rings**. Several grades of Vespel® must meet ASTM D6456-10[82] which can be required from some transportation customers.

The above examples provide a non-exhaustive overview of the use of the use of Vespel® parts and shapes in the automotive industry. **Importantly, the Vespel® parts and shapes are available as different components and in different grades, which all have their own specific characteristics and properties. Therefore, the specific grade of Vespel® can be designed and adapted according to the requirements of the application**.

A restriction on PFAS without a derogation for the transportation industry could have significant implications for the EU's ability to achieve its net-zero economy goal by 2050 as outlined in the European Green Deal. The Green Deal aims to transition the EU and its Member States to a sustainable economy with reduced reliance on fossil fuels. Batteries play a crucial role in achieving objectives related to low-emission mobility, decarbonized energy generation, and digitalization, as highlighted by the European Commission. The European Commission recognizes batteries as a strategic value chain and acknowledges their importance in enabling sustainable development, green mobility, clean energy, and climate neutrality. They are particularly vital in the shift toward electric vehicles.[83]

In this context, DuPont's Vespel® parts and shapes in the transportation area, such as in uses related to batteries, are important for zero-emission vehicles. By providing a more sustainable energy storage solution, providing engineered parts in EVs, and turbochargers, these products are contributing to reduce greenhouse gas emissions and support the transition to a low-carbon economy and DuPont's focus on sustainability and circularity aligns with the objectives of the European Green Deal, making DuPont an important player in the transition to a greener and more sustainable future.[84]

<u>**Aerospace applications**</u>

DuPont performed an SEA on the use of PFAS within the Aerospace Supply Chain for Vespel® parts and shapes and Kalrez® perfluoroelastomer parts. This SEA will be provided as an attachment in a separate submission.

Vespel® parts and shapes have diverse applications in the aerospace applications. Vespel® parts and shapes can be formed into different shapes and sizes to be used as bushings, wear strips, wear pads, track liners, bumpers and washers in aircraft engines. **Vespel® products are used on nearly all civil airline jets, engines and turboprops in service, as well as military jets and helicopters. It is highly likely that all of these aircraft will use at least one type of Vespel® component relevant to the scope**

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82 Standard specification for finished parts made from polyimide resins. Available at: https://www.astm.org/d6456-10r18.html (Accessed in June 2023).

83 RECHARGE, 2023. Application for derogations from PFAS REACH restriction for specific uses in batteries – First submission
. Submission number: cb6a7d0a-caa1-42fa-a806-f7410538f8b9.

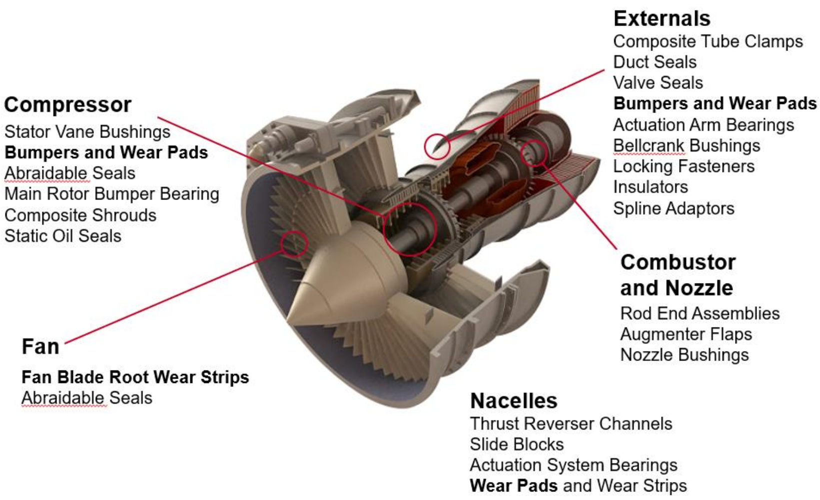
84 European Commission, 2022. Zero emission vehicles: first 'Fit for 55' deal will end the sale of new CO2 emitting cars in Europe by 2035. Available at: https://ec.europa.eu/commission/presscorner/detail/en/ip_22_646 (Accessed in June 2023).

of the restriction. This section will provide a non-exhaustive overview of the use of Vespel® parts and shapes products in the aerospace industry and aircraft engines.

Within aircraft engines, Vespel® components are used in many areas to **reduce the frictional co-efficient between moving components**. Vespel® components can be present as various shapes and sizes to fit specific areas within an engine. It is important to note that some of the key benefits of Vespel® are that parts are lightweight, can be used continuously at 260°C, are resistant to hydrocarbon fuels, are formulated to function over a wide temperature range, and can be machined easily to fulfil specific design **criteria. Parts and components are machined to precise measurements to perfectly fit into the areas needed; any increase in weight or dimensions outside of specification would disrupt the function of the engine. Unless already specified as alternate, any material change would require thousands of hours of engine testing before they are put into commercial engines.**

Components that are used in aerospace applications need to withstand temperatures over 315°C (for short durations) over the expected lifetime of the engine, whilst also delivering the specified functionality without a decrease in performance. Without Vespel® components, the metal-on-metal interactions would cause excessive vibration and higher levels of friction. This could lead to galling and metallic wear debris build up within the engine. Should this occur, it can be fatal to the engine, causing potential short circuits as well as locking components, resulting in engine failure.

Figure 13: Vespel® components used within aircraft engine manufacturing.



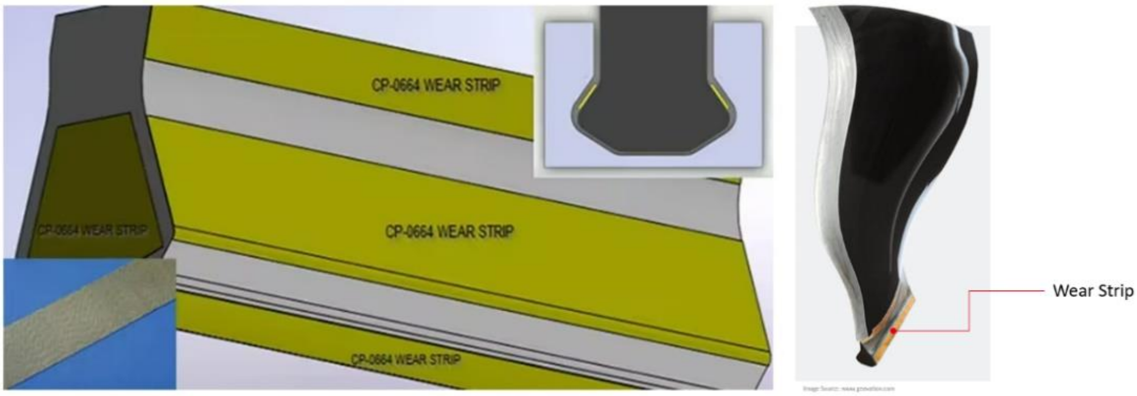
Source: DuPont, 2022 (https://www.dupont.com/content/dam/dupont/amer/us/en/vespel/public/documents/en/DuPont%20Kalrez%20and%20Vespel%20Parts%20for%20the%20Aerospace%20Industry%20-%20Overview%20Brochure%20-%20VPE-A40093-00-A0323.pdf)

Figure 13 illustrates the extensive use of Vespel® products in aircraft engine manufacturing. **The use of these components is typically where there is relative motion that could cause vibrations or mechanical wear of the components in contact**. Common applications in an aircraft engine are in variable stage and actuation systems in engine compressors, bleed valve systems, valves, and actuators for nacelles and aircraft surfaces.[85] Importantly, while Figure 13 gives an overview of the variety of Vespel® components that are used, Vespel® uses are not limited to this overview.

Vespel® wear strips are PTFE fabric composites and are widely used in aircraft engine components. Wear strips slow the wear rate by providing a self-lubricating, low friction gliding functionality, and function well in dirty environments. These wear strips are used on the fan blade root in aircraft engines and in nacelles to assist with the insertion of the engine and prevent vibrational wear.

For the fan blade roots' applications of wear strips, the wear strips are specifically designed to reduce the friction between the fan blade and the rotating disk, which houses the fan blade root. This helps to reduce wear and fretting fatigue caused via operation, whilst in metallic fan blades wear strips deliver this same functionality and provide additional corrosion protection.[86] Vespel® wear strips help to more accurately align composite fan blades within the compressor assembly. If not set properly or consistently, operation of the engine could be significantly impacted. **Due to the high rotational speeds and mass, any imbalance will** result in an increase in vibration leading to premature wear across the entire fan blade assembly and other connected engine systems. Figure 14 illustrates the functioning of Vespel® wear strips on fan blades.

Figure 14: Vespel® wear strips used on fan blades.



Source: Based on DuPont's internal data, 2023.

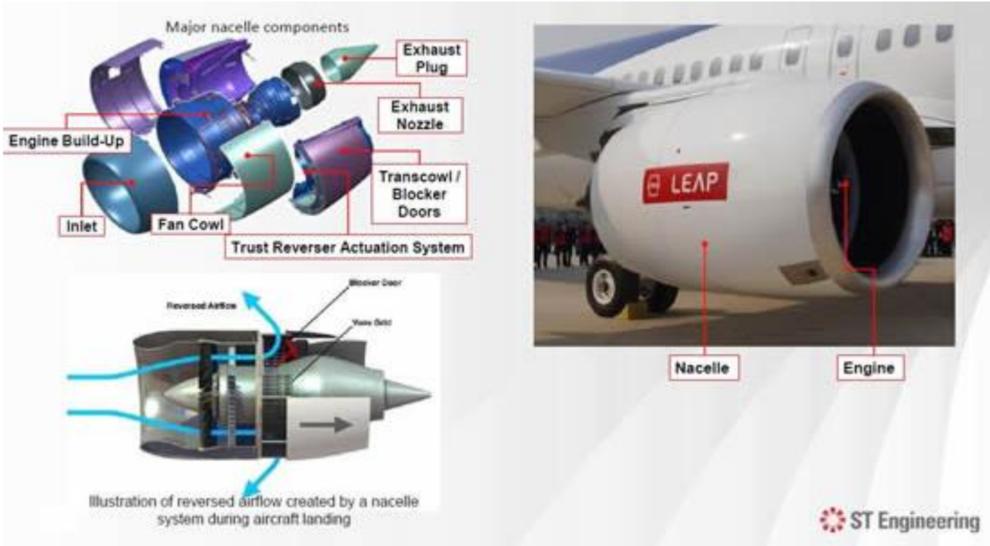
Wear strips are also used in engine nacelles, the casing that houses the engine, providing efficient aerodynamics during flight and attaching the engine to the plane. Figure 15 gives an overview of the nacelle in relation to the engine itself. **Wear strips are beneficial for use in nacelles to assist with the insertion of the engine, making it easier to align the engine within the nacelle**. Wear strips therefore help to reduce the likelihood of damaging the engine components during assembly. Additionally, these wear strips will reduce the engine vibration against the nacelle during operation. This vibration causes an acceleration of wear rate on the engine components and the nacelle itself. Vespel® wear strips increase the mean time between repairs by serving as sacrificial components to protect hard-to-machine metal engine components. Vespel® wear strips are also used in thrust reversal systems for breaking. While thrust reversal systems are not particularly high temperature or high speed, Vespel®

[85] DuPont, 2023. Vespel® Brings High-Temperature Performance to Aircraft Bushings and Washers - Case Study. Available at: https://www.dupont.com/knowledge/vespel-bushings-washers.html (Accessed in June 2023).

[86] RPA (2023): Socio-Economic Impact Assessment for the use of PFAS within the Aerospace Supply Chain, report for DuPont Specialty Products USA, LLC, June 2023, Norwich, Norfolk, UK.

wear strips perform well in dirty environments where oils and greases would pick up debris and eventually become an abrasive mass.

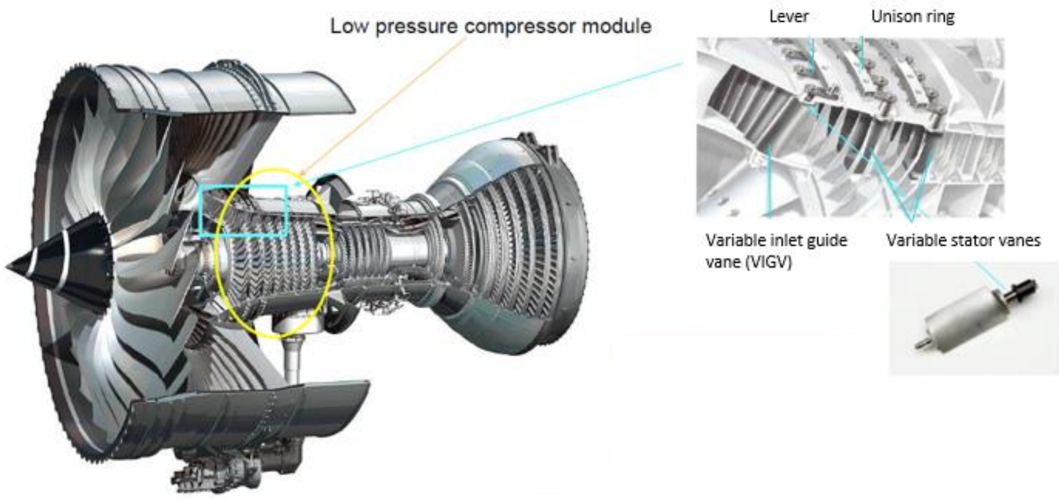
Figure 15: Overview of an engine nacelle.



Source: DuPont, 2022 (https://www.blueskynews.aero/issue-479/ST-Engineering-to-acquire-nacelle-manufacturer-MRA-Systems.html)

On top of wear strips, washers, bushings, and wear pads are also typically made from Vespel® products. Some of these grades contain fillers to further enhance the low friction performance of parts in areas where oil-based lubrication cannot be used. One of the key benefits of using Vespel® parts in jet engine compressors is their ability to withstand high temperatures and pressures without degrading or losing their mechanical properties. These properties are particularly important in the environment of a jet engine, where even small changes in performance can have a significant impact on overall engine efficiency and reliability.

Figure 16: Cross section of an engine, indicating bushing and washer uses. Core Vespel application variable vane bushes in Jet Engines.



Source: Based on DuPont's internal data, 2022

Figure 16 shows how washers and bushings are used on the rotating vanes of the compressor section of the engine. **Depending on the type of engine, there can be up to 600 bushings in the compressor section**. Without them, the ability to actuate variable stator vanes inside the compressor would require significantly larger actuators to overcome the friction between sliding components, resulting in a significant increase in weight. Bushings are also used on the lever to activate the stator vanes and on the outside casings. In addition, the reduction of wear and improved efficiency by minimizing energy losses due to friction is an added benefit. Not only do Vespel® bushings provide lubricity, but Vespel® is often used as a sacrificial component in moving assemblies to safeguard hard-to-machine metal components. Vespel® bushings provide the lowest wear while preventing galling of metal components.

Many Vespel® parts are used in the compressor section of the engine to deliver functionality whilst also providing creep and impact resistance, dimensional stability, and thermal resistance. This includes a number of engine components, including variable stator vanes and torque box/bell crank linkage arms. Thrust washers using Vespel® grades are used in the compressor section to transfer axial loads between rotating and stationary parts and to provide a low friction interface between the compressor rotor and stator subassemblies, helping to improve efficiency. Washers are used in numerous places throughout an engine and can sometimes form part of the bushing. All of these benefits result in aircraft engines that are more fuel efficient, are more reliable and thus safer, and are lower cost to operate.

Kalrez® perfluoroelastomer parts

Kalrez® seals are sold in multiple performance grades, many of which are relevant to the aerospace industry resulting from decades of R&D work. A non-exhaustive list of aerospace relevant grades of Kalrez® are as follows[92]:

- Kalrez® 4079AMS was the first to be developed and gained AMS accreditation in 1985. This grade is rarely used in new designs but is still important for legacy parts where redesign of the component and qualification of a superior material is not necessary.

- Kalrez® Aerosel™ 7777 was developed as the next generation FFKM material to Kalrez® 4079. This grade meets AMS specifications, shows improved temperature resistance and is still manufactured and used in the design of new parts today. This grade is versatile and can be used in most oil seal applications.

- Kalrez® Aeroseal™ 7797 has the same temperature resistance as Kalrez® 7777 and was developed as a seal material with greater hardness to meet specifications provided by aircraft engine manufacturers. This grade is therefore for use in applications with higher requirements for hardness and tensile strength but with less requirement for flexibility.

- Kalrez® Aerosel™ 7800 has similar temperature resistance to Kalrez® 7777, meets AMS specifications and demonstrates improved metallic corrosion properties.

Some of the key physical properties of these grades of Kalrez® are listed in Table 2. For Vespel® and Kalrez® see section 5 for the associated hazard properties.

Table 2: Key physical properties of Kalrez® grades for oil seals in aerospace

Property	Kalrez® 4079AMS	Kalrez® Aeroseal™ 7777	Kalrez® Aerosel™ 7797	Kalrez® Aerosel™ 7800
Hardness, Shore (A)	75	75	90	75
50% Modulus (Mpa)	n/d	n/d	15.91	n/d
100% Modulus (Mpa)	7.24	7.58	n/d	11.3
Tensile strength at break (Mpa)	16.88	17.91	23.84	20.1
Elongation at break (%)	150	160	77	150
Compression Set (204°C) (%)	25	15	11	20
Compression Set (300°C) (%)	n/d	19		52
Compression Set (325°C) (%)	n/d	34	n/d	n/d
Maximum Service Temperature (°C)	316	325	325	325
Temperature of Retraction (°C)	-2	-4	-5	-3

Source: Kalrez® technical datasheets

The aerospace industry is governed by multiple standards across many different countries and continents. Aerospace manufacturing processes in the EU are regulated by the European Union Aviation Safety Agency (EASA) and must conform to the:

- Implementing Rules for the Airworthiness and Environmental Certification of aircraft and related products[87] and
- Commission Regulation[88] on the continuing airworthiness of aircraft and aeronautical products, parts and appliances, and on the approval of organisation and personnel involved in these tasks.

Aircraft typically have design specifications that are frozen for many decades (the manufacturing lifespan of the aircraft model) **and that must go through strict protocols to be amended**. These changes must be certified and approved by OEMs, design owners, and by governing aerospace agencies. This is due to aircraft flying all over the globe and operating in different jurisdictions in which they must be maintained, manufactured, and assembled to common approved standards across countries. Several grades of Vespel® must meet ASTM D6456-10[89] and SAE Aerospace Material Specifications (AMS) 3644G[90] standards. These standards are specific to polyimide parts. In addition, there are many customer and industry standards and specifications relevant for different applications or materials used within an aircraft, all of which contribute to the airworthiness of an aircraft. Both for Vespel® parts and shapes as well as Kalrez® perfluoroelastomer parts, Internal Traffic in Arms Regulations (ITAR) limit how much information may be shared in public forums.

[87] (EU) No 748/2012. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1473415871666&uri=CELEX%3A32012R0748 (Accessed in June 2023).

[88] Commission Regulation (EU) No 593/2012 of 5 July 2012 amending Regulation (EC) No 2042/2003. Available at: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32012R0593 (Accessed in June 2023).

[89] Standard specification for finished parts made from polyimide resins. Available at: https://www.astm.org/d6456-10r18.html (Accessed in June 2023).

[90] SAE International, 2023. Plastic: Polyimide for moulded rod, bar, and tube, plaque, and formed parts. Available at: https://www.sae.org/standards/content/ams3644g/ (Accessed in June 2023).

All aerospace components, including wear strips and 6FTA/6FDA resins, need to meet both internal and external expectations on suitability while complying with all aforementioned standards.

3.3.5. Military and defence and their use of Vespel® parts and shapes and Kalrez® perfluoroelastomer parts

Military and defence applications include air, space, land, and marine technologies. These include but are not limited to aircraft, tanks, submarines, naval ships, and amphibious and land vehicles. The applications are confidential but key requirements include strength, coefficient of friction, electrical resistivity, chemical resistivity, dimensional stability, thermal stability.

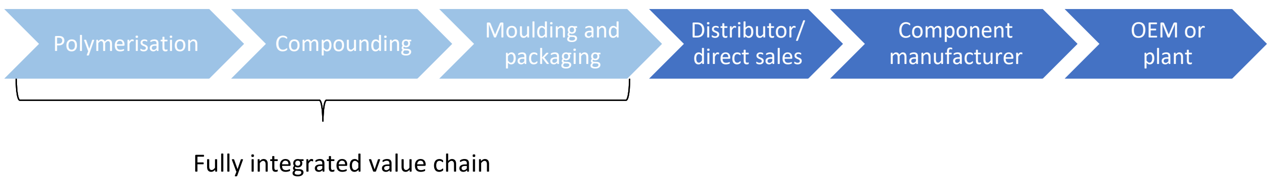
3.4. Overview of the supply chains of Vespel® parts and shapes and Kalrez® perfluoroelastomer parts

The supply chain associated with Vespel® parts and shapes and Kalrez® perfluoroelastomer parts comprises several key participants. **DuPont plays multiple roles in the supply chain as a polymer producer (FFKM only), formulator, article manufacturer, and supplier**. Professional machine shops are involved in the production process for some products. Distributors play a role in the distribution and logistics of these Vespel® parts and shapes and Kalrez® perfluoroelastomer parts. Original equipment manufacturers (OEMs) incorporate Vespel® parts and shapes and Kalrez® perfluoroelastomer parts into their components.

DuPont supply chain

The figure below highlights the steps in the typical supply chain for Kalrez® perfluoroelastomer parts and the steps performed by DuPont. This vertical integration across the supply chain enables complete product control, traceability, sustainability, and structural cost advantages. It permits DuPont to embrace new methods, innovation, and R&D to advance products and solutions and to facilitate its commitment to sustainable and ethical sourcing of raw materials in the manufacturing of Kalrez® perfluoroelastomer parts for highly demanding industrial operating environments. The typical supply chain for DuPont is as follows:

Figure 17: Typical Kalrez® perfluoroelastomer parts supply chain.



Source: Based on Dupont's internal data.[91]

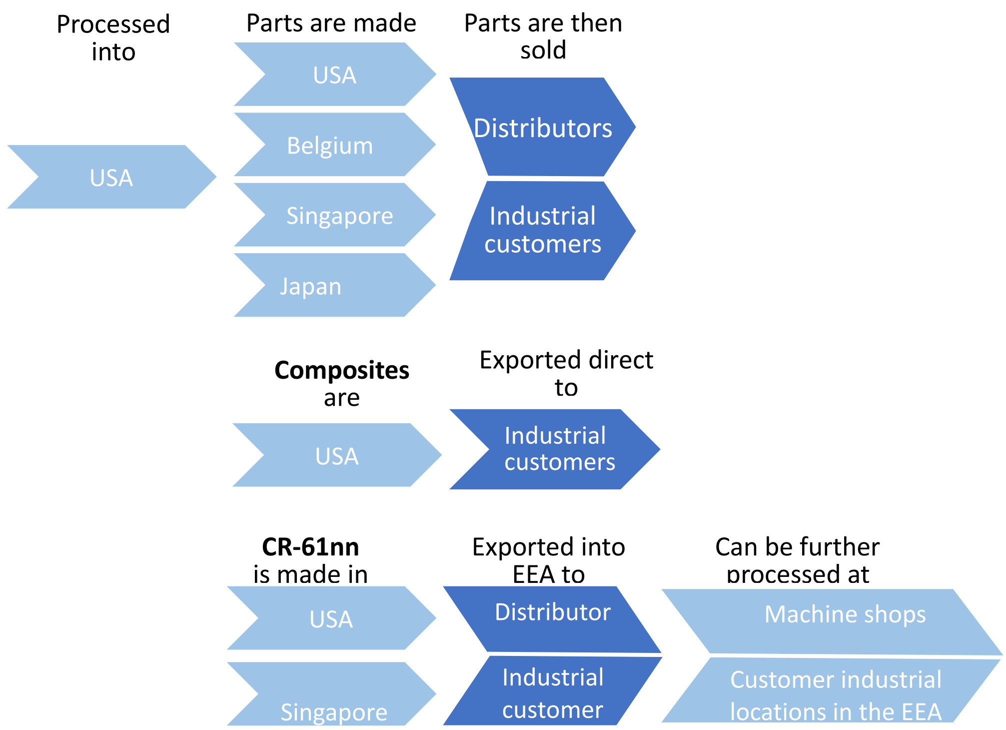
- **Raw materials (including PFAS) are sourced from the EU and from around the world.** DuPont is committed to sourcing these materials from ethical and responsible suppliers and has developed a supplier code of conduct to ensure that the suppliers meet DuPont's standards.

[91] DuPont, 2023. Kalrez perfluoroelastomer parts and elastomers basics – value chain comparison

- **Kalrez® perfluoroelastomer parts: The raw materials are then processed** into active materials that are used in the perfluoroelastomer parts manufacturing process. The manufacturing of Kalrez® perfluoroelastomer parts takes place outside the EU. **Kalrez® parts are then sold to the final customers via trade channels** (i.e., distributors and/or retailers). **These distributors and retailers subsequently distribute the finished parts to component manufacturers across the EEA, who then ultimately sell them to OEMs or plants**. DuPont's customer base typically consists of distributors and OEMs who rely on DuPont's products and services. In the EEA, customers (channel partners or OEM) import Kalrez® materials.
    - In contrast to other FKM or general FFKM seal supply chains, **DuPont's Kalrez® perfluoroelastomer parts supply chains are, as noted above, fully integrated, including the polymerisation, compounding, moulding, and packaging stages**. There is also a high-performance network of distribution partners.

- **Vespel® parts and shapes:** The raw materials for the S polyimide product line are processed into resin in the USA. Parts are then made from that resin in USA, Mechelen (Belgium), Singapore or Japan. Parts are sold either via distributors or direct to industrial customers who can use it as is or further machine it. DuPont's Vespel® composites are made in the USA and exported direct to industrial/transportation/aerospace customers. Further machining can be done at customer industrial locations within the EEA. CR-61nn is made in the USA and Singapore and is exported into EEA to a distributor or industrial customer from one of those sites. It can be further processed at machine shops or customer industrial locations in the EEA.

Figure 18: Typical Vespel® raw materials for the S polyimide product line.



Source: DuPont, 2023

4. ANALYSIS OF ALTERNATIVES

4.1. Aim, scope, and methodology

This section provides a closer look at the **use, function, and requirements** of PFAS in Kalrez® perfluoroelastomer parts and Vespel® parts and shapes that are used in highly demanding industrial operating environments. It outlines the available alternatives and the technical obstacles that prevent substitution, before exploring the challenges related to the development process of new substances. The analysis of alternatives concludes that **there are no suitable alternatives** for these PFAS.

4.2. Kalrez® perfluoroelastomer parts

This section will provide an overview of the key function and technical performance that the current selection of PFAS offers and what specific properties are required by the demanding industrial operating environments. Moreover, this section will create an overview of the current identified known potential alternatives to PFAS and why they are not a suitable alternative.

4.2.1. Function and technical performance of Kalrez® perfluoroelastomer parts and technical criteria for evaluating alternatives

Fluoropolymers used in Kalrez® (FFKM) perfluoroelastomer parts, include FFKM, FKM, PFA, and PTFE micropowder, are used in elastomeric sealing elements that are an integral, indispensable part of seals for exploration, production and refining processes in the oil and gas, chemical processing including pharmaceutical manufacturing, aerospace, and semiconductor manufacturing. These industries require seals that can withstand harsh environmental conditions, including extreme temperatures and high pressures as well as resistance to a large set of chemicals. **The versatility of Kalrez® perfluoroelastomer parts enables tailored designs that precisely meet specific sealing requirements, ensuring optimal performance and reliability.**

In complex systems and equipment like those found in semiconductor manufacturing, oil and gas, aerospace, and chemical processing, routine inspection by disassembling the entire equipment is impractical and challenging, and it also always involves managing these processes well in order to avoid dangers to workers as well as to the environment. **Therefore, it becomes vital for the sealing components to exhibit prolonged operational durability without the risk of failure.** Kalrez® perfluoroelastomer parts are purposefully engineered for high-temperature scenarios in harsh environments, often serving as the only viable solution for safeguarding critical components that, if compromised, could result in catastrophic failures.

It is crucial to recognize the potential consequences of substituting Kalrez® perfluoroelastomer parts with inferior sealing materials. Such a substitution could lead to sudden failures, directly impacting the safety of employees working in these industrial operating environments. Moreover, it could jeopardize the safety of the environment as well as society as a whole in the event of a major catastrophe. **Therefore, the performance and reliability of Kalrez®** perfluoroelastomer parts **play a crucial role in ensuring the safety of individuals and the robustness of the overall industrial infrastructure.**

Kalrez® perfluoroelastomer parts are engineered to provide more stability, more resistance, and more effective sealing. Aside from their cleanliness and purity, Kalrez® parts are engineered to be one of the most inert polymer structures available, standing up to more than 1,800 different chemicals while offering high-temperature stability.

Perfluoroelastomer materials offer:

- Higher temperature capability versus other elastomers
- Very broad chemical compatibility versus limited capabilities by other elastomers
- Low compression set, resulting in improved seal life.

Aerospace Industry

Perfluoroelastomer (FFKM) sealing elements stand up against jet fuel, engine lubrication oils, hydraulic fluids, and rocket propellants and oxidizers—all at extreme temperatures. The long-term, proven performance of perfluoroelastomers can mean less frequent seal changes, repairs, and inspections which decreases worker exposure to hazardous materials, and increases process and equipment uptime for greater productivity and yield. As an example, the increase in gas turbine temperature has improved engine efficiency by 40% over the years resulting in lower emissions. There are no alternatives to fluoropolymers that offer the combined properties of maintaining seal integrity, long seal life, broad chemical resistance, and high temperature stability up to 327 °C.

Semiconductor Manufacturing Industry

Contamination Considerations - Reducing contamination from particles, metallic contaminants and outgassing caused by seal deterioration is the major goal of semiconductor fabricators. Perfluoroelastomers (FFKMs) are used in deposition processes due to their extraordinary chemical resistance and thermal stability. Despite these qualities, FFKM performance can vary depending upon their chemical composition. Specially formulated products, such as DuPont™ Kalrez® 9100, are designed to help reduce the potential for contamination while maintaining sealing functionality in aggressive plasma environments.

Plasma Resistance

Plasma is a powerful tool for etching, cleaning, deposition, etc. Fluorine-containing plasmas, e.g., NF_3 and CF_4, are used for deposition process chamber cleaning due to their high reactivity towards materials to be removed. Since all materials are consumed in plasma, seals need to withstand plasma attack, i.e., exhibit low weight loss (erosion) and leave minimal particles behind after being etched. Plasma attack can be chemical (seal exposed to radicals), physical (seal subjected to ion bombardment) or both. In most seal locations on wafer processing equipment, the plasma attack mechanism is mainly chemical. FFKMs exhibit better resistance to such environments versus other elastomeric materials.

Chemical Process Industry

Kalrez® Spectrum™ 6375 is a carbon black-filled product for general use in O-rings, seals, diaphragms and other parts specifically for the chemical process industry. This product has excellent broad chemical resistance, good mechanical properties, and outstanding hot-air aging properties. It is designed to give outstanding performance to the widest possible range of chemicals and temperatures. Mixed streams, once a problem for many chemical processors, can now be handled.

Furthermore, the curing system also allows for a maximum service temperature of 275°C (525°F) which translates to increased chemical resistance over all temperature ranges, especially if high temperature process excursions occur. This combination of chemical and thermal resistance provides advantages for chemical processors. Kalrez® Spectrum™ 6375 is well suited for use in mixed process streams because of its excellent resistance to acids, bases, and amines. It is also recommended for use in hot water, steam, pure ethylene oxide, and propylene oxide.

Oil and Gas Industry

Ball valves are primarily used for shut-off applications in the energy industry and must function in a wide range of chemical environments, both gas and liquid, where significant performance differences are often observed between various types of sealing materials. Kalrez® 0090 O-rings are TOTAL and NORSOK[92, 93] compliant with exceptional chemical resistance and Rapid Gas Decompression performance making them an excellent choice for refinery ball valve applications. Thanks to the exceptional chemical resistance and outstanding RGD performance, these o-rings exhibit very little or no seal degradation. They reduced additional maintenance and associated shutdowns while increasing reliability and safety.

According to DuPont's case study on natural gas sampling and delivery, the transportation of natural gas through pipelines poses challenges due to the accumulation of contaminants, such as moisture, sulfur, and chemicals during the journey. To ensure the purity and energy content of the gas, samples are taken at various points in the pipeline using the GENIE® Probe Regulator™ (GPR™) developed by A+ Corporation. The GPR™ utilizes Kalrez® Spectrum™ 6375 O-rings to provide a reliable and tight seal. These O-rings are chemically inert and capable of withstanding the harsh chemical environment present in the pipeline. The foot valve of the GPR™, where the O-ring is located, controls the entry of gas into the probe and prevents liquid contaminants from entering the sampling system. The Kalrez® O-rings have demonstrated superior performance and compatibility, expanding the applications of the GPR™ beyond natural gas pipeline usage. Kalrez® Spectrum™ perfluoroelastomer parts are designed to resist aggressive chemicals commonly encountered in natural gas and hydrocarbon processes. These parts offer excellent chemical resistance and sealing properties, making them suitable for demanding environments.

A summarizing overview of the specific functionality and properties of Kalrez® perfluoroelastomer parts, tailored to high demanding industrial operating environments, is presented in Table 3 below.

[92] Kalrez® 0090 perfluoroelastomer parts shows the highest TOTAL GS EP PVV 142 (Rev.5) certification rating and is therefore TOTAL qualified. In the test, the material was tested in its resistance to rapid gas decompression or explosion decompression concerning O-rings used in industrial valve industry. Source: https://o-ring.info/catalog/datasheets/kalrezr-0090/kalrez-0090.pdf.

[93] NORSOK is a series of standards developed by the Norwegian petroleum industry for oil and gas companies. Their main objectives are to ensure safety, enhance value, and promote cost-effectiveness in petroleum industry developments and operations. These standards are designed to replace individual oil company specifications and also serve as reference points in governmental regulations.

Table 3: Functionality provided by Kalrez® perfluoroelastomer parts

Functionality provided by Kalrez® (FFKM)	Description
Chemical resistance and broad chemical compatibility	Kalrez® perfluoroelastomer parts are engineered to be one of the most inert polymer structures available, **withstanding exposure to more than 1,800 different chemicals**. The ability to withstand exposure to such a wide range of chemicals is of utmost importance for seals employed in demanding industrial environments where specific harsh oils and chemicals are frequently utilized. Moreover, they offer universal resistance to various types of chemicals, which possess different chemical compositions and can potentially interact differently with alternative sealing materials. In applications where seals are required to be in constant contact with chemical fluids throughout their service lifetime, it is crucial for the seals to exhibit strong chemical resistance without experiencing significant changes in their physical properties over extended periods of time. Kalrez® excels in this regard, demonstrating resistance to highly challenging materials such as e.g., oils, amines, brines, hydrogen sulfide, pure ethylene oxide, propylene oxide, jet fuel, engine lubrication oils, hydraulic fluids, rocket propellants, and oxidizers.
Highest temperature resistance and thermal stability	**In industrial operating environments, temperature variations from -15 °C to 300 °C are common**. Therefore, it is crucial for seals to exhibit high resistance to these temperatures over extended periods as a regular service temperature (i.e., not only as peak service temperature). It is key for a seal to be able to maintain the sealing integrity when exposed to temperature and/or pressure cycling. The excellent thermal stability of perfluoroelastomer allow to keep excellent elastic recovery. **Depending on the specific grade employed, Kalrez® perfluoroelastomer parts can offer temperature resistance of up to 327 °C.**
Durability	The **extreme durability and capability of maintaining their form** under extreme environments is a key property that make fluoropolymers and perfluoroelastomers so important in industrial operating environments. **This point has also been reflected in the Annex XV report by the dossier submitters**.[94]
Mechanical strength	The **mechanical strength** under extreme environments is a key property that make fluoropolymers and perfluoroelastomers so important in industrial operating environments. **This point has also been reflected in the Annex XV report by the dossier submitters.**[95]
Corrosion resistance	It is of high importance that the seal is does **not damage other equipment** (hardware) in which the seal is housed and being compliant with the counter surface to maximize sealing efficiency to prevent seal leakage that may have severe consequences.
Plasma resistance	In semiconductor manufacturing, seals must withstand plasma attacks without experiencing weight loss or leaving behind significant particles after etching. **Plasma, a powerful tool for processes like etching, cleaning, and deposition, utilizes reactive plasmas containing fluorine** (e.g., NF_3 and CF_4) for **chamber cleaning**. Seals must endure plasma attacks by exhibiting minimal erosion (low weight loss) and particle generation. The attack can be chemical (seal exposed to radicals), physical (seal bombarded by ions), or a combination of both. **FFKMs demonstrate superior resistance to such environments compared to other elastomeric materials, making them most suitable for e.g., seal applications in wafer processing equipment.**

[94] Annex A to the restriction report, version 2 (22 March 2023), p. 148.

[95] Annex A to the restriction report, version 2 (22 March 2023), p. 148.

Low outgassing properties	Semiconductor fabricators aim to **minimize contamination** caused by seal deterioration, including particles, metallic contaminants, and outgassing.
Rapid gas decompression resistance	Kalrez® perfluoroelastomer parts **exhibit no or little seal degradation** when being formulated to have resistance to RGD Rapid Gas Decompression. This is highly important in the energy and oil and gas industry.

Source: Downstream user consultation performed by RPA (2023)[96]

In summary, the technical criteria for evaluating alternatives to Kalrez® perfluoroelastomer parts in terms of their suitability for the given applications in the transportation (including aerospace), petroleum and mining, chemical processing, semiconductor manufacturing, military and defence, and energy sectors include:

- **Chemical Resistance**: The alternative material should exhibit minimal swelling or degradation when exposed to aggressive reagents. It should maintain its integrity and functionality in the presence of various chemicals.
- **Thermal Stability**: The material should have the ability to withstand high service temperatures exceeding 250°C without significant degradation or loss of performance.
- **Outgassing**: In the context of semiconductor manufacturing, the alternative should have low outgassing properties. This means it should release minimal contaminants or impurities that could interfere with the semiconductor fabrication process.
- **Plasma Resistance**: Given the requirements of semiconductor manufacturing, the material should possess resistance to plasma. It should be able to withstand the effects of plasma without degradation or damage to its properties.
- **Rapid Gas Decompression**: For applications in the oil and gas industry, particularly in relation to safety standards like NORSOKF M-710, the alternative material should be capable of withstanding rapid gas decompression. This ensures the material remains intact and prevents failures or safety hazards in such environments.
- **Further criteria** that are of relevance in certain applications are UV resistance, water moisture resistance as well as a low compression set and compression stress relaxation.

All of these criteria should be met over extended time periods to provide a safe extended service life span.

[96] RPA, 2023. Socio-Economic Impact Assessment for the use of PFAS within the Aerospace Supply Chain, report for DuPont Specialty Products USA, LLC, June 2023, Norwich, Norfolk, UK.

FFKM's unique chemistry is characterized by high-temperature resistance and stability resulting from the C-F bonds present in the material. Industries utilize FFKM as a sealing material particularly for high-temperature applications, in many cases combined with the other criteria listed above. **Therefore, any alternative material must demonstrate equal or superior performance and functionality compared to FFKM to be considered**. In order to be considered a technically feasible alternative, the material should show equal or greater performance in both chemical and thermal resistance. The extreme durability and capability of maintaining their form and mechanical strength as well as the corrosion resistance under extreme environments (e.g., found in down hole drilling, chemical processing industry, semiconductor manufacturing) are therefore the key properties that make fluoropolymers and perfluoroelastomers so important in industry. This point has also been reflected in the Annex XV report by the dossier submitters.

Kalrez® perfluoroelastomer parts are used in critical applications such as semiconductor fabrication equipment, oil field equipment, chemical processing industry and airplane engines. These devices require an elastomeric seal that is able to withstand the environmental conditions of the application, including, media, temperature, pressure, speed, and abrasion, while also not damaging other equipment (hardware) in which the seal is housed and being compliant with the counter surface to maximize sealing efficiency to prevent seal leakage, fugitive emissions or total seal failure. DuPont™ Kalrez® elastomeric seals are used in applications requiring high temperature and/or chemical resistance and are often the only solution for critical components that could result in catastrophic failures.

The next section will provide an assessment of alternatives to Kalrez® (FFKM) perfluoroelastomer parts.

4.2.2. Alternatives to FFKM

Alternatives do not exist to FFKM at this time. This section will provide an overview of the potential identified known alternatives to FFKM.

<u>A general overview of potential alternatives to FFKM</u>

Before analysing specific alternatives to FFKM, this section will provide a general overview of the potential materials that may potentially be an alternative to FFKM. From this broad approach, this section will be narrowed down on more specific potential alternatives.

Elastomers for the oil and gas, chemical processing and semiconductors sectors must have chemical resistance to substances such as oil, hot water, brines, amine and H_2S, as well as heat, which – according to the widely accepted ASTM D2000 chart **- only permits NBR, HNBR (in applications until 150 °C), FKM and FFKM** (see Figure 19 below).

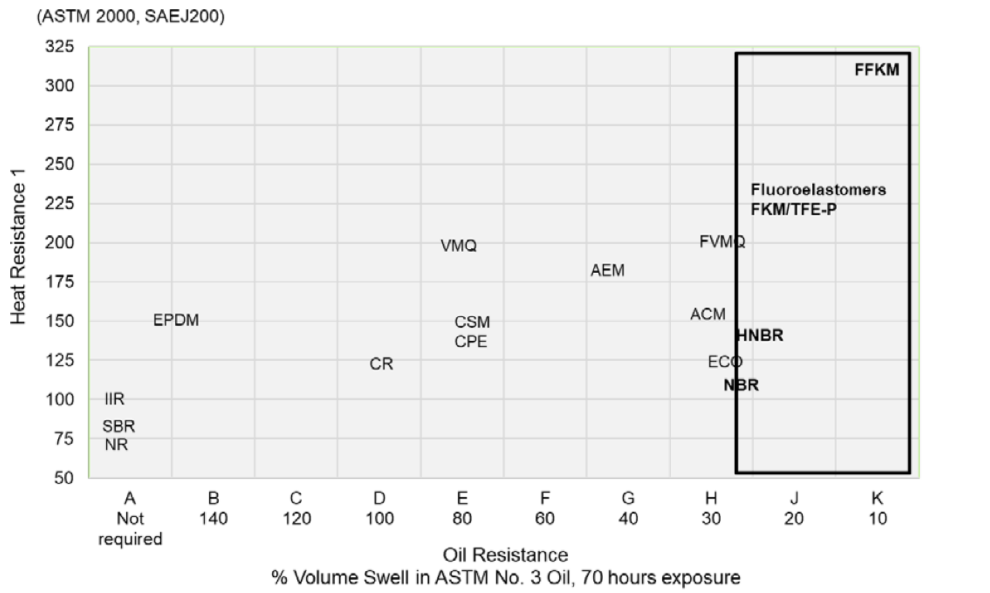
However, as the resistance of FKM to amines (used as corrosion inhibitors)[97] and hydrogen sulfide (H_2S) is limited, there are certain applications in the oil and gas sector above 150 °C that only leave

[97] SAE Technical Paper 2003-01-3029, 2003, https://10.4271/2003-01-3029.

FFKM as a technically possible solution under extreme conditions. Moreover, according to AMS7257[98], the maximum volume swell for oil seals is 0 to +5%. This criterion can effectively eliminate all other sealing materials shown in Figure 19 including FKM.

In chemical processing industries, equipment is typically equipped with EPDM, NBR, and HNBR elastomers. Only when these non-PFAS elastomers are lacking the required temperature and/or chemical resistance, are elastomers such as FKM or FFKM used. FFKM is used when other solutions do not provide the required performance in the application.
In semiconductor manufacturing, FFKM is used due to the requirements for combination of temperature resistance, plasma resistance, and low outgassing. Silicone rubber (VMQ) is described later in this document.

Figure 19: Oil and heat resistance comparisons to various polymer materials according to standards ASTM2000 and SAE J200.



[1] Maximum temps at which vulcanizates can be aged for 70 hours with changes in tensile strength ≤ ±30%, elongation ≤ -50% and hardness ≤ ±15 points

Source: Based on DuPont's internal data, 2022. see next section for further information on the materials

98 SAE, 2014. Perfluorocarbon (FFKM) Engine oil, fuel, and hydraulic fluid resistant 70 to 80 hardness for high temperature seals in engine oil systems, fuel systems, and hydraulic systems. Available at: https://www.sae.org/standards/content/ams7257e/ (Accessed in July 2023).

It should be noted that **FFKM is only used where absolutely necessary and the conditions do not allow any other material**. This is because perfluoroelastomers are substantially (factor 10x vs closest elastomer) more expensive than alternative materials; therefore, they are only purchased for applications where no other elastomeric material can withstand the chemical and temperature environment. Figure 20 below also highlights the price bonds for high performance elastomers, showing the relative high price in euro/kg of FFKM. Substitution of FFKM therefore naturally takes place due to economic considerations alone where technically possible. This point has specifically been acknowledged by the dossier submitters.[99] **Given the relative high cost of FFKM, in applications where FFKM are used, the next-best alternative has already been tested against the performance requirements for temperature resistance, plasma chemical resistance, and chemical resistance limited oil swell and deemed inappropriate for the specific application.**

Figure 20: Price bonds for high performance elastomers.

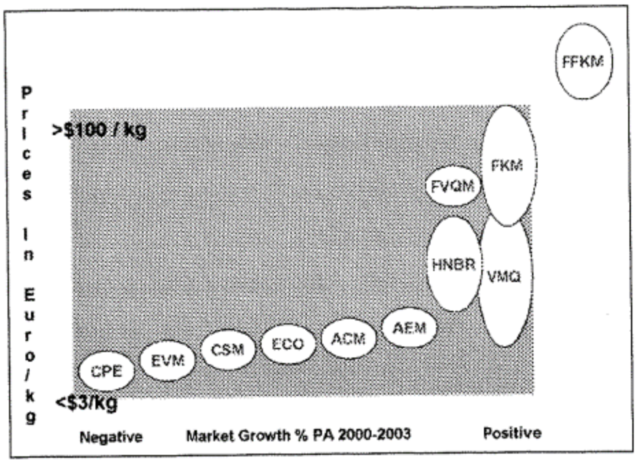


Chart 10
Price bands for high performance elastomers
(Source: Compilation of Industry Data)

Source: This is a copy paste of Chart 10 in Beswick (2000)[100]

To illustrate how chemical resistance can vary, Table 4 below presents an overview of all chemical substances and elastomer resistance to the particular chemical.[101] On all aspects, FFKM outperforms alternatives, demonstrating the limitations of potential alternatives.

[99] Annex E to the restriction report, version 2 (22 March 2023), p. 498-499.

[100] Beswick, R., 2000. An overview of the high-performance elastomer industry. High performance elastomers 2000 (Berlin, 10-11 October 2000).

[101] DuPont, 2023. Kalrez® perfluoroelastomer parts chemical resistance. Available at: https://www.dupont.co.uk/knowledge/chemical-resistance-kalrez-parts.html (Accessed in July 2023).

Table 4: Comparison of chemical resistance ratings of various O-ring materials to different chemicals.

	Perfluoro-elastomer (FFKM)	Fluoroelastomer (FKM)	Fluorosilicone (FVMQ)	Neoprene (CR)	Buna-N Nitrile (NBR)	Ethylene Propylene (EPDM)
Hardness durometer	65 to 95	55 to 95	40 to 80	30 to 95	40 to 95	40 to 90
Tensile strength	2,000	2,500	800	3,000	2,500	2,500
Wear resistance	**	**	Not recommended	**	**	**
Fireproof hydraulic fluids	****	*	***	*	Not recommended	***
Lubricating oils	****	****	****	**	**	Not recommended
Fuel oils	****	****	****	*	**	Not recommended
Hydraulic oils	****	****	****	**	****	Not recommended
Petrol (normal)	****	****	****	*	***	Not recommended
Petrol (high-octane)	****	****	****	Not recommended	**	Not recommended
Kerosene	****	****	****	*	***	Not recommended
Aromatic hydrocarbons	****	****	***	Not recommended	*	Not recommended
Alphatic hydrocarbons	****	****	****	**	***	Not recommended
Alcohols	****	****	****	****	***	****
Ketones	****	Not recommended	Not recommended	Not recommended	Not recommended	**
Concentrated acids	****	***	**	Not recommended	Not recommended	*
Diluted acids	****	****	**	**	*	**
Alkalis	****	Not recommended	*	**	*	***
Flame resistant	Yes	Yes	No	Yes	No	No

Source: DuPont and industry sources.[102]
Note: 4 stars = Excellent, 3 stars = Very good, 2 stars = Good, 1 star = Reasonable.

[102] DuPont, 2023. Kalrez® perfluoroelastomer parts chemical resistance. Available at: https://www.dupont.co.uk/knowledge/chemical-resistance-kalrez-parts.html (Accessed in July 2023).

To illustrate the difference in performance regarding temperature resistance even more elaborately, Table 5 below offers a comparison of temperature resistance ratings of various O-ring materials. Based on the temperature resistance required to be successful in high demanding industrial operating environments, it can be assumed that all these alternatives would be inadequate in terms of their technical performance.

Table 5: Comparison of temperature resistance ratings of various O-ring materials

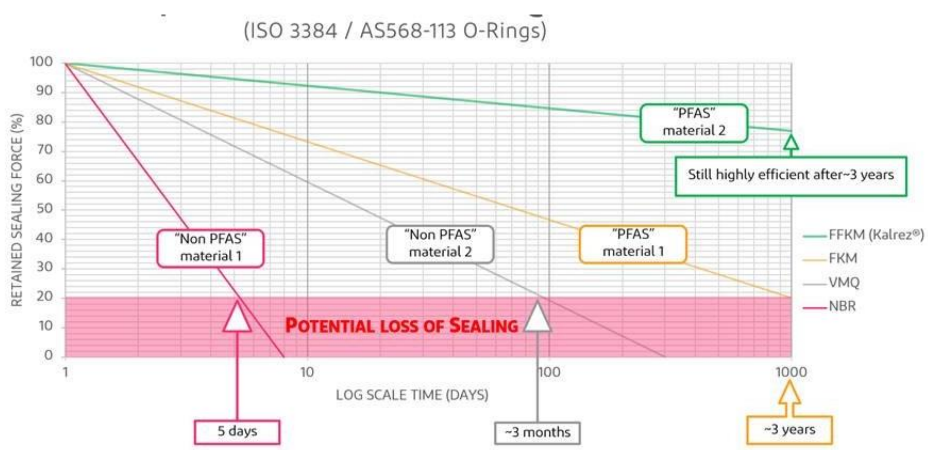
Material	Temperature resistance
Kalrez® (FFKM)	Up to 327 °C
Nitrile (NBR/HNBR)	Up to 120 °C/150 °C
Ethylene propylene diene terpolymer (EPDM)	Up to 149 °C
Silicone (VMQ)	Up to 230 °C
Fluorosilicone (FVMQ)	Up to 200 °C
Fluoroelastomer (FKM)	Up to 230 °C
Polysulfide (T)	Up to 120 °C

Source: DuPont consultation

While PFAS alternatives such as other FFKM grades or FKM may in certain cases offer similar heat and chemical resistance, they **lack the same level of resilience, resulting in significantly shorter seal life**. This poses risks and health hazards due to equipment failure. Although alternatives generally come at lower costs, it is important to consider the heightened health hazards and risks associated with equipment failures. These alternatives exhibit significantly lower temperature and chemical resistance, leading to increased environmental hazards and risks due to fugitive emissions.

Figure 21 below provides a specific example for O-Rings. Non-PFAS alternatives significantly reduce the sealing potential of O-rings. Switching to alternatives therefore increases the wear and tear of this application. PFAS materials, notably FFKM (, are highly efficient for a longer duration. **A decrease in sealing potential results in a lowered technical performance and may consequentially lead to equipment failures.**

Figure 21: Compression stress relaxion test in -150 °C air.



Source: Based on DuPont's internal data, 2023

Structural failure in high-demanding applications can lead to potentially catastrophic consequences for both the environment and human health. This is why these industries are committed to always using high performing materials that avoid leakages to the best possible extent. It is therefore important to make sure that the use of alternative materials with lower levels of functional performance are not detrimental to the safety of the workers operating facilities, as well as to the surrounding environment.

Please note that FKM and FVMQ are considered PFAS and are therefore within the scope of the proposed restriction, making them unsuitable alternatives, as these too would be restricted. Therefore, from here on, the analysis of alternatives will only focus on non-PFAS materials that are therefore not in scope of the restriction.

<u>Hydrogenated Nitrile Butadiene Rubber (HNBR)</u>

HNBR is a synthetic elastomer that is created by hydrogenating nitrile butadiene rubber (NBR). The material is versatile and used in many industries for its resistance to heat, chemicals, oil, and abrasion, while maintaining its strength. As illustrated in Figure 21, selection of a non-PFAS material requires a concession in performance. Out of all potential non-PFAS alternatives, HNBR shows a similar level of oil resistance compared to FFKM. Nevertheless, it still shows approximately 35% volume swell after exposure to oil for 70 hours. The maximum percentage of volume swell acceptable for oil seals is 5%. **Therefore, even though HNBR outperforms other non-PFAS materials in oil resistance, it would still not be able to deliver the appropriate sealing function that is required in high demanding industrial operating environments.**

Additionally, where FFKM offers temperature resistance up to 327 °C, the temperature resistance of HNBR is significantly lower, at 150 °C. HNBR is not technically feasible to be used in operating at temperatures above 150 °C **and does not have the full chemical resistance performance of FFKM.** The system will have to be redesigned if the thermal exposure is greater than 150 °C resulting in much more significant cost or complete work stoppage of up to 150°C.[103] Moreover, in industrial operating environments under 150°C, HNBR seals would deteriorate or at an accelerated rate, resulting in a lifespan significantly shorter than 1,000 hours. **Therefore, more frequent maintenance, repair, and operational activities would be necessary.** This lack of technical performance and replacement is both impractical and unsafe and not desirable in harsh operating environments.

HNBR is a mid-performance material compared to FFKM and is available at a lower cost. Where possible, HNBR already being used as O-rings and seals in some less technically demanding applications; therefore, it is assumed that these materials will be available in sufficient supply to replace FFKM seals. However, the use of an inferior material in terms of lower temperature and oil resistance would require the redesign of parts and systems to allow a new material to ensure compatibility with the surrounding assembly system. This would present a large investment in time and cost. In addition, **the volume swell and lower temperature resistance would require system redesign, imposing significant costs on the original equipment manufacturers. Even at slightly**

[103] RadoRubber, 2023. Hydrogenated NBR elastomer. Available at: https://www.rado-rubber.com/specialities/hnbr/ (Accessed in July 2023).

elevated temperatures or with non-oil solvents, volume swell of O-rings requires them to be replaced even after several days of use. This lack of technical performance and replacement is both impractical and unsafe and not desirable in harsh operating environments.

Comparing all the aspects of temperature resistance, chemical resistance, and economic feasibility, an overview of the conclusion of the assessment of HNBR is summarised in Table 6 below. It may be concluded that whereas HNBR may be a feasible alternative in applications with less demanding temperature and oil resistance requirements, it does not reach the performance of FFKM that is required by demanding industrial operating environments.

Table 6: Summary of technical and economic feasibility of using HNBR as an alternative

	HNBR
Oil resistance	Compared to FFKM, HNBR shows a similar level of oil resistance. Nevertheless, it shows approximately 35% volume swell after exposure to oil for 70 hours, well exceeding the maximum percentage of volume swell acceptable for oil seals.
Temperature resistance	FFKM offers a temperature resistance up to 327 °C, whereas the temperature resistance of fully hydrogenated HNBR is 150 °C (maintaining its sealing capabilities for a max. of 1000 hours), which would result in rapid failure in demanding industrial operating environments.
Costs to implement	As HNBR is already being used as O-rings and seals in some less technically demanding applications, it is assumed that these materials will be available in sufficient supply to replace FFKM seals. Nevertheless, as seals should be replaced at more regular intervals, this may result in a loss of efficiency and overall additional costs to original equipment manufacturers. Alternatively, the system will have to be redesigned if the thermal exposure is greater than 150 °C resulting in much more significant cost or necessity to replace (if possible).

Source: RPA, 2023[104]

Silicone (VMQ)

Silicone rubber (VMQ) is a type of synthetic elastomer. The term silicone often refers to a group of polymers. These silicones possess rubber-like characteristics, exhibit resistance to heat, are non-reactive, and resistant to harsh conditions. Some grades of silicone rubber are already used in seals in demanding environments. VMQ is the most thermally resistant non-PFAS substance, as shown in Figure 19.

VMQ can withstand temperatures up to 200 °C, which is lower than the temperature resistance of FFKM, which is capable of withstanding up to 327 °C. However, VMQ has a tendency to swell when exposed to oil, resulting in an 80% increase in volume after 70 hours of oil exposure. Up to 150 °C, VMQ maintains its physical properties without any loss in quality. **Beyond 200°C, its performance deteriorates, limiting its operational lifespan to approximately 10,000 hours.**[105] Nevertheless, silicone rubbers remain elastic even at temperatures as low as -70 °C. Therefore, while VMQ may not

[104] RPA, 2023. Socio-Economic Impact Assessment for the use of PFAS within the Aerospace Supply Chain, report for DuPont Specialty Products USA, LLC, June 2023, Norwich, Norfolk, UK.

[105] Shin-Etsu Silicone, 2020. Characteristic properties of silicone rubber compounds. Available at: https://www.shinetsusilicone-global.com/catalog/pdf/rubber_e.pdf (Accessed in July 2023).

be suitable for high-temperature industrial environments, it could potentially be used in very cold processes and geographies **Conversely, in high-temperature industrial environments exceeding 200°C, VMQ seals would deteriorate rapidly or even completely, necessitating more frequent maintenance, repairs, and operational activities. Both the practical and safety aspect of this is highly fundamental.**

Silicone rubbers demonstrate poor performance in comparison to FFKM when exposed to oils, petrol, and similar solvents. As depicted in Figure 19 in particular, they are highly prone to swelling, exceeding the acceptable volume swell limit of 5% specified in AMS7257. This swelling would render a VMQ sealing system ineffective in containing essential oils and fluids required for demanding industrial operations, potentially leading to severe consequences if the system were to leak. **VMQ does not meet the essential technical performance requirement of resistance to oil.**

Given that silicone rubbers are already being used as O-rings and seals in other applications, it is assumed that these materials will be available in sufficient quantities to replace FFKM. The use of an inferior material with lower temperature and oil resistance would necessitate redesigning components and systems to ensure compatibility. This would require significant investments in terms of time and cost, which may not be feasible for downstream users. **Furthermore, the substantial 70% increase in volume swell and decrease in performance in case of exposure to temperatures of 200°C. Importantly, beyond 200°C, VMQ would lead to more frequent replacement of the seals and complete deterioration of the seal. This is highly undesirable from a safety, practical, and economic perspective and would necessitate system redesign by the equipment manufacturers.**

Comparing all the aspects of temperature resistance, chemical resistance, and economic feasibility, an overview of the conclusion of the assessment of VMQ is summarised in Table 7 below. All in all, it may be concluded that whereas VMQ may be a feasible alternative in applications with less demanding temperature and oil resistance requirements, it does not reach the excellent performance of FFKM (Kalrez®) that is required by demanding industrial operating environments.

Table 7: Summary of technical and economic feasibility of using VMQ as an alternative

	VMQ
Oil resistance	VMQ's shows poor resistance to oil and large swell increase. This swelling would make a VMQ sealing system incapable of effectively and safely containing the essential oils and fluids required for operations in demanding industrial environments.
Temperature resistance	VMQ is often more suitable for low temperature applications or up to 200 °C, which is not high enough to replace FFKM with its temperature resistance up to 327 °C.
Costs to implement	Since silicone is already commercially feasible and being used in various applications, and to some extent in aerospace, its economic feasibility is similar to FFKM. Nevertheless, as seals should be replaced at more regular intervals, this may result in a loss of efficiency and overall additional costs to original equipment manufacturers. Or, the system will have to be redesigned if the thermal exposure is greater than 200 °C resulting in much more significant cost or complete work stoppage

Source: RPA, 2023[106]

4.2.3. Typical innovation process and timing for Kalrez® perfluoroelastomer parts

<u>For the past 50 years, there have been no new inventions or successful developments to replace FFKM.</u>

It is important to consider the tolerance for emissions of toxic or dangerous materials into the environment. **This adds an additional challenge in finding alternatives that not only meet performance requirements but also have lower environmental impact**. A case study in a steam generator operating at 140°C (within EPDM range of temperature) demonstrated that replacing EPDM by FFKM led to a 5x improvement of the seal lifetime.

Another aspect is the use of polymerization aids for Kalrez® perfluoroelastomer parts. If a suitable alternative for the polymerization aid can even be found, the research and development (R&D) process for finding non-PFAS alternatives to this polymerization aid for Kalrez® perfluoroelastomer parts is expected to take at least 15 years.

As an example of a prior complex R&D process for the development of previous alternative fluorinated surfactants, spanned a period of 10 years and resulted in more than 40 million EUR developments costs. The R&D took 5 to 10 years, followed by internal qualification and subsequent evaluations by customers. The patent and replacement since the year 2000 of cut-off PFOA-based surfactants has led to no suitable hydrocarbon surfactant alternative so far.

In conclusion, there are no suitable alternatives to FFKM at this time. Research is underway for development of a non-fluorinated surfactant.

[106] RPA, 2023. Socio-Economic Impact Assessment for the use of PFAS within the Aerospace Supply Chain, report for DuPont Specialty Products USA, LLC, June 2023, Norwich, Norfolk, UK.

4.3. Vespel® parts and shapes

This section will provide an overview of the key functions and technical performance of Vespel® parts and shapes and what specific properties are required by these demanding industrial operating environments. Moreover, this section will create an overview of the current identified known alternatives and why they are not suitable alternative for these applications.

4.3.1. Function and technical performance of PFAS in Vespel® parts and shapes and technical criteria for evaluating alternatives

Vespel® parts and shapes, including fluoropolymer ingredients like PTFE, PFA, and NR-150 Resin, are used as wear, friction, sealing, and light-weighting solutions in various high-demand industries. DuPont's Vespel® parts and shapes provide a unique combination of the physical properties common among engineered plastics, metals, and ceramics in a single material. These properties include proven performance when used continuously in air up to 300 °C and for short excursions to as high as 550 °C, low wear and friction at high pressures and velocities (lubricated or unlubricated), creep resistance, strength and impact resistance, chemical resistance, and machinability. **These properties make Vespel® crucial for use in challenging industrial applications, which require high stability along with durable, long-lasting properties.**

The primary role of Vespel® components in high demanding industrial operating environments is to reduce the impacts of vibration and wear on critical components. **A slow wear rate can be directly linked to the lifetime of a component, resulting in reduced maintenance, operating costs, and very importantly, improved safety.**

The versatility of Vespel® parts and shapes stems from the availability of different grades, each possessing its own distinctive characteristics achieved through various types and levels of fillers in combination with the PFAS materials used. This range of grades allows Vespel® parts and shapes to be tailored precisely to the specific demands and requirements of high-demanding industrial operating environments. Vespel® parts and shapes can be pre-formed and bonded to a specific geometry and can therefore minimize galling by preventing metal-on-metal components.

An overview of the specific functionality and properties of Vespel® parts and shapes, tailored to high demanding industrial operating environments, is presented in Table 8 below.

Table 8: Functionality provided by Vespel® parts and shapes

Functionality provided by Vespel®	Description
Chemical resistance	**Chemical resistance is a critical property, playing a crucial role in safeguarding materials against degradation when exposed to various processes.** It is particularly important to prevent any damage for example during de-icing or cleaning procedures applied to engines, aircraft wings, and assemblies. In these operations, it is vital that materials do not undergo chemical breakdown. Furthermore, there is a possibility of unintended interactions with fuels, lubrication oils, and greases, making chemical resistance a key requirement for ensuring the integrity of components in these industries.
Electrical resistance	The presence of a non-conductive material in demanding industrial operating environments is crucial to prevent any interference or disruption of electronic components within operating systems, which may arise from the release of particulates during service. Vespel® parts and shapes, with its non-conductive properties, effectively addresses this concern by minimizing the risk of electrical disturbances in these critical systems.
Prevention of galvanic corrosion	In certain applications, Vespel® parts and shapes can also serve as a protective barrier to inhibit galvanic corrosion between dissimilar metals, further enhancing the longevity and reliability of components in challenging operating conditions.
Vibration and wear resistance	There are many **vibrating metal components** in the oil and gas and transportation industries. Having a material in between these metal components not only reduces noise but reduces friction and wear rates, thus also increasing safety.
Thermal resistance	**Vespel® parts have the ability to maintain performance levels when used continuously in air at temperatures >315°C and up to 370°C, and short excursions to as high as 550 °C.** Thermal insulation capabilities in parts provided to the glass industry helps avoid defects caused by cold spots on glass. Vespel® parts and shapes offer insulator sleeves for plasma cutting torches to thermally insulate the plasma cutting torch tip.
Self-lubricating/low coefficient of friction	Oil-based lubricants typically face limitations when exposed to high temperatures, as they tend to burn up or evaporate under such conditions. Oil lubrication systems also perform poorly in dirty environments. **Consequently, it becomes essential to utilize oil-free self-lubricating parts and components that possess a low coefficient of friction in applications involving motion in high temperature environments and/or dirty environments**. The self-lubricating characteristics of PFAS contribute significantly to prolonging the lifespan of products. By eliminating the requirement for oil nipples and reducing friction and wear, PFAS-containing materials reduce weight, simplify engine design, and enhance durability. The properties of low wear and friction are particularly vital as they lead to decreased maintenance needs and reduced power consumption for mechanical components, as well as increased safety through reduced risk of failure.
Shear strength	In systems where relative motion is present, the shear strength and mechanical resistance of parts become crucial factors. **Without adequate strength, the**

	increased pressure and stress exerted on the components can lead to deformation and degradation over time. Therefore, it is imperative to ensure that the parts possess sufficient shear strength and mechanical resistance to withstand these dynamic forces and maintain their structural integrity in the long run.
Non-galling	The material should exhibit minimal friction and abrasion when it comes into contact with other surfaces. **Excessive friction could lead to components getting stuck or debris being dislodged**. Furthermore, the material should provide smooth wear characteristics and not impede sliding motion, irrespective of temperature variations. It should facilitate the transfer of material from one surface to another seamlessly across a wide temperature range.
Non-flammability and the absence of a melting point	**The absence of a melting point** materials is crucial, especially in high-stakes applications like aero engines, oil, gas and mining, as well as the automotive industry, where it plays a critical role in ensuring safety.
Low outgassing	Low outgassing properties are vital to prevent contamination of critical semiconductor manufacturing processes and **minimize defects** as described in chapter 3.2.
Lightweight	**Vespel® parts and components are lightweight**, reducing the overall weight of systems and contributing to energy efficiency and reduced fuel consumption.

Source: Downstream user consultation from RPA, 2023[107]

In summary, the technical criteria for evaluating alternatives to PFAS used in Vespel® parts and shapes in terms of their suitability for the given applications include:

- **Chemical resistance**: The alternative material should not undergo a chemical breakdown when exposed to aggressive reagents. It should maintain its integrity and functionality in the presence of various chemicals.
- **Self-lubricating properties:** The alternative material should have self-lubricating properties, which are highly important to minimize friction and wear between components, reducing the need for additional lubrication and extending the product's lifespan. Low wear/friction characteristics further contribute to reduced maintenance requirements and energy consumption.
- **Lightweighting:** The weight of the alternative material should be of consideration, particularly in industries such as transportation and aerospace where weight reduction is sought to enhance fuel efficiency and overall performance.
- **Low outgassing**: The alternative material should exhibit low outgassing. This is highly essential, particularly in sensitive manufacturing processes such as semiconductor production to prevent contamination and maintain the desired product quality.
- **Thermal insulation capabilities:** The resistance to heat transfer is highly valuable in various applications where temperature differentials need to be minimized or controlled.

[107] RPA, 2023. Socio-Economic Impact Assessment for the use of PFAS within the Aerospace Supply Chain, report for DuPont Specialty Products USA, LLC, June 2023, Norwich, Norfolk, UK.

This property helps prevent issues like cold spots or heat transfer, contributing to the overall performance and reliability of the product.

- **Other performance criteria** include water/moisture resistance, electrical resistance, non-flammability, low coefficient of friction and thermal stability.

It is important that any material replacing the PFAS in Vespel® parts and shapes demonstrates equal or greater functionality in comparison to existing Vespel® formulations. It is of importance to emphasize the link between material performance and maintenance intervals. If there would be a reduction in performance in any of the above areas by using an inferior alternative to the PFAS, this would at least result in an increased activity of maintenance and repair activities. When parts wear faster, this puts them more at risk of catastrophic failure, which creates increased safety risks. The next section will provide an assessment of alternatives to the PFAS that are used in Vespel® products.

The following paragraphs describe in further detail the link between requirements in key sectors and the functional performance provided by Vespel® parts and shapes.

Our assessment here focuses on function and technical performance of PFAS in Vespel® products related to transportation (including aerospace), petroleum and mining, chemical processing, semiconductor manufacturing, military and defence, energy, and industrial manufacturing such as automotive manufacturing, textile, glass handling and industrial welding/plasma/cutting tools. The Vespel® family can be broken down into groups:

- Vespel® ISO Shapes: Available in rods, tubes, and blocks, these parts are formed under isostatic pressure ensuring uniform properties in all directions. These are typically the toughest of all forms. This process does not intentionally use PFAS. US government regulations prevent export of this manufacturing technology.
- Vespel® Plaque Shapes: Available as blocks, disks, and rings. These are hot moulded under pressure. Plaque Shapes: Physical properties are similar to ISO Shapes, but critical properties are anisotropic. Production rates are very low, making this form unsustainable for high volume applications such as the automotive market segment.
- Vespel® Direct Formed Parts: Available as net and near net shapes. This rapid form process is only available in small shapes, but the preform blanks require less machining than ISO or Plaque shapes. PTFE is required as a polymeric processing aid.
- Vespel® S resins are polyimide materials that can be formulated with or without lubricants to produce tough parts and shapes with excellent high temperature properties. These can be further classified into three product forms based on how the resin is processed.
- Vespel® SP-211 and SP-221 Parts and Shapes: Available in Direct Formed, Plaque, and ISO form, these shapes contain a maximum of 10wt% PTFE for superior static coefficient of friction.
- Vespel® CR (Chemical Resistance): Designed to perform in aggressive chemical environments, CR-6100 is a PFA composite. While not as thermally resistant as polyimide composites, it excels under chemically aggressive conditions where most other resins (and even inorganic materials) fall apart.

- Vespel® NR150 and Vespel® PMR-II-50 Based Parts: These high temperature composite resins use 6FTA [4,4'-hexafluoroisopropylidine-bisphthalic acid] as part of the polymer structure. These composites are utilized for their ability to form tough carbon fibre composites that can survive temperatures above which other composite resin matrices fail.
- Wear Strips: Composed of 30-40wt% PTFE fibre, these composite wear strips deliver low friction and wear properties to any bonded surface. They perform well in dirty environments where environmental contaminates would bind to traditional lubricants for form an abrasive sludge. While used primarily in aerospace applications, they also find applications elsewhere, such as e.g., in wind turbine connectors.[108]
- Other Vespel® liner grades can range from 30-80% PTFE dependent on the properties required.

Function and technical performance of Vespel® products in transportation sector

Transportation sector: Mechanical parts such as washers, bushings, and seal rings in the transmission and driveline, brake pad sensor pads, EGR valves in emissions control, and rollers in the clutch. Examples include:

  - Automotive: Light vehicles, military vehicles, off road (construction, mining, farming vehicles such as tractors), and military vehicles such as armoured cars, tanks.
  - Marine: Generally military applications (submarines, naval ships, amphibious vehicles- applications are confidential but key requirements include strength, coefficient of friction, electrical resistivity, chemical resistivity, dimensional stability, thermal stability.
  - Aerospace: Vespel® products in the aerospace transportation sector provide wear and friction reduction, high-temperature resistance, chemical resistance, dimensional stability, and weight savings, contributing to improved performance and reliability in critical components. Thermal stability is of utmost importance, particularly in applications such as aero engines, where it is considered important for safety.

By withstanding high temperatures and harsh operating environments, Vespel® parts and shapes provide new design options for automotive powertrain and driveline components. Fluoropolymers like PTFE are critical ingredients when blended with other engineering plastics and polyimide resins by acting as a processing additive, and as an internal lubricant or physical property modifier for critical non-metallic engineered components, in aerospace and other transportation related uses. Alternatives have been tried for most of these applications but have not provided the performance characteristics required for the critical applications.

Vespel® parts and shapes offer outstanding friction reduction properties. Friction is the major contributing factor in automotive loss of efficiency through the whole powertrain from the engine down to the wheels. These products enable new designs of turbochargers and emission control systems (EGR valves) for new fuel-efficient engines. Low leakage and friction polyimide seal rings reduce energy losses in automatic transmissions. Thrust plugs and bearings made of polyimide resins enable electric motors to be smaller and more energy efficient.

108 US20230082462 A1; "Connecting structure of segmented wind turbine blades", DU PONT DE NEMOURS, 2022-09-09.

Advanced mobility with electric, hydrogen and hybrid options are growing fast and their wear and friction, low weight and thermal requirements are often greater than internal combustion engines. Additionally, modern models of ICE (Internal Combustion Engine) and BEV (Battery Electrical Vehicles) generate more heat and involve more aggressive gases, fluids, and acidic gas/air mixtures, often under high pressure. Many traditional materials can no longer perform in these much hotter, confined, and stressed environments. Seal rings for transmissions in off road vehicles, such as tractors and mining vehicles, demand high performance. There are a few composite applications in transportation, primarily for the military in armoured cars and tanks, to withstand extreme conditions with high MTTR (mean time to repair). Composites generally have not scaled to non-aerospace transportation except for key areas like the military (see Table 1).

<u>Function and technical performance of Vespel® products in chemical processing sector:</u>

Vespel® parts and shapes are in a diverse area of the chemical processing sector including:

- Mechanical and sealing parts for pumps, values and compressors in the chemical processing sector and the gas sector (chemical resistance, seizure failure reduction, vibration reduction)
- Ball Valve Seats for Liquid Natural Gas (sealing in cryogenic conditions)
- Sealing parts in hydrogen stations (gas permeability and low wear key characteristic)
- Pump Wear rings, throttle bushings, agitator bushings, vertical pump shaft bearings (chemical resistance, seizure failure reduction, vibration reduction)

<u>Function and technical performance of Vespel® products in industrial manufacturing sector:</u>

Vespel® parts and shapes are in a diverse area of the industrial manufacturing sector including:

- Inserts and fingers to handle glass on the manufacturing line in glass handling equipment,
- bushings in the textile machines,
- insulating parts in welding/cutting torches (welding tools are then used in multiple industries that use welding/cutting torches such as construction, transportation, automotive manufacturing, etc.)
- Wear pads in compressors for heat pumps,
- Ball bearings in dental drills,
- Ferrules in scientific equipment

<u>Function and technical performance of Vespel® products in military and defence:</u>

Military applications cover a broad spectrum of uses, most of them would be considered in the 'transportation' sector, but with very specific uses across the various branches. Like the aerospace sector in general, long cycles of support are expected, with requirements for strict reporting of any changes to the manufacturing process. Generally military applications (submarines, naval ships, amphibious and land vehicles, space, and aerospace)- are confidential but key requirements include strength, coefficient of friction, electrical resistivity, chemical resistivity, dimensional stability, thermal stability.

Summary of key technical performance and requirements of Vespel® parts and shapes per key sector

The following table provides an overview of the key function and performance in general as well as more specific to key sectors:

Table 9: Overview of the key function and performance in general as well as more specific to key sectors.

Sector	Key function and performance
Key general performance characteristics	- Water/moisture resistance - Chemical resistance - Electrical resistance - Temperature resistance (thermal stability) - Non-flammability - Low coefficient of friction - Self-lubricating properties - Low wear/friction - Light weighting - Absence of a melting point - Low outgassing - Thermal insulation
Transportation sector (including aerospace)	- By withstanding high temperatures and harsh operating environments, Vespel® parts provide new design options for automotive powertrain and driveline components - Outstanding friction reduction properties - The lightweight nature of PFAS materials helps in achieving fuel efficiency and lower energy consumption - Thermal stability is of utmost importance, particularly in applications such as aero engines, where it is considered critical to safety.
Industrial Sector	- Chemical resistance and low chemical permeability - Compliance to create a physical barrier between mated surfaces - Low wear and friction where used in moving parts
Semiconductor Sector	- Chemical resistance and low chemical permeability - Compliance to create a physical barrier between mated surfaces - Low outgassing and resistance to particle generation

**Source: RPA, 2023*[109]

4.3.2. Identification of known potential alternatives to Vespel® parts and shapes

This section will further elaborate on identified non-PFAS alternative materials and their feasibility to replace Vespel® parts and shapes in high demanding industrial operating environments.

[109] RPA, 2023. Socio-Economic Impact Assessment for the use of PFAS within the Aerospace Supply Chain, report for DuPont Specialty Products USA, LLC, June 2023, Norwich, Norfolk, UK.

Table 10: Identified potential alternatives to Vespel® parts and shapes.

Alternative	Vespel® parts and shapes Comparison
Steel & other metals	Higher weight, higher coefficient of friction higher fuel consumption, more maintenance, and higher cost to maintain. Vespel® parts and shapes are typically used as a sacrificial component to protect metal countersurfaces. Metals typically require lubrication to prevent galling, and hydrocarbon oils and greases are limited in temperature to <200°C due to evaporation and oxidation.
Polypropylene	Very low temperature resistance, below 100°C, not sufficient resistance to aggressive chemicals/oxidation.
Polyvinyl chloride (PVC)	Very low temperature resistance, below 100°C. Decomposes readily to form hydrochloric acid at high temperature, leading to corrosion.
Glass/ceramics/mica	Natural mica is a mined material and requires careful handling and sourcing. It exhibits properties such as being more brittle and challenging to machine compared to other options. Additionally, the production of parts using natural mica tends to be more expensive. As a result, it is estimated that only a limited portion, approximately 5%, can be effectively replaced by ceramics or other suitable alternatives.
Polyether sulphone	Long-term service temperature up to 180 °C is too low for many applications for which Vespel® parts and shapes are used. Resistant to certain types of media (e.g., aliphatic hydrocarbons, alcohols, some types of chlorinated hydrocarbons, certain aromatic chemical agents, oil and grease), but not sufficiently broad chemical resistance.
Isostatic shapes	Uses PTFE in production of high-volume direct-form products. Stock shapes could theoretically be used instead of direct-form parts. However, opting for stock shapes is considerably more expensive, and there are limitations in production capacity to meet even current demand. Moreover, using stock shapes leads to increased material waste as the parts need to be machined to achieve the desired specifications.
Polyamides	Long-term service temperature up to 200 °C with specialized PA6.6 Not able to withstand a broad range of relevant aggressive media
Polyether ether keytone (PEEK)	Glass transition temperature: If the performance temperature of 150°C is not exceeded and hence, Vespel® parts and shapes are not required, PEEK is used. PEEK is not a thermoset material. It is uncertain whether these alternatives contain PFAS. In some cases, a tolerance of 5-10% failure rate might be accepted, otherwise a redesign of the system is considered. PEEK design guide suggests that PTFE is commonly used as a processing aid.[110]
Polyamide-imide	Competitive material for lower temperature applications but is also commonly formulated with PTFE to enable processing.[111]

Source: RPA, 2023[112]

[110] Available at: https://www.emcoplastics.com/assets/pdf/peek/Processing%20Guide-PEEK.pdf (Accessed in July 2023).

[111] Available at: https://drakeplastics.com/wp-content/uploads/2020/01/Torlon-PAI-Design-Guide_EN-227547.pdf (Accessed in July 2023).

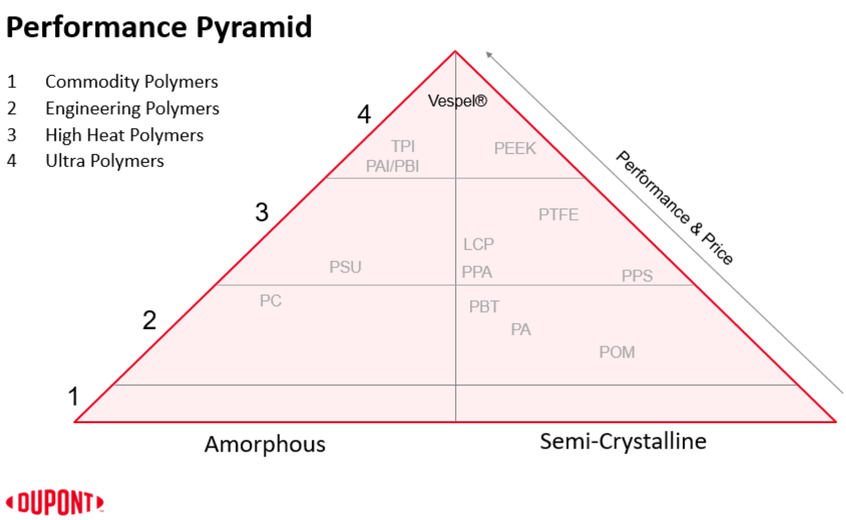
[112] RPA, 2023. Socio-Economic Impact Assessment for the use of PFAS within the Aerospace Supply Chain, report for DuPont Specialty Products USA, LLC, June 2023, Norwich, Norfolk, UK.

Alternatives are unable to meet the critical requirements of applications that demand the properties that Vespel® parts and shapes offer.

For some Vespel® parts and shapes, the PFAS provide critical wear and friction properties which no other materials can achieve. In these products, fluoropolymers are a significant component of the Vespel® part and shapes. Also, the use of PTFE in direct-form parts is able to reduce the mould-wall friction during processing, and also withstand the final sintering cycle which reaches temperatures >400°C. To our knowledge there are no other materials in existence that can achieve this, with the efficacy of PTFE, or at the low loadings used with the fluoropolymer processing aid. These low loadings enabled by the PFAS are unique, as they lead to no impact on the final properties of the Vespel® part. Initial scouting experiments have shown that alternative solid lubricants are required at >10x the loading level, which significantly impacts the mechanical integrity, and likely various other properties of the final part.

Figure 22 illustrates Vespel® parts and shapes' excellent performance in comparison to other polymers.

Figure 22: Performance pyramid



Source: Based on DuPont's internal data, 2023

<u>**Bronze**</u>

Bronze is a self-lubricating metal alloy that is composed of copper and tin. It possesses several characteristics that makes it useful for industrial operating environments. It is harder than pure copper, providing durability and resistance to wear and corrosion. It is also more malleable and ductile than iron, allowing for easy casting and shaping.

Nevertheless, using bronze instead of Vespel® parts and shapes would increase friction within component systems. This would require redesigning certain components to be larger in order to generate the necessary force. For example, actuators designed to work with Vespel® may not supply sufficient torque when bronze bushing are used due to increased friction. Consequently, the entire system would need to be redesigned. Additionally, bronze bushings rely on lubrication, which would not be feasible in all industrial operating environments due to high operating temperatures, as any lubricants used would quickly evaporate or burn up. Implementing lubrication systems would add weight, and frequent oil replacement would be necessary to maintain viscosity. **If the lubrication system fails, bronze bushings can render countersurfaces irreparable**. This difference in friction resistance is also illustrated in a test in Figure 23 below.

Figure 23: Vespel® thrust washer in comparison to bronze

Source: Based on DuPont's internal data, 2023

Using bronze as a replacement for Vespel® wear strips may lead to additional risks, including increased vibrations and friction between the bronze material and equipment components. **Bronze would require the use of a lubricant; otherwise, the metal-on-metal friction could result in the release of small metal fragments within the equipment.** These fragments could inadvertently spread to other machining and industrial parts, potentially causing an equipment failure. Moreover, the interaction between dissimilar metals in a metal-on-metal scenario could induce galvanic corrosion, further compromising the integrity of the components.

Considering these risks and challenges, it can be concluded that switching to bronze as a replacement for Vespel® parts and shapes would not be technically feasible or advisable, particularly in the context of demanding industrial operating environments.

Bronze bushings are also cheaper than Vespel® bushings, so existing applications would have already considered bronze as an alternative.

Comparing both the technical and economic feasibility, an overview of the conclusion of the assessment of bronze as an alternative for Vespel® is summarised in Table 11 below.

Table 11: Summary of technical and economic feasibility of using bronze as an alternative.

	Bronze
Chemical resistance	Under normal operating environments, bronze exhibits resistance to fluids containing ethylene glycol
Electrical resistance	Electrical conductor
Temperature resistance	Maximum operating temperature of 260 °C to 398 °C
Self-lubricating	Yes, but requires lubrication to keep frictional heating low.
Vibration and wear resistance/low coefficient of friction	Coefficient of friction of 0.08 – 0.14
Shear strength	80 – 140 MPa, vary depending on the alloy
Costs to implement	The use of bronze, with its larger parts, increased weight, and higher coefficient of friction, would necessitate a redesign of systems to accommodate the necessary force. This system redesign would entail thorough equipment testing to ensure the effective operation of the systems.

Source: RPA, 2023[113]

<u>Isostatic Vespel®</u>

Isostatic Vespel® is produced using a proprietary (and export controlled) isostatic process, which does not involve intentionally adding PFAS materials. **The isostatic process allows for the creation of large meter-long rods of Vespel® that are subsequently transformed into stock shapes**. These stock shapes can be made from various grades of Vespel® and possess isotropic properties, meaning they exhibit consistent directional properties throughout the material. This type of Vespel® is often used for custom orders in commercial aviation, where isotropic properties are required for specific applications.

The rate of production would not be sufficient to meet the demand for commercial aviation and industrial operating environment equipment and shapes, which relies on the faster production of direct form parts, capable of being produced at a rate of thousands per 24 hours. Scaling up production would require additional production vessels.

Comparing both the technical and economic feasibility, an overview of the conclusion of the assessment of isostatic Vespel® as an alternative for direct form Vespel® products summarised in Table 12 below.

[113] RPA, 2023. Socio-Economic Impact Assessment for the use of PFAS within the Aerospace Supply Chain, report for DuPont Specialty Products USA, LLC, June 2023, Norwich, Norfolk, UK.

Table 12: Summary of technical and economic feasibility of using isostatic Vespel® as an alternative.

	Isostatic Vespel® shapes
Chemical resistance	Under normal operating environments, isostatic Vespel® shapes are resistant to fluids containing ethylene glycol
Electrical resistance	Electrical insulator
Temperature resistance	Maximum operating temperature up to 370 °C.
Self-lubricating	Yes
Vibration and wear resistance/low coefficient of friction	Coefficient of 0.03 (lubricated)
Shear strength	77.2 MPa @23 °C SP-21 ISO, 89.4 MPa @23 °C SP-1 ISO
Costs to implement	Redesign would be necessary, in some cases, if switching to isostatic Vespel® shapes as a replacement for current Vespel® parts. Meeting the current demand for direct form Vespel® parts would require the construction of a new facility. The manufacturing process of Vespel® shapes involves machining away up to 50% of the material, which cannot be recycled and must be incinerated. This is due to the complexities of the shape that cannot be easily achieved through isostatic manufacturing methods.

Source: RPA, 2023[114]

__Thermoplastics, in particular PEEK and PAI__

Thermoplastics are a class of polymer materials that can be repeatedly melted and solidified under pressure. Some common examples of thermoplastics include polyether ether ketone (PEEK), polyamide imide (PAI), polycarbonate (PC), polyacetal (POM), high-temperature nylon (HTN), and polyethylene terephthalate (PET). In the following section, the suitability of these materials as potential alternatives to Vespel® parts and shapes will be assessed, taking into consideration their technical feasibility.

Many Vespel® grades exhibit an extensive useful temperature range from -196°C to 350°C and do not have an observable melting point. When comparing the thermal properties of alternative thermoplastics to those of Vespel® parts and shapes, it becomes evident that they lack the necessary thermal resistance requirements for industrial operating environments. Table 13 below illustrates the thermal properties of the aforementioned thermoplastics.

114 RPA, 2023. Socio-Economic Impact Assessment for the use of PFAS within the Aerospace Supply Chain, report for DuPont Specialty Products USA, LLC, June 2023, Norwich, Norfolk, UK.

Table 13: Thermal properties of thermoplastics in comparison of Vespel®.

	Continuous service temperature
Vespel® (polyimide parts only)	300°C –370°C
Polyether ether ketone (PEEK)	154°C – 260°C
Polyamide imide (PAI)	220°C – 280°C
Polycarbonate (PC)	115°C – 130°C
Polyacetal (POM)	80°C – 105°C
High-temperature nylon (HTN)	210°C – 230°C
Polyethylene terephthalate (PET)	80°C – 140°C

Source: Xometry, 2022[115]

While PEEK and PAI do not reach the same level of temperature resistance, they are closest in temperature resistance performance to Vespel® direct form parts compared to other thermoplastics. Therefore, this assessment will only examine these two alternatives further. PEEK and PAI design guides recommend the use of PTFE processing aids and would be also restricted based on the draft proposal scope.

PEEK and PAI exhibit higher coefficients of friction compared to Vespel® direct form parts, namely 0.049, 0.051, and 0.030, respectively)[116]. **This implies that when using these materials, the energy loss will be higher, resulting in more energy consumption**.

Furthermore, the PV limits of PEEK and PAI are inferior to those demonstrated by Vespel® direct form parts. The PV limit represents the point at which failure occurs under a specific PV load, typically identified by a sudden increase in wear rate of the material[117]. PEEK has a PV limit of 5.2 MPa*m/s, while PAI has a limit of 1.8 MPa*m/s.[118] In contrast, Vespel® grades, such as SP-21 and SCP-5050, exhibit PV limit of 12.3 and 24, respectively. **These lower PV limits of the substitute materials imply that they would not be able to withstand the same pressure and velocity of moving parts as Vespel®, and their deterioration would occur at a faster rate even under lower operating conditions. This improved level of performance also provides Vespel® direct form parts with a much higher safety factor, which can be critical in many transportation or industrial applications.**

As PEEK and PAI were concluded not to be technically feasible candidates, an economic assessment was not performed.

[115] Xometry, 2022. Nylon: Uses, Types, and Materials. Available at: https://www.xometry.com/resources/materials/nylon/ (Accessed in July 2023).

[116] DuPont, 2015. DuPont™ Vespel® parts and shapes white paper. Available at: https://www.dupont.com/content/dam/dupont/amer/us/en/vespel/public/documents/en/Vespel(R)_Innovation_Opportunities_English_White_Paper_21Apr15.pdf (Accessed in July 2023).

[117] DuPont, 2022. DuPont™ Vespel® S line. Available at: https://www.dupont.com/content/dam/dupont/amer/us/en/vespel/public/documents/en/Vespel(R)_Innovation_Opportunities_English_White_Paper_21Apr15.pdf (Accessed in July 2023).

[118] DuPont, 2022. DuPont™ Vespel® S line. Available at: https://www.dupont.com/content/dam/dupont/amer/us/en/vespel/public/documents/en/Vespel(R)_Innovation_Opportunities_English_White_Paper_21Apr15.pdf (Accessed in July 2023).

Comparing both the technical and economic feasibility, an overview of the conclusion of the assessment of thermoplastics PEEK and PAI as an alternative for Vespel® direct form parts are summarised in Table 14 below.

Table 14: Summary of technical and economic feasibility of using thermoplastics (specifically PEEK and PAI) as an alternative.

	Thermoplastics (PEEK and PAI)
Chemical resistance	Under normal operating environments, PEEK and PAI exhibits resistance to fluids containing ethylene glycol
Electrical resistance	Electrical insulator
Temperature resistance	260 °C and 280 °C respectively
Self-lubricating	Yes, if composite with other materials (graphite)
Vibration and wear resistance/low coefficient of friction	Coefficient of friction of 0.049 for PEEK and 0.051 for PAI (lubricated)
Shear strength	55 MPa @ 23 °C
Costs to implement	As the materials would melt in high-temperature sections of industrial operating environments, it would not be used. Yet, assuming technically feasible, it would necessitate a complete redesign of equipment used.

Source: RPA, 2023[119]

4.3.3. Typical innovation process and timing for Vespel® parts and shapes

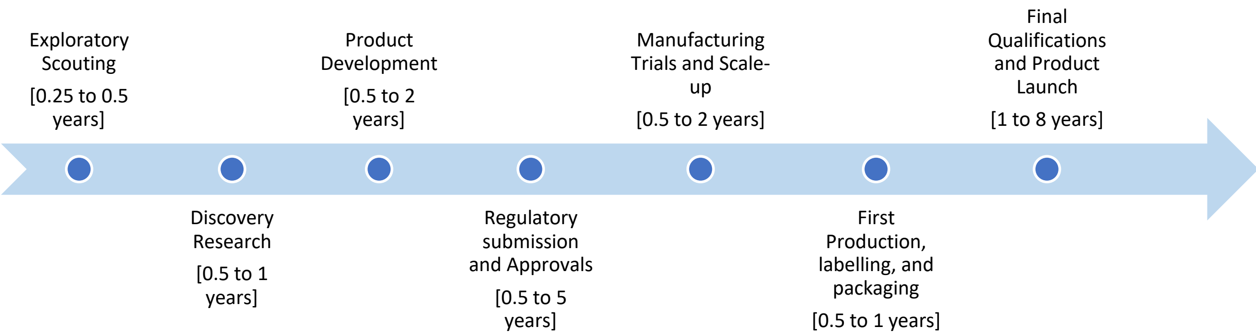
For Vespel® parts and shapes, projects have been initiated to develop alternatives to PFAS in some products such as replacing the PTFE micropowder that is used in direct-form parts. In all other Vespel® products that use PFAS, the fluoropolymer constitutes a large fraction of a part or purchased component, and therefore no alternatives exist.

Historically innovation in Vespel® has been driven by both process development and new industrial applications. The overall development timeline for substitution efforts – if alternatives can be found - spans several years, typically requiring 5+ years for research and development for the exploratory phase of alternate material identification. Then, a qualification for all materials impacted occurs (additional 3 years) before customer qualification. Qualification with customers will vary with application and hazards of part failure. Given the high cost of the materials in this marketspace, it is a market reality that it would have been replaced with cheaper materials that would match the requirements should such products already exist.

An example innovation process is shown below, with timing varying with end use application and industry.

Figure 24: Example Timeline of Vespel® New Product Development Process.

[119] RPA, 2023. Socio-Economic Impact Assessment for the use of PFAS within the Aerospace Supply Chain, report for DuPont Specialty Products USA, LLC, June 2023, Norwich, Norfolk, UK.



As shown in Figure 24, the innovation process from exploratory scouting to final qualification and product launch can take many years. Initial research efforts include exploratory scouting of new replacement materials or technologies, initial discovery experiments to test hypotheses, and then significant product development if the technology proves successful. Implementing a new polymeric processing aid (PTFE micropowder) would necessitate requalifying everything, involving a rigorous process of requalifying resin and obtaining approval from both internal and customer stakeholders. Quality assurance measures would also be crucial. The transition to the program would require converting production equipment to ensure compliance, which entails expenses without generating immediate income. Research and development efforts are conducted on in-kind equipment, but all innovations must ultimately undergo qualification on production assets. Consequently, every individual part would need to go through a qualification process. In cases where emissions or safety are affected, local agencies may need to be informed or provide regulatory approval. The approval process in such areas can take 5 to 10 years once the design is submitted for review.

In the majority of the Vespel® product lines, the PFAS plays a critical role in the property and function of the material, and therefore no alternative materials are being explored to replace the PFAS. This includes the PFA in Vespel® CR, the granular PTFE in SP-211, the PTFE fabrics in Vespel® wear strips, track liners and other composites, and the 6FTA based resins using in Vespel® composite materials.

4.4. Overall conclusion on suitability and availability of alternatives

Kalrez® perfluorelastomer parts (FFKM)

Considering the extreme conditions which occur in highly demanding applications as described in this section, there are no alternatives to FFKM.

It should be noted that **FFKM is only used where absolutely necessary and the conditions do not allow any other material**. This is because perfluoroelastomers are substantially (factor 10x vs closest elastomer) more expensive than alternative materials; therefore, it is only purchased for applications where no other elastomeric material can withstand the chemical and temperature environment. Substitution of FFKM therefore naturally takes place due to economic considerations alone where technically possible. **This point has specifically been acknowledged by the dossier submitters.**[120] In other words, given the relative high cost of FFKM, **in applications where FFKM are used, the next-best alternative has already been tested against the performance requirements and has been found to be inadequate.**

Vespel® parts and shapes

After a strategic assessment of the product line, projects have been initiated to develop alternatives to PFAS in some products such as replacing the PTFE micropowder that is used in direct-form parts. In all other Vespel® products that use PFAS, the fluoropolymer constitutes a large fraction of a part or purchased component, and therefore no alternatives exist.

Alternatives have been explored for the polymeric processing aid in direct form parts but have not provided the performance characteristics required for the critical applications. The main obstacle encountered with many alternative materials is their inability to match the desired combination of chemical resistance, thermal stability, compliance, low friction, and/or tribological properties required for specific applications, resulting in premature failure. In the case of non-PFAS alternatives, their performance falls significantly behind the fluoropolymer. They are unable to meet the critical requirements of applications that demand both high temperature and high chemical resistance.

The same economic logic described above with Kalrez® perfluoroelastomer parts is also relevant for Vespel® parts and shapes. Given the high cost of the material, it is a market reality that it would have been replaced with cheaper materials should such products exist that meet all the requirements.

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120 Annex E to the restriction report, version 2 (22 March 2023), p. 498-499.

5. PERSPECTIVE ON IMPACTS

The sections below provide a general overview of the environmental, social, and economic impacts, considering hazard properties of the PFAS used in Vespel® parts and shapes and Kalrez® perfluoroelastomer parts, market impacts (i.e., on the product market), and macroeconomic consequences resulting from a potential restriction of the PFAS used in used in Vespel® parts and shapes and Kalrez® perfluoroelastomer parts.

5.1. Environmental impacts

5.1.1. Hazard properties

The proposed restriction aims to limit the risks to the environment and human health from the manufacture and use of a wide range of PFAS due to their persistent, bioaccumulative and toxic (PBT) or very persistent and very bioaccumulative (vPvB) properties. Therefore, this section aims to present the hazard properties of the PFAS utilized in Vespel® parts and shapes and Kalrez® perfluoroelastomer parts. The analysis of hazard properties below mainly focuses on Polytetrafluoroethylene (PTFE), Poly(tetrafluoroethylene-co-perfluoroalkylvinyl ether) perfluoroalkoxy polymer (PFA), FKM, and FFKM (Perfluoroelastomer).

Annex XIII to the REACH Regulation sets criteria for identification of the substances that are PBT and vPvB. Below are the PBT/vPvB assessments for PTFE, PFA, FKM, and FFKM:

P/vP - Persistency: Although the exact degradation half-life data of PTFE, PFA, FKM and FFKM are not measured, they are expected to be on the order of years, surpassing the vP criteria. Therefore, PTFE, PFA, FKM, and FFKM meet the P/vP criteria[121].

B/vB – Bioaccumulation: Due to their high number average molecular weight, PTFE (389,000 – 8,900,000 Da)[121], PFA (200,000 – 450,000 Da)[122], and FFKM (60,000 -10,000,000 Da)[123] are not expected to bioaccumulate. Animal studies suggest this is true for PTFE[124] and is expected to be the same for PFA, FKM, and FFKM.

121 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.

122 Henry et al., 2018.

123 Henry et al., 2018.

124 Lee S, Kang KK, Sung SE, Choi JH, Sung M, Seong KY, Lee J, Kang S, Yang SY, Lee S, Lee KR, Seo MS, Kim K. In Vivo Toxicity and Pharmacokinetics of Polytetrafluoroethylene Microplastics in ICR Mice. Polymers (Basel). 2022 May 30;14(11):2220. doi: 10.3390/polym14112220. PMID: 35683896; PMCID: PMC9182653.

T - Toxicity: PTFE, PFA, FKM, and FFKM are not classified as carcinogenic (category 1A or 1B), germ cell mutagenic (category 1A or 1B), or toxic for reproduction (category 1A, 1B, or 2). Their large molecular weight and structural properties prevent them from entering human cells, binding to cell receptors, or interacting with other biomolecules. Although there is limited available data on the toxicity of FFKM,[125] its characteristics such as lack of water solubility and other properties suggest that the substance is unlikely to be toxic (not T).

Based on the above information, it can be concluded that PTFE, PFA, FKM, and FFKM are very persistent (vP), not bioaccumulative (not B), and likely not toxic (not T) according to REACH Annex XIII. Therefore, PTFE, PFA, FKM, and FFKM do not meet the PBT/vPvB criteria as specified in REACH regulation.

5.2. Economic impacts

The sections below provide a general overview of the social and economic impacts only for market impacts, substitution costs, and macroeconomic consequences resulting from a potential restriction of the PFAS ingredients. The economic impacts assessment does not include Kalrez® perfluoroelastomer parts due to its manufacturing location falling outside the geographical scope of the assessment.

5.2.1. Non-use scenario

The non-use scenario is built on the assumption that PFAS, covering usage, manufacturing, and placing on the market in the EU will be restricted and consequently excluded from the market starting in 2027. **The non-use scenario will be assessed in further detail during the second submission by DuPont, that is planned within the timeline given by the public consultation.**

5.2.2. Business impacts on manufacturers of Vespel® parts and shapes

A detailed data gap analysis was conducted to gather information from DuPont on Vespel® parts and shapes and Kalrez® perfluoroelastomer parts that are used in high demanding industrial environments.

In the oil and gas industry, a prohibition on the use of Kalrez® and Vespel® products would halt oil extraction in high-pressure and high-temperature environments, significantly limiting oil extraction. Kalrez® perfluoroelastomer parts are critical for reducing emissions in the petroleum sector, thereby also limiting the availability to reduce emissions in this sector.

[125] DuPont's FFKM grade meets FDA (Food and Drug Administration) and USP (United States Pharmacopeia) Class VI (in vitro & in vivo test) regulatory standards - which are preferred for applications involving contact with humans, including skin contact. When an FFKM grade is classified as FDA and USP Class VI, it indicates that the material has met the required standards for biocompatibility and safety, including skin contact with humans. These classifications provide reassurance that the material is suitable for use in medical devices, pharmaceutical processing, and other applications involving direct contact with living organisms.

Regarding the semiconductor manufacturing industry, which rely heavily on Kalrez® perfluoroelastomer parts**, this would eliminate all semiconductor manufacturing in the EEA, limit innovations in the EEA, and potentially also the EEA's competitiveness in this sector**. Without the use of Kalrez® perfluoroelastomer parts, the European Chips Act would not be possible due to the criticality of sealing elements in the chip manufacturing equipment. All the tools that are designed for chip manufacturing use a plasma environment at a high temperature and rely on aggressive chemistries, such as fluorine. These operations operate under a vacuum and require reliable sealing. **As a consequence of the potential restriction of Kalrez®** perfluoroelastomer parts**, the semiconductor chips which are found in microprocessors, including computers, smartwatches, mobile phones, and cameras could not be manufactured in the EEA. Therefore, EEA would need to rely on importing vital components and would not have the capability to manufacture them independently.**

Industrial and chemical processing applications would also be heavily impacted, as many chemical plants rely on Kalrez® perfluoroelastomer parts. **The proposed restriction would limit operations in the chemical processing industry in the EEA, affecting the production of numerous consumer goods that depend on the chemical industry, such as ethylene oxide.** Ethylene oxide requires FFKM and is one of the most important raw materials used in large-scale chemical production of many consumer and industrial goods: pharmaceuticals, lubricants, paint thinners, plasticizers, brake fluids, detergents, solvents, lacquers, paints, natural gas purification, detergents, surfactants, emulsifiers, and dispersants. Ethylene oxide is also a commonly used sterilization method in the healthcare industry.

In aerospace applications, if no derogations for the PFAS used in the applications is granted, aircraft would be unable to be serviced and new engines would not be able to be built. The current design and construction of air engines are based on the use of Vespel® parts and shapes and Kalrez® perfluoroelastomer parts. Engines are precisely engineered and controlled to ensure proper and safe functioning. Without Vespel® components, the metal-on-metal interactions would cause excessive vibration and higher levels of friction. This could lead to galling and metallic wear debris build up within the engine. Should this occur, it can be fatal to the engine, causing potential short circuits as well as locking components, resulting in engine failure. Kalrez® perfluoroelastomer parts are a high-performance material that was designed specifically as a sealing material for harsh thermal and chemical environments. It can withstand operating temperatures of up to 325°C and shows minimal swelling upon submersion in multiple oils such as HTS oils. AMS7257 specification covers FFKM. In addition, OEMs will typically only use materials which meet their own internal standards, which may exceed those of AMS7257 (reference aero SEA). Additionally, the growing demand for satellite and space applications, critical for wireless connectivity and national defence, relies on Vespel® parts and shapes unique performance under high vacuum and cryogenic conditions.

The transportation and automotive industry, relying on Vespel® parts and shapes, would face challenges as well. Manufacturers of various driveline components and OEMs would need to identify and qualify alternatives for existing systems such as transfer boxes, e-axles, EGRs, and turbochargers. This would require a significant amount of complex work, potentially involving subsystem redesigns in some cases. The impact on hydrogen transportation could be particularly significant, resulting in a slowdown of major projects aimed at developing hydrogen-powered transportation.

5.3. Wider economic impacts

It is also important to consider the wider macroeconomic impacts and consequences on the EU society at large, by focusing on the expected consequences for the EEA market as a result of the proposed restriction. In particular, there are concerns on the overall EU trade balance and on the competitiveness of the EEA market due to the restriction of PFAS in Kalrez® perfluoroelastomer parts and Vespel® parts and shapes in highly demanding industrial operating environments.

Impacts on the market – Quality and costs

If PFAS were restricted, sectors relying on **Vespel® parts and shapes and Kalrez® perfluoroelastomer parts, all stakeholders and downstream users** would be heavily affected.

Kalrez® perfluoroelastomer parts

Particularly for FFKM, the development of new molecules with the same performance characteristics as the one currently available today is currently not technically available. Currently, alternatives do not exist. Therefore, the availability and quality of sealing parts in the EEA would be adversely affected because of the restriction.

Vespel® parts and shapes

Regarding Vespel® parts and shapes, for which part of the manufacturing takes place in the EEA, all investments currently made in manufacturing assets and future investments, existing **Vespel® manufacturing assets will have no utility should a total PFAS ban be enacted.** The majority of equipment installed in Mechelen's manufacturing facility is specially designed for customers in the EU region. Greater than 80% of Mechelen manufacturing supplies EMEA/EEA customers. Relocating investments outside of the EEA would incur significant costs to DuPont. Exiting of manufacturing from the EU will be detrimental to the EEA chemical industry (including oil and gas), transportation, and aerospace industries that need Vespel® parts and shapes that are manufactured in Mechelen. Not only would this reduce the flexibility of the EEA supply chain but would reduce the overall economic contributions of DuPont to the EEA.

Impacts on the market – Competitiveness

The potential restriction of PFAS, which applies equally to all producers when placing products on the EEA market under REACH Regulations, would place customers of PFAS containing Vespel® parts and shapes and Kalrez® perfluoroelastomer parts at a significant disadvantage compared to non-EEA competitors.

Impact on Kalrez® perfluoroelastomer parts

While the manufacturing of Kalrez® perfluoroelastomer parts takes place outside the EU, a considerable number of customers in the EEA import these perfluoroelastomer parts.

The most likely anticipated outcome for downstream users that are highly dependent on Kalrez® perfluoroelastomer parts are:

- For the EEA oil and gas industry, the most likely response of downstream customers is the ending of oil and gas extraction in high-pressure and high-temperature environments. Without access to Kalrez® perfluoroelastomer parts, oil and gas operations in the EEA would come to a complete halt due to a lack of current viable alternatives.
- For the EEA semiconductors industry, there would be a potential elimination of all semiconductor manufacturing in the EEA if a feasible alternative is not be found for Kalrez® perfluoroelastomer parts. Moreover, manufacturers will likely cease production and move outside the EEA.
- For the EEA chemical processing industry, as a result of the restriction, the CPI would most likely stop their operations. Most of the plants rely on fluoropolymer seals and Kalrez® perfluoroelastomer parts to comply with industry emission requirements. Moreover, manufacturers will likely cease production and move outside the EEA.
- Production of Hydrogen can be achieved through Methane cracking into Hydrogen and CO2. Methane requires a refinery that uses FFKM seals for its producing. In order to offset the CO2 emission, carbon capture can be put in place, which typically uses an amine based process to capture the CO2. FFKM are used to seal amines. Hydrogen can also be produced by electrolyser and FFKM seal can be used to seal the electrode as it gets at elevated temperature and in contact with water/steam. CO2 capture, also called carbon capture, once isolated need to be reinjected under high pressure which therefore requires seal having good RGD.
- The aerospace industry would experience significant disruptions, impacting various sectors such as machine shops, engine system manufacturers, and airframe manufacturers. This is due to the industry's reliance on complex global supply chains that are tightly interconnected.[126] Any restrictions imposed on one part of the supply chain would trigger a chain reaction, ultimately leading to a cease of all downstream supply chains.

Impact on Vespel® parts and shapes

Vespel® parts and shapes are produced and imported into the EU. A broad restriction on PFAS, including the ban on importing Vespel® parts and shapes which contain PFAS, would severely disadvantage highly demanding EU industries in the global market. Additionally, **a broad restriction of PFAS used in the production and manufacturing of Vespel® parts and shapes in the EEA would disadvantage EU markets in their competition with the rest of the world**, that would have access to a wider portfolio of products. This would impact multiple components in vehicles and the industrial producers that make those components.

The manufacturing of Vespel® parts and shapes located in Mechelen would shut down. A complete shutdown of this manufacturing facility would result in a decommissioning cost of the Mechelen manufacturing site amounting to approximately 20 to 25 M EUR. Any production that is currently exported from the EEA would be supplied by other regions.

[126] RPA, 2023. Socio-Economic Impact Assessment for the use of PFAS within the Aerospace Supply Chain, report for DuPont Specialty Products USA, LLC, June 2023, Norwich, Norfolk, UK.

The most likely anticipated outcome for downstream users would be highly dependent on the EEA industry's reliance on Vespel® parts and shapes:

- For the EEA oil and gas industry, the most likely response of downstream customers would be the ending of oil and gas extraction in high-pressure and high-temperature environments. Without access to Vespel® parts and shapes, oil and gas operations in the EEA would come to a complete halt due to a lack of current viable alternatives.
- If Vespel® products could not be manufactured and became limited in availability in the EEA, then the EEA transportation and aerospace industry would stop offering specific product lines and stop operations due to lack of alternatives.

As a result of the decreased competitiveness of the EEA market, **the attractiveness of the EEA for investment in innovation and R&D would severely be jeopardised, thereby posing a risk to ongoing multi-billion EUR investments that are currently being planned.** The investment initiative by Intel in Germany aimed at establishing two chip-making plants in Magdeburg as part of the Intel's expansion strategy in the EU could potentially face challenges and hinder the biggest foreign investments in German history as a result of the potential restriction. This investment has received government subsidies amounting to around 10 billion EUR.

Impacts on the market – Trade (Kalrez® perfluoroelastomer parts and Vespel® parts and shapes)

A broad restriction on would create a significant disadvantage for European companies in their global trade. Currently, the EEA heavily relies on Kalrez® perfluoroelastomer parts and Vespel® parts and shapes. If the import of Kalrez® perfluoroelastomer parts and the import and manufacturing of Vespel® parts and shapes in the EEA were to be restricted, it would force industries with demanding industrial operating environments dependent on these materials to cease their operations.

Any disruption in the availability of these essential Vespel® and Kalrez® materials could have severe consequences for the EEA's overall economy, in particular on the industrial operating environments within the EEA that rely on the two product lines.

5.4. Social impacts: Unemployment

The collection of information related to social impacts on DuPont as a result of the restriction is still ongoing. A PFAS restriction would likely result in layoffs due to closure of the Mechelen manufacturing facility. Detailed information related to social impacts will be submitted in a second submission by DuPont that is planned within the timeline given by this public consultation.

6. CONCLUSION

This analysis identifies the main potential negative consequences that the EEA society at large would face in the framework of the potential REACH restriction of PFAS used in Kalrez® perfluoroelastomer parts and Vespel® parts and shapes in demanding industrial operating environments. It has been performed in line with existing ECHA guidance under REACH.

Based on the evidence-based considerations, the assessment justifies the request:

- **A time-unlimited derogation (exemption from the proposed restriction) for fluoropolymers including FFKM (such as Kalrez® perfluoroelastomer parts), FKM, PTFE, and PFA in transportation (including aerospace), petroleum and mining, chemical processing, semiconductor manufacturing, military and defence, energy, and industrial manufacturing (such as automotive manufacturing, textile, glass handling, scientific laboratory instruments, and industrial welding/plasma/cutting tools),**
- a 15-year derogation for fluorinated polymerization aids for PTFE micro-powder as a user of PTFE micro-powders with a review at 6 years after EiF to evaluate the research progress and extend the derogation, if necessary,
- a 15-year derogation for fluorinated polymerization aids for PFA as a user of PFA with a review at 6 years after EiF to evaluate the research progress and extend the derogation if necessary, and
- a 15-year derogation for fluorinated polymerization aids for FFKM with a review at 6 years after EiF to evaluate the research progress. This progress can be used to assess the societal value versus the risk and the progress toward finding alternatives to assess the likelihood of a needed extension beyond 12 years.

If the exemption for the use of fluoropolymers, including perfluoroelastomers, is granted for industrial uses, then DuPont fully supports annual reporting requirements via a site-specific management plan to manufacturers of fluoropolymers in the EU and importers of articles which use fluoropolymers to gather data on the use of PFAs in industrial sectors and to monitor any developments/changes. DuPont agrees that the site-specific plan should include:

- Information on the identity of the substances and the products they are used in;
- A justification for the use;
- Details on the conditions of use and safe disposal.

DuPont agrees that the management plan shall be reviewed annually and kept available for inspection by enforcement authorities upon request.

The assessment concludes that a broad restriction without above mentioned exemptions in the transportation (including aerospace), petroleum and mining, chemical processing, semiconductor manufacturing, military and defence, energy, and industrial manufacturing (such as automotive manufacturing, textile, glass handling, scientific laboratory instruments, and industrial welding/plasma/cutting tools), related to Vespel® parts and shapes and Kalrez® perfluoroelastomer parts, will have disproportionate negative impacts on the EU's economy and society.

The above statement is founded on the following:

- **Industrial operating environments heavily rely on the use of Kalrez® perfluoroelastomer parts and Vespel® parts and shapes, which contain or depend on fluoropolymers such as PTFE and PFA**. These materials are essential for high-demand applications due to their unique combination of properties. The proposed restriction on PFAS **would prohibit manufacturing and use of Vespel® parts and shapes importing and use of Kalrez® perfluoroelastomer parts in the EEA until alternatives, if any, are found.**

- The analysis of alternatives concludes that there are currently no technically suitable nor economically feasible alternatives readily available to substitute Kalrez® perfluoroelastomer parts and Vespel® parts and shapes that contain PFAS providing comparable product performance benefits.
    - **For Kalrez® perfluoroelastomer parts, alternative materials do not offer the desired combination of thermal stability and chemical resistance for reliable sealing in critical dynamic and static applications. This then leads to issues such as leakage, process contamination and part failures.** In the case of in-kind alternatives (non-fluoropolymer elastomeric materials), their performance falls significantly behind the incumbent fluoropolymer. They are unable to meet the critical requirements of applications that demand high temperature, and/or high chemical resistance. While not-in-kind alternatives may offer similar heat and chemical resistance (e.g., metal), they lack the level of elastic resistance needed to properly seal in the demanding application, resulting in ineffective sealing, shorter life and overall poor-quality parts. **This poses safety risks and health hazards due to equipment failure.** In addition, their much higher stiffness would require a complete redesign of the hardware which translates into time, costs, and compromises to the overall integrity of the system.
    - For Vespel® parts and shapes, projects have been initiated to develop alternatives to PFAS in products such as replacing the PTFE micropowder that is used in direct-form parts. In all other Vespel® products that use PFAS, the fluoropolymer constitutes a large fraction of a part or purchased component, and therefore no alternatives exist. **For Vespel® parts and shapes, several alternatives were considered. These included bronze, Isostatic Vespel® shapes, as well as thermoplastics like PEEK and PAI.** However, both bronze and thermoplastics were deemed technically unfeasible for various reasons. Bronze had a higher coefficient of friction, necessitated redesigning other engine components, and added weight. Thermoplastics were unsuitable due to their inability to operate within the required temperature range. Isostatic Vespel® shapes, on the other hand, showed potential to fulfil some technical criteria in specific applications. However, it would not meet all requirements, particularly in high-temperature environments, where dimensional tolerance and coefficient of thermal expansion are critical to operation.

- **If a suitable alternative for the fluorinated polymerization aids for Kalrez® perfluoroelastomer parts can even be found, the research and development (R&D) process for finding these non-fluorinated polymerization aids for Kalrez® is expected to take at least 15 years. The manufacturing sites for Kalrez® are located outside of the EU. Therefore, the primary impact of the potential EU PFAS restrictions would be discontinued use of Kalrez® perfluoroelastomer parts in EU industries that rely on these high performance perfluorinated elastomers today.**

- **Without any derogation related to PFAS used in Vespel® parts and shapes in the applications, the primary impact of the potential EU PFAS restrictions would be no importation of these products into the EU for the key industries. The industries these products support would not be able to continue operations. In the case of a complete shutdown of operations in the EEA, the Mechelen manufacturing facility would close.** As a result, during this period, the supply of Vespel® direct formed products to the industries currently served by Mechelen would cease completely.

- As a result of the potential broad restriction for FFKM and fluoropolymers used in Vespel® parts and shapes, the aerospace industry, including commercial flights into and out of the EEA will cease, impacting travel and shipping, which will also impact industries that rely on those industries. **It is expected that complete substitution in the aerospace market will take more than 30 years in the components where PFAS can be removed due to lengthy qualification times.**

- Electric vehicles demand critical light weighting to maximize vehicle range. Using Vespel® bushings enables motor and drive systems that do not rely on heavy and resource intensive lubrication systems.

- Vespel® CR products reduce environmental emissions in the chemical industry as well as the petroleum and mining industry. Where used, Vespel® parts and shapes increase the reliability and safety, and lowers the cost of ownership of industrial processes. Restricting the use of Vespel® products will reduce EEA competitiveness, and result in an increase in industrial accidents with corresponding loss of life and environmental pollution.

- Additionally, the proposed restriction on the use of PFAS, **in particular of fluoropolymers would prohibit the manufacturing of Vespel® parts in the EEA and importing PFAS-containing Vespel® parts and shapes. The import of Kalrez® perfluoroelastomer parts in the EEA would also be prohibited.** A large number of EEA industries rely on Vespel® parts and shapes and Kalrez® perfluoroelastomer parts in their industrial operating environments, such as the oil and gas industry, electrical engineering, aerospace, chemical processing, and transportation sector which would all be halted. **A full PFAS ban would eliminate the ability to supply into the market for these high performing materials within the EEA. This would have dire consequences on industrial operating environments that rely on these products.**

- From an EEA macroeconomic standpoint, the broad restriction of critical fluoropolymers in the EEA will have significant impacts on the competitiveness of the EEA markets in the industrial operating environments, on competition in the EEA, on innovation, and on the overall EEA trade balance. Since many fluoropolymer applications are used to reduce chemical emissions, restricting the use of fluoropolymers would make meeting environmental emissions goals difficult to impossible. A broad restriction of PFAS used in the production and manufacturing of Vespel® parts and shapes in the EEA would put EU markets at a disadvantage in competition with non-EEA markets, as EEA companies would no longer be able to provide the product to customers outside the EEA, while the rest of the world would have access to a wider portfolio of products. The 'wider economic impacts' section (4.3) provides a discussion on the wider macroeconomic impacts and consequences on EU society at large.

ANNEX I

Table 1: Non-exhaustive list of DuPont™ Vespel® products.

Product	Properties
Vespel® SP-1	- For physical and electrical properties - Superior wear, maximum strength and elongation - Minimal electrical and thermal conductivity - Low outgassing with high purity
Vespel® SP-3	- For unlubricated sealing and low wear in vacuum or dry environments - Maximum wear and friction resistance - Ultra-low outgassing
Vespel® SP-21	- For balanced low wear and physical properties - Low-friction properties work with or without lubrication - Long elongation and high stiffness - A graphite-filled polymer
Vespel® SP-211	- For low coefficient of friction and unlubricated wear - Lower coefficient of friction even without lubrication than SP-21 - Excellent creep resistance
Vespel® SP-22	- For low wear and dimensional stability - Enhanced resistance to wear and friction - Minimal thermal expansion - Oxidative stability
Vespel® SP-202	- For electrical conductivity with low wear rates - Electrostatic charge removal - Maintains tolerances in high heat and through multiple cycles
Vespel® SCP-5000	- For strength and hardness - Chemical resistance over broad temperature range - High wear resistance with low outgassing and high purity - Thermal oxidative stability - Very low hydrogen permeation
Vespel® SCP-5009	- For high temperatures and excellent compressive strength - Lower coefficient of friction without lubrication - Excellent sealing capability
Vespel® SCP-50094	- For high temperatures and wear resistance - Superior wear under high pressure and/or velocity - Thermal oxidative stability
Vespel® SCP-5050	- For high temperatures, wear resistance and exceptional coefficient of friction - Coefficient of thermal expansion similar to steel; matched to SS 316L at high and at cryogenic temperatures - Exceptional thermo-oxidative stability
Vespel® CR-6100	- Provides excellent widespread chemical resistance for applications in refineries or chemical processing - CTExy is matched to steel - PFA matrix provides lubrication for dry wear resistance in pumps.
Vespel® CR-6110	- Provides excellent chemical resistance for wafer holding in semiconductor manufacturing
Vespel® CP-0664, ASB-0664, ASB-0670	- Thin sheet composite providing low sliding resistance for aerospace applications. - Provides excellent resistance to vibrational wear even in dirty environments. - Used in thrust reverser systems, composite fan blade systems, and around the engine nacelle and wing mounts.
Vespel® CP-0644, CP-2014, CP-2015, CP-8000, CP-8007	- Fluorine containing polyimide/carbon fibre braid composite. - High strength, high temperature bushing, and washer applications.

CP-8001, CP-8003, CP-2103	- Fluorine containing polyimide/carbon fibre braid composite.
CP-0653, ASB-3000	- Fluorine containing polyimide/carbon fibre braid composite with fabric liner for Aerospace
CP-0652, CP-0826, CP-0866	- Various Liner composite grades for Aerospace
CP-0630	- Composite liner for industrial and transportation

Table 2: Non-exhaustive list of DuPont™ Kalrez® products.

Product	Properties
Kalrez® Spectrum™ 6375	- Black - +275 °C - Broad chemical and temperature, multi-purpose
Kalrez® Spectrum™ 7075	- Black - +327 °C - Highest temperature, low compression set
Kalrez® 4079	- Black - +316 °C - Low compression set
Kalrez® Spectrum™ 7375	- Black - +300 °C - Broad chemical and water/steam resistance
Kalrez® Spectrum™ 6380	- Cream - +225 °C - Hot amines (>80°C), chlorine dioxide, ethylene dioxide
Kalrez® Spectrum™ 0040	- Black - +220 °C - Lowest service temperature, O-rings
Kalrez® Spectrum™ 7275	- Light brown - +300 °C - Ethylene oxide, acrylic acid, chlorosilanes
Kalrez® OG193	- Black - +250 °C - Best RGD resistance, custom parts, chemical resistance
Kalrez® 0090	- Black - +250 °C - Best extrusion resistance, good RGD resistance, hot water, amines, bases
Kalrez® Spectrum™ 7090	- Black - +325 °C - Low compression set, high temperature
Kalrez® 7390	- Black - +300 °C - Broad chemical and temperature, multi-purpose
Kalrez® W24OUP	- Black - +230 °C - Chemical and thermal stability, resistance to acids/bases
Kalrez® 9600	- Olive-green - +315 °C - Best chemical resilience (to Ammonia, Ozone, and Water Vapor) in compression and ultra-low outgassing at high temperature conditions

Kalrez® 9500	- Tan - +310 °C - Best thermal stability, very low outgassing and excellent mechanical strength
Kalrez® 9300	- Brown - +300 °C - Best resistance to oxygen and fluorine-based plasma and etch process chemistry, very low metals content, excellent thermal stability and mechanical strength
Kalrez® 9100	- Amber - +300 °C - Thermal stability, very low outgassing, excellent elastic recovery, good mechanical strength properties
Kalrez® 8002	- Clear - +275 °C - Best resistance to dry process chemistry, good mechanical strength
Kalrez® 8705	- Black - +327 °C - Best resistance to high concentrations of damaging oxygen free radicals, great sealing functionality in high temperature vacuum applications
Kalrez® 8900	- Black - +325 °C - Great thermal stability, very low outgassing and excellent (low) compression set properties, excellent mechanical strength
Kalrez® 8575	- White - +300 °C - Best thermal stability and long-term sealing performance, less Infrared (IR) absorption and significantly reduced outgassing properties at elevated temperature, good mechanical properties
Kalrez® 7075UP	- Black - +327°C - Best thermal stability, very low outgassing, great seal force retention, good mechanical properties

Table 3: Suitability of Kalrez® form by grade for Oil &Gas products only.

Kalrez® grades	O-ring	T-seal	Packer	S-Seal	V-ring	Chevron stack	Boot	X-ring	Metal bonding
OG193	✓	✓	✓		✓	✓			✓
0090	✓	✓			✓	✓		✓	✓
7390	✓	✓			✓	✓		✓	
7375	✓	✓		✓	✓	✓	✓	✓	
6375	✓	✓							✓
0040	✓								
3065					✓	✓			

Table 4: Vespel® selection guide by application, for automotive applications.

Typical applications	Component	SP-1 Maximum strength and elongation	SP-21 Enhanced wear resistance	SP-22 Maximum creep resistance	SP-2515 Match aluminium 's CTE	SCP-5050 Lowest CTE	SCP-50094 Highest PV limit
Tranmissions (xEV & ICE) Variable valve timing Hydraulic motor	Seal ring 		✓	✓	✓		
Transmissions (xEV & ICE) Differential unit Lubricated clutch system	Thrust washer 		✓		✓		✓
Emission system (EGR, Turbochanger) Selenoid valves	Bushing 			✓	✓	✓	
Electrical motors (window lift, wiper, seat, sunroof)	Thrust plug 	✓	✓				
Transmission (xEV & ICE) Variable valve timing	Aluminium wear and friction 		✓		✓		
Chain guide Shift fork pad	Wear pad 	✓	✓				
Hydrogen valve seats	Hydrogen seal 	✓				✓	

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