Impact Study

Deliverable D7.4

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Executive Summary

This deliverable presents the results of Task T7.5 of the ZeroF project, which aims to assess the impact of adopting PFAS-free coating technologies on the value chains of food packaging and upholstery textiles. The study explores how ZeroF's innovations, designed to replace PFAS while offering enhanced water and oil resistance, will influence stakeholder dynamics, market structures, regulatory alignment, and technological feasibility across European industries. This work is a core component of Work Package 7 and feeds into the broader exploitation strategy by evaluating market readiness, environmental benefits, and potential barriers to adoption of the ZeroF technology.

This deliverable is mainly intended for industrial partners of the ZeroF project to understand the market uptake of their innovations. However, the report can also be relevant for policymakers, regulatory authorities, sustainability and innovation managers in the food packaging and textile sectors, and EU-level stakeholders supporting the safe and sustainable transition away from PFAS.

The impact study was conducted using a two-phase methodology. In the first phase, the current PFAS-dependent value chains in food packaging and upholstery textiles are mapped. This includes a desk research, technology benchmarking, stakeholder mapping, and market analysis. Stakeholders assessed include raw material providers, equipment and coating technology developers, packaging/textile manufacturers, end users, and distributors. Interview insights from partners such as Yangi, Kemira, VTT, Leitat, Ecima and Textils.CAT are used to validate the findings.

In the second phase, an estimation is made on how these value chains might evolve with the widespread adoption of ZeroF. PESTEL and SWOT analyses help structure foresight on regulatory, economic, and technological trends. Particular attention is given to identifying changes in stakeholder roles, market entry challenges, and performance limitations. Interviews were conducted to explore real-world constraints and scalability of the ZeroF approach.

The study confirms that ZeroF technology is technically ready for market entry in selected low-barrier applications, such as cold food packaging and residential upholstery, where its current levels of grease and oil repellence are sufficient. However, broader adoption will require overcoming key challenges related to cost, performance, and value chain adaptation. The ZeroF innovations to PFAS-free coatings are expected to restructure existing industrial value chains by introducing new supplier dynamics, licensing models, and manufacturing processes. While ZeroF offers a viable and sustainable alternative, further work is needed to address limitations in abrasion resistance, recyclability, and the cost differential compared to established PFAS-based solutions.

The results point to a clear opportunity for researchers to further develop PFAS-free formulations that meet the performance demands of high-barrier food packaging and textile upholstery applications. Future work should focus on enhancing coating durability, advancing bio-based and low-impact chemistries, and ensuring compatibility with circular economy principles such as recyclability and biodegradability. This deliverable offers a strategic, evidence-based roadmap to support the continued maturation and market integration of ZeroF technology, as its innovations progress toward higher technology readiness levels (TRLs) and broader commercial application.

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Keywords

ZeroF, PFAS, forever chemicals, health and environment dangers, PFAS-free coating, upholstery textile, food packaging, exploitation, Intellectual Property, ownership, IP protection, patent, trade secret.

Abbreviations and acronyms

ACRONYM	DESCRIPTION
AKD	Alkyl Keten Dimer
ASA	Alkenyl Succinic Anhydride
CeFAE	Cellulose Fatty Acids esters
CFAE	Carbohydrates Fatty Acid esters
IP	Intellectual Property
IPR	Intellectual Property Rights
MCC	Microcrystalline Cellulose
OEMs	Original Equipment Manufacturers (OEMs)
Ormocer®	Silane-based organic-inorganic hybrid coatings, trademarked
PES	Polyester
PFAS	Per- and polyfluoroalkyl substances
PLA	Polylactic Acid
RSB	Result-Strategy-Beneficiary
SSbD	Safe and sustainable-by-design
Thermocell®	Cellulose Fatty acid esters, trademarked
TRL	Technology Readiness Level
WP	Work package

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1. Introduction

The transition toward sustainable, non-toxic materials has become a strategic priority across industries, driven by growing regulatory pressure, heightened consumer awareness, and emerging environmental risks. In this context, the ZeroF project aims to develop and scale PFAS-free coatings for food packaging and upholstery textiles, materials that traditionally rely on per- and polyfluoroalkyl substances (PFAS) for performance but pose serious environmental and health threats.

This impact study (Task T7.5) was designed to systematically evaluate how the integration of ZeroF technology may reshape existing industrial value chains. Specifically, the study investigates both the food packaging and upholstery textile sectors, mapping the current state of PFAS-dependent systems and assessing the potential shifts that may result from adopting ZeroF's alternatives. The analysis is grounded in a combination of market data, stakeholder interviews, and policy review to deliver a robust understanding of the economic, environmental, and operational implications of this transition.

Conducting an impact study of this nature is critical for several reasons. First, it enables the consortium to anticipate shifts in stakeholder roles, supply chain configurations, and business models that may arise with the adoption of PFAS-free technologies. Second, it helps identify the regulatory levers, competitive pressures, and consumer dynamics that will influence the market's readiness. Third, it provides a structured framework to assess not only the opportunities for ZeroF but also the technical and economic barriers to its adoption.

By comparing current and future value chains and integrating expert insights, this report offers a forward-looking assessment of the ZeroF technology. This impact analysis supports the broader exploitation strategy of the project and contributes to shaping actionable pathways for ZeroF's deployment at scale.

1.1 Objectives

The objective of this task is to assess the impact of adopting ZeroF technology on value chains. Assuming the adoption of the process, the integration of PFAS-free moulded packaging and PFAS-free textiles using ZeroF technology will be modelled, considering the emergence or disappearance of stakeholders and changes in business models.

1.2 Methodology

1.2.1 Overview

The methodology for this study combines desk research with a series of interviews conducted with industry and research experts, whose insights informed both phases of the analysis. These interviews included contributions from key partners such as Kemira, Yangi, VTT, Leitat, Ecima, and Tèxtils.CAT.

The impact study is comprised of two main phases: the analysis of the current value chain, and the future value chain modelling.

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Analysis of the current value chain

The first phase focuses on understanding the existing landscape of PFAS use in food packaging and identifying opportunities for PFAS-free alternatives like ZeroF. This includes stakeholder mapping to determine the roles, relationships, and influence of key actors along the value chain. The analysis also explores alternative technologies to PFAS, assessing their market readiness and competitive positioning. Interview insights helped to validate the value chain, and shed light on current adoption barriers and industry dynamics.

Future value chain modelling

The second phase explores how the value chain could evolve as PFAS-free technologies mature and regulatory pressures increase. This includes modelling potential shifts in demand and supply, anticipating how stakeholder roles and dynamics may change in response to innovation and policy. To structure this foresight, SWOT and PESTEL analyses were applied, with a particular emphasis on policy measures and regulatory trends that could accelerate or hinder adoption.

The findings from both research and interviews were synthesised into a strategic roadmap for the adoption and scale-up of ZeroF solutions. This roadmap outlines both short-term actions and long-term strategies, closely aligned with the project's broader Exploitation Plan.

1.2.2 Perimeter

The initial reference for evaluating the impact of the new coating material will be the commonly used PFAS in paper-based packaging coatings, i.e., TG-8111. Our focus will be on paper-based, single-use, water- and oil-resistant packaging in Europe. In parallel, the textile developments within ZeroF have primarily focused on 100% polyester (PES) fabrics, which are widely used in home textile applications such as upholstery.

2. Current market in grease resistant containers for food

2.1 Packaging with PFAS

PFAS are widely used in the food packaging sector to prevent grease and water from migrating into food during baking, transportation and storage. In the case of fast-food packaging, the grease and water can also migrate from the food into the packaging. The higher the concentration of PFAS in paper or paperboard, the greater the grease resistance. The level of grease resistance needed depends on the specific use of the packaging (examples: butter wraps require a higher grease resistance than popcorn bags).

Applications are primarily intended for fatty foods, especially those that will be heated within the packaging or stored for extended periods. Examples include fast food wrappers for French fries and hamburgers, microwave popcorn bags, baking paper, baking cups and molds, sandwich and butter wraps, chocolate wrappers, and packaging for dry foods and pet food.

PFASs are made of fully or partly (poly)fluorinated carbon chain connected to different functional groups (OECD, 2020). In packaging, depending on the fluorinated carbon chain, a distinction can be made between PFASs. Long chains refer to :

- **Perfluorocarboxylic acids** (PFCAs) with carbon chain length C8 and higher. They include perfluorooctanoic acid (PFOA), which have been phased out from the EU market.
- **Perfluoroalkane sulfonic acids** (PFSAs) with carbon chain lengths C6 and higher. They include perfluorohexane sulfonic acid (PFHxS) and perfluorooctane sulfonate (PFOS); and
- **Precursors** of these substances may be produced or present in products.

Short chains refer to PFCAs with carbon chain lengths inferior to C8 and PFSA with carbon chain lengths inferior to C6 (OECD, 2020).

Sizing with PFAS

To create the chemical barrier in packaging that prevents grease and water from seeping through, a process known as sizing with PFAS is often used. Sizing involves modifying the substrate to control its absorbency, making it resistant to liquids like water, oil, and grease. This process enables PFAS to bond to the substrate, remain in place, and form an effective barrier. Depending on the type of treatment, sizing can alter either the surface or internal structure of the substrate. There are two main approaches to sizing:

- **Internal sizing**: In this method, chemicals are added directly to the pulp during the papermaking process and become embedded within the paper web. This treatment is best used when packaging needs to resist moisture from within its structure. This enhances barrier properties against grease, stains, and water.
    - *Examples: Alkyl Ketene Dimer (AKD)*
- **External sizing**: This involves applying a surface treatment to the finished paper. Since the sizing agent is applied as a coating rather than integrated into the pulp,

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smaller quantities are typically required. PFAS-based coatings often fall in this category.

2.2 Benchmark of PFAS-free food containers

2.2.1 Physical alternatives to PFAS- free food containers

Alternatives to PFAS coatings involve developing a paper structure that resists grease penetration. These PFAS-free alternatives are described in the following section. Figure 1 represents a simplified model of the value chain of these alternatives.

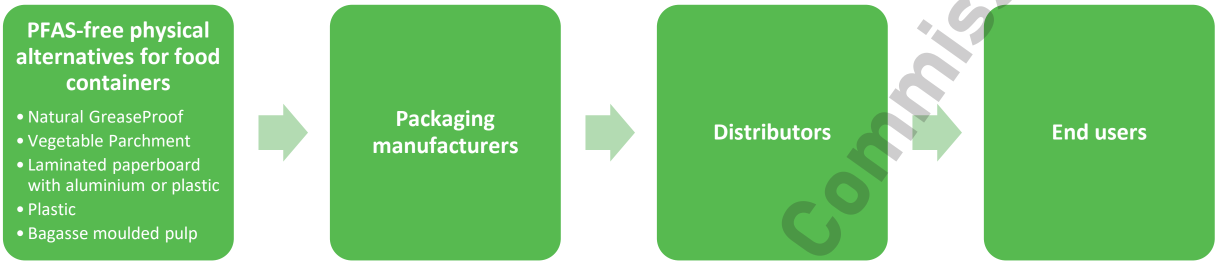

Figure 1. Value chain of physical alternatives to PFAS containers

Natural Greaseproof containers

Natural greaseproof paper (NGP) is commonly used in baking papers, food trays, and containers. It offers both water and grease resistance due to its dense structure, achieved through intensive fibre refining. This process allows the fibres to form strong hydrogen bonds and pack tightly together. Unlike PFAS-coated papers, which rely on chemical treatments to create barrier properties, NGP has a dense, additive-free structure that prevents grease penetration.

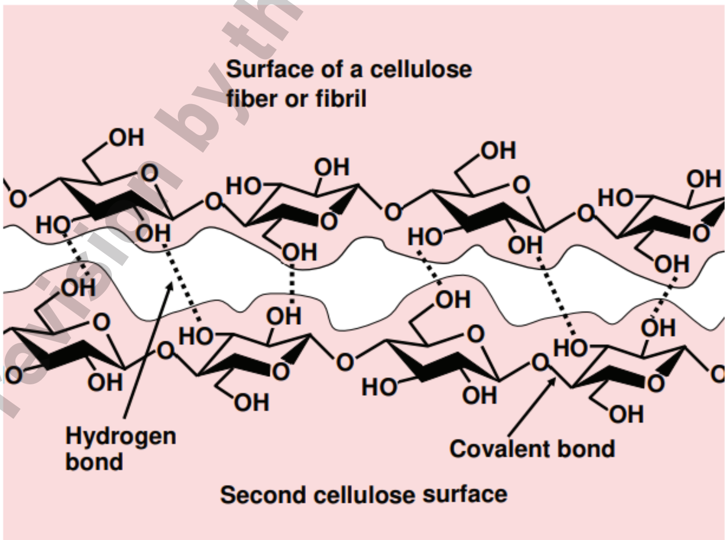

Figure 2. Links between hydrogen bonds between two cellulose surfaces (Hubb & Pruszynski, 2020)

In the market, Nordic Paper supplies the papers Singleproof® and SuperPerga® for greasy food products, as highlighted in the figure below.

Figure 3. Natural Greaseproof paper for food containers, an alternative to PFAS-coated food containers (Nordic Paper, 2025)

Containers with Vegetable Parchment laminated with paperboard

Vegetable parchment is produced by treating paper with a sulfuric acid bath, followed by dilution with water to stop the reaction, and then drying (as illustrated in the figure below). This process results in a dense, low-porosity structure that offers a good resistance to both water and grease. Vegetable parchment is commonly used for food wraps and liners.

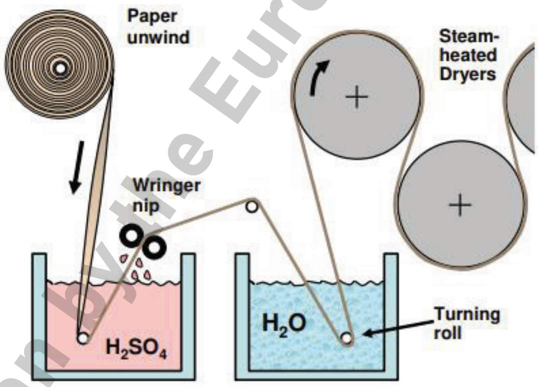

Figure 4. Parchmentizing process (Hubb & Pruszynski, 2020)

When laminated with paperboard, vegetable parchment becomes suitable for thermoforming, making it ideal for food trays and containers used in ready meals, takeout, and greasy foods such as pizza. An example of such a container, produced by Ahlstrom, is shown in the figure below.

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Figure 5. Ahlstrom NatureMold™, a Genuine Vegetable Parchment-based moulding material

Laminated paperboards

Another common alternative to using fluorochemicals is to **laminate the paper with a layer of aluminium or plastic**. These materials not only block grease and moisture, but also provide a barrier against oxygen—something that PFAS coatings do not offer. However, laminated packaging is harder to recycle because the layers are difficult to separate during the recycling process.

Plastic

Lastly, **plastic** has historically served as a substitute for paper; however, there is a growing trend in the EU to reduce its use in food packaging due to its environmental impact, ranging from the formation of the so-called 'sixth continent' of plastic waste, to harmful effects on biodiversity, and the generation of microplastics that may pose risks to human health.

2.2.2 Chemical alternatives to PFAS-free food containers

Chemical barriers can also be obtained through **sizing without PFASs**. As previously mentioned, sizing reduces the paper or moulded pulp absorption while strengthening the printability and water resistance. There are two ways to do sizing:

- Internal sizing: Provides repellence and barrier performance against grease, stains, and water by incorporating agents during the pulp stage
- Surface treatment: This includes applying a coating or treatment to the surface of moulded pulp or paper to enhance its barrier properties. One example is dispersion coating, which forms a thin film to block grease or moisture without the use of fluorochemicals.

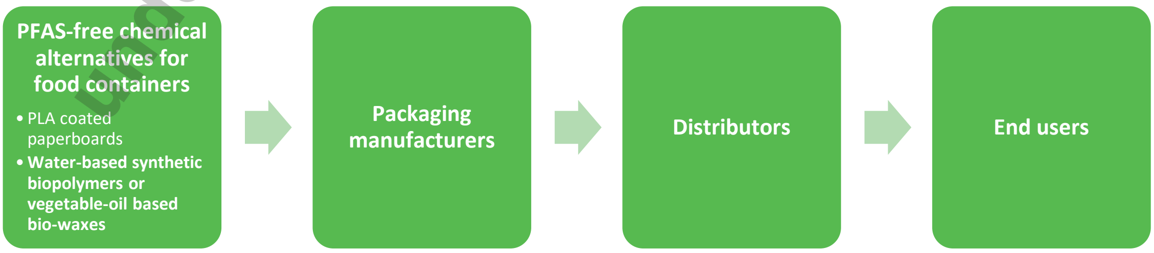


Figure 6. PFAS-free chemical alternatives for food containers

Water-based synthetic biopolymers or vegetable-oil based bio-waxes

Water-based synthetic biopolymers or **vegetable-oil based bio-waxes** are also used in food packaging. Both types offer grease, water and moisture resistance as well as protection against water vapor. This provides ideal packaging applications for foods like hamburgers and dim sum. The water vapor barrier properties can be tailored to meet specific food preservation needs. A PFAS-free solution using spray coating or bagasse-based moulded pulp is available from Greencoat.

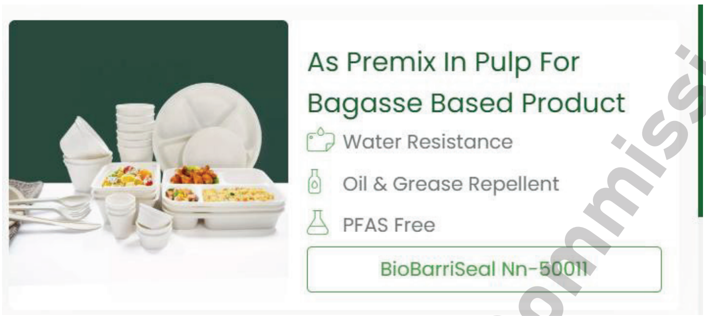
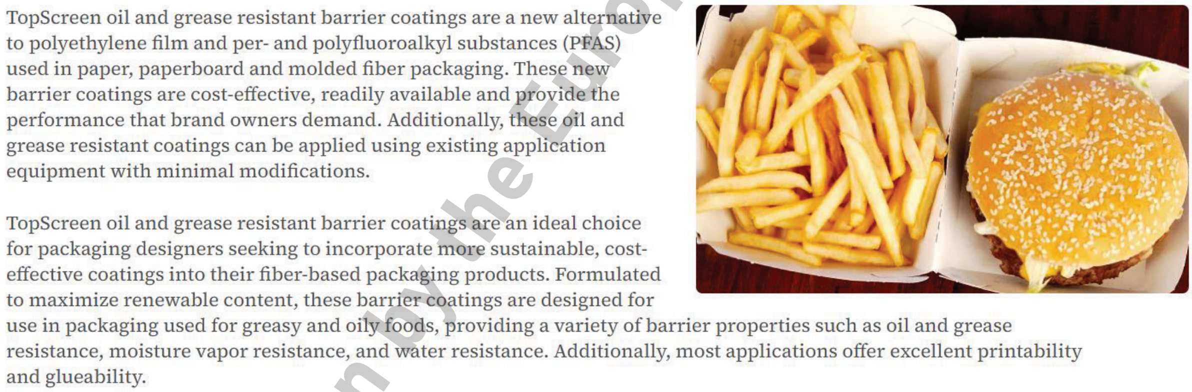


Figure 7. BioBarriSeal, a PFAS-free barrier coating dispersion tailored for bagasse-based moulded fibre products (Greencoat, 2025)

Another example of these formulations is TopScreen™, produced by Solenis, and can be used for hamburgers, fries and pet food.



TopScreen oil and grease resistant barrier coatings are a new alternative to polyethylene film and per- and polyfluoroalkyl substances (PFAS) used in paper, paperboard and molded fiber packaging. These new barrier coatings are cost-effective, readily available and provide the performance that brand owners demand. Additionally, these oil and grease resistant coatings can be applied using existing application equipment with minimal modifications.

TopScreen oil and grease resistant barrier coatings are an ideal choice for packaging designers seeking to incorporate more sustainable, cost-effective coatings into their fiber-based packaging products. Formulated to maximize renewable content, these barrier coatings are designed for use in packaging used for greasy and oily foods, providing a variety of barrier properties such as oil and grease resistance, moisture vapor resistance, and water resistance. Additionally, most applications offer excellent printability and glueability.

Figure 8. TopScreenTM by Solenis

PLA coated paperboards

Other **bio-based materials**, such as **PLA**, can be a good alternative of PFAS-free coatings. However, PLA is primarily used as a plastic substitute rather than a direct replacement for paper, and it has faced criticism for its limited recyclability.

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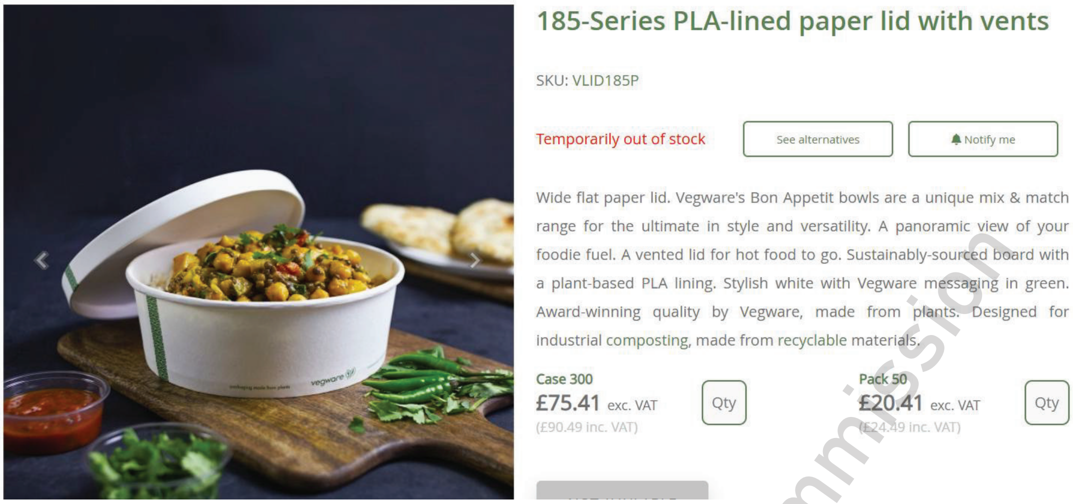

Figure 9. Vegware paperboard with PLA lining

Additional alternatives

Additional alternatives to fluorochemicals coatings in the packaging sector include aqueous dispersions of copolymers (styrene and butadiene), aqueous dispersions of waxes (different from TopScreen), starch, clay, chitosan or cellulose derivatives. A detailed explanation of each alternative is beyond the scope of this paper, in order to maintain conciseness.

2.3 Moulded products in food packaging

Moulded pulp products are a growing trend in packaging material, with a global market estimated at €4.2 billion (USD 4.6 billion) and projected to reach €5.1 billion (USD 5.7 billion) by 2027 (Markets and Markets, 2023). The market gathers different types of applications, such as food and beverages, healthcare, electronics, among others. Food packaging represents 35% of the moulded pulp packaging market.

In food packaging and food service applications, a wide range of packaging types are used, each tailored to the specific needs of the food product, its storage conditions, and how it will be handled or consumed. Factors like protection, preservation, breathability, and structural support all influence the choice of packaging. Below are some common forms of food packaging, each designed to meet particular functional and practical requirements.

Trays

Trays feature a flat, shallow design and are commonly used to hold and display a variety of food products, including fish, meat, fruits, and vegetables. Their structure provides stability and support, helping to prevent damage during handling, transportation, and storage. They are suitable for both refrigerated and frozen storage applications.

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Figure 10. Trays from Ecoproduct

Bowls & Cups

Bowls and cups are designed for both hot and cold food items, making them versatile options for a range of packaging applications.

Clamshells

Clamshells have a two-part design that ensures protection of the food during transportation and storage. In food packaging and service, they are commonly used for items such as fruits and pastries.

Plates

Plates are shallow and designed for on-the-go or event-based dining. Hefei Craft Tableware makes Sugarcane dishes and plates, which offer both water and grease resistance.

Figure 11. Clamshells, Plates and Bowls - VanguardTM Ecoproducts

Within the ZeroF project, the primary product focus is on trays with a depth of 40 mm and bowls intended for cold food items. Food packaging for cold items requires less water, grease, and heat resistance, making ZeroF technology more feasible and easier to implement.

2.3.1 Materials for moulded pulp

Moulded pulp can be made from a variety of biobased materials beyond traditional wood fibres. These include bagasse (sugarcane fibre), wheat straw fibre, bamboo fibre, palm leaves, and elephant grass—offering sustainable alternatives for packaging production.

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PFAS-free moulded products from bagasse in the market

One example of a PFAS-free moulded product is Vanguard™ EcoProducts Europe, which uses sugarcane to create grease-resistant packaging without relying on PFAS chemicals.

Figure 12. Moulded Pulp from Bagasse with grease resistance without PFAS

Another example is the Greencoat tray, previously mentioned for its sustainable, PFAS-free formulation.

2.3.2 Moulding process

Wet Moulding

Moulding for packaging materials can be done through wet and dry moulding. In wet moulding, a mould is dipped into a fibre suspension, and vacuum suction is used to draw water out while allowing the fibres to adhere to the mould. After further dewatering, the material is pressed to remove additional moisture and consolidate the fibres. The moulded product is then dried through a thermoforming step, which further reduces moisture content. In some cases, additional finishing steps, such as surface treatments, are applied before trimming and cutting.

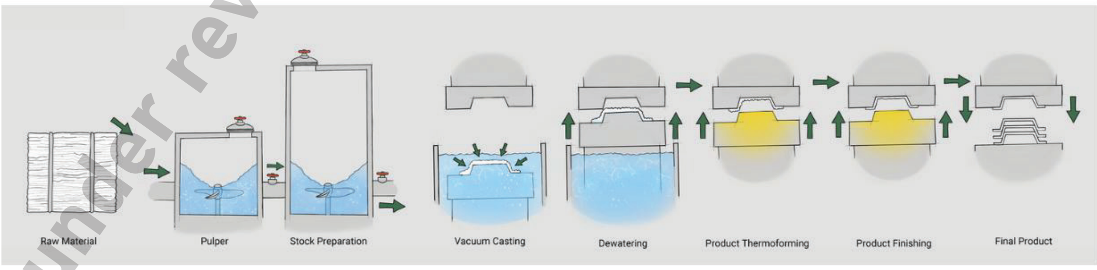

Figure 13. Thermoforming "Thin Wall" Wet Moulding process (Yangi, 2024)

Dry Moulding

Dry moulding, or dry forming, involves processing high-quality cellulose to separate the fibres, which are then uniformly distributed and interlocked to form a consistent structure.

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The geometry and basis weight of the resulting pads can be tailored to the specific application. Once formed, the pads undergo finishing steps such as trimming, cutting, or coating to achieve the desired appearance and performance characteristics.

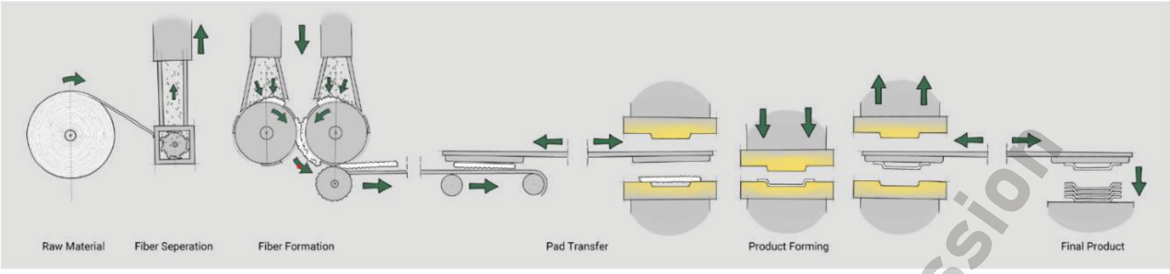

Figure 14. Dry Forming Process at YANGI's (Yangi, 2024)

Both wet and dry moulding are used to produce fibre-based packaging materials, but they differ significantly in terms of process characteristics, resource requirements, and product outcomes. Dry moulding is generally faster, more energy-efficient, and better suited for producing simple, rigid forms. Wet moulding, on the other hand, enables more intricate shapes and smoother surfaces but involves longer cycle times and higher water and energy consumption. Table 1 below provides a comparative overview of the two methods, highlighting their respective advantages and limitations.

Table 1. Benchmark between Wet and Dry Forming

	Wet Moulding (Yangi, 2024)	**Dry Forming** (Yangi, 2024)
End product	**Type**: deeper & intricate products **Characteristics**: smooth, rigid surfaces and flexible designs	**Type**: shallow products **Characteristics**: strength, rigidity, and simple shapes
Cycle times	30-70 seconds	4 seconds
Water consumption	More water consumption than dry forming	Less water consumption than wet moulding
Energy	More energy consumption than dry forming	Less energy consumption than wet moulding
Cost	Potential higher operating and production costs. Specialised equipment required for water-based processes	Potential lower operating and production costs & cheaper tooling

2.4 Performance of PFAS-free containers

A performant food container needs to have a good grease resistance and water absorptiveness. There are a variety of ways to test the grease and water resistance of packaging.

- **The KIT Level** measures the grease resistance of a material based on the TAPPI test method. This test involves applying reagents to the surface of PFAS-treated paper and assigning a resistance rating between 1 and 12, with 12 representing the highest grease resistance. Paper intended for brief contact with dry foods typically requires a lower KIT level, while packaging for greasy foods exposed over longer periods demands a higher

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rating. However, this method is less applicable to PFAS-free alternatives, as it relies on chemical interactions specific to fluorochemicals. Despite this limitation, KIT Level testing remains the industry standard for assessing grease resistance in food packaging.

- The **Cobb test** measures how much water a paper or paperboard surface absorbs over a specified time, typically 60, 180, or 1800 seconds (Cobb60, Cobb180, Cobb1800). Results are expressed in grams per square metre (gsm), indicating the material's resistance to water penetration.
- The **WVM resistance value** evaluates how effectively a packaging material prevents moisture from passing through. This property is essential for food packaging applications that require moisture retention, such as burger wrappers, ensuring that food stays fresh while preventing excessive water absorption.

The required level of resistance in food packaging depends on the type of food and the duration of exposure to grease.

Short-term packaging applications

Short-term packaging applications refer to single-use food packaging designed for immediate consumption and short-term storage. These applications are commonly used in fast food, takeout, and quick-service restaurants. Short term packaging applications are typically boxes used in fast food, such as burger boxes, clamshells, and fry boxes.

Additional applications include Salad boxes , requiring moisture and grease resistance for fresh produce, and Ice cream cups, where TopScreen™ formulations serve as PFAS-free alternatives to PFAS coatings.

Long-Term or High-Performance Packaging Applications

More demanding food packaging applications require enhanced barrier properties to withstand high temperatures, moisture, and grease exposure while maintaining food safety and sustainability. These applications include popcorn bags, food trays for bake-and-serve meals, ready meals, and service counter/takeaway containers, as well as cold food trays.

For cold food trays, where moisture condensation is a concern, coatings help prevent softening and structural degradation, making them suitable for refrigerated meals and takeaway applications.

3. Current dry moulded pulp packaging & coating value chain

This section focuses on the dry moulded packaging and coating value chain. Dry forming technologies are increasingly prioritised in the industry for their sustainability, efficiency, and scalability. Compared to traditional wet moulding, dry moulding offers significant advantages in water and energy use, making it a key area of innovation and investment in the transition toward PFAS-free, fibre-based packaging solutions. The following analysis outlines the structure of the packaging and coating value chain, highlighting the roles of ZeroF partners Yangi and Kemira, alongside other key stakeholders and possible competitors, as shown in Figure 15.

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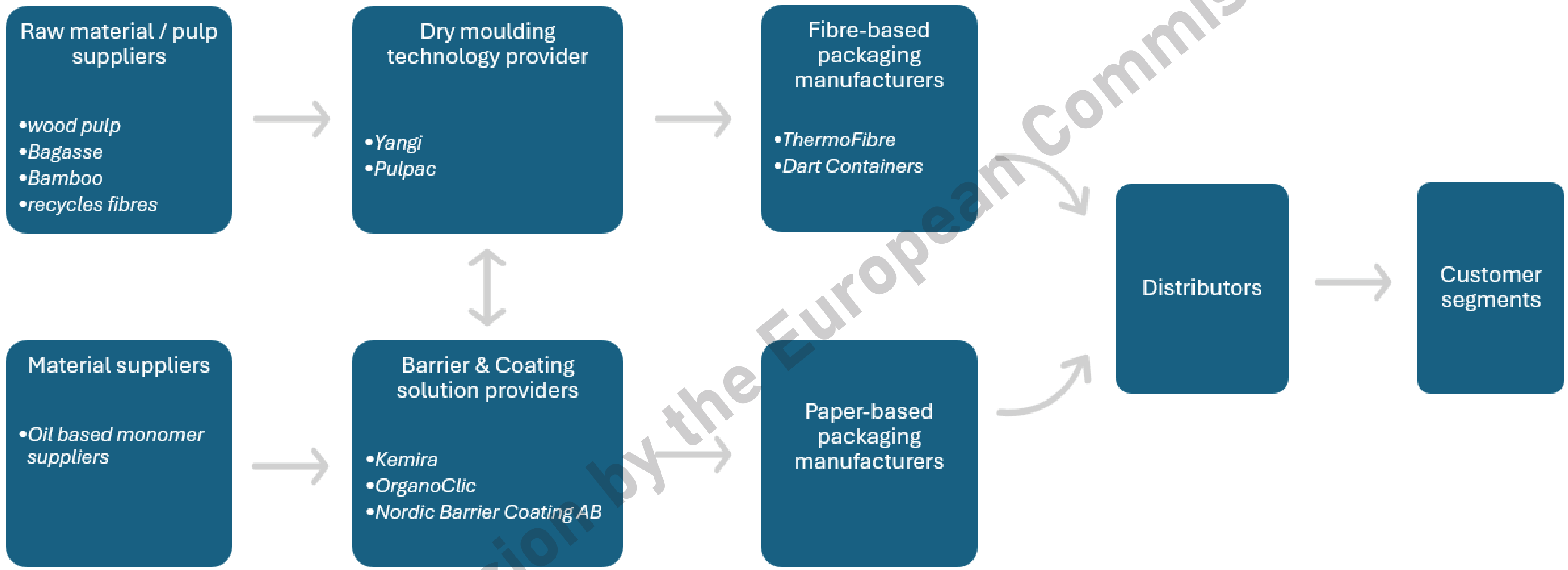

Figure 15. Current dry-moulded packaging value chain

Raw material suppliers

Raw material suppliers hold a critical upstream position in the dry moulded packaging value chain. For forming the physical structure of fibre-based packaging, these suppliers provide cellulose-based fibres sourced from materials such as wood pulp, bagasse (from sugarcane), bamboo, and recycled paper. These fibres form the base of moulded products created through dry forming technologies like Yangi's. To meet the quality and sustainability standards required for food and consumer packaging applications, many fibre suppliers invest in certifications (e.g., FSC, PEFC) and ensure consistent environmental and performance characteristics.

In parallel, the production of functional coatings and barrier layers, such as those provided by Kemira, relies on a different set of raw materials. These include oil-based monomers, bio-based polymers, and a range of chemical additives. These inputs are supplied by specialty chemical companies and are critical to formulating high-performance, PFAS-free coatings that offer resistance to grease, moisture, and heat.

Equipment technology provider

Yangi is a global leader in sustainable packaging solutions and a key partner in the ZeroF project. Specialising in dry forming technology, Yangi provides advanced technology, materials and processes to produce fibre-based packaging that is resource-efficient, low in CO_2 emissions, and compatible with global recycling systems. Their innovation marks a significant shift in the packaging industry, moving beyond environmentally taxing plastics and the water- and energy-intensive wet moulding methods, toward a breakthrough dry forming approach that redefines sustainability in packaging (Yangi, 2024). Yangi specialises in product specifications and tooling, which they license to other manufacturers. Their technology enables the integration of internal pulp sizing with external coatings, such as those provided by companies like Kemira. This approach enhances the product functionality. The collaboration with coating suppliers highlights a dual relationship, where the expertise in chemistry can also help Yangi develop new product specifications.

PulPac is one of Yangi's main competitors within the dry forming packaging market. Pulpac also offers similar technologies for dry moulded fibre packaging. It is actively developing PFAS-free coating solutions in collaboration with OrganoClick and Nordic Barrier Coating AB, who are responsible for the coating chemistry, which applies the barrier coating in the production of nonwoven materials used in the process of PulPac (Packaging Europe). PulPac licenses its technology to manufacturers such as ThermoFibre and Dart Container, who pay PulPac royalties based on their packaging sales. This ensures PulPac benefits from the commercial success of its licensees.

Additive & barrier technology provider

Kemira is a chemical industry group focused on enabling efficient, sustainable, and compliant production processes. Its solutions support the development of fibre-based products such as paper, board, moulded fibre packaging, tissue, and textiles. In the context of food packaging, Kemira's chemistries enable liquid resistance and barrier functionality. As a partner in the ZeroF project, Kemira complements Yangi's machinery and forming expertise by providing the chemical components needed to enhance packaging performance. Together, their contributions support innovation in PFAS-free packaging. Other coating and barrier solutions include, OrganoClick and Nordic Barrier Coating AB, although each organisation differs significantly in scale, scope, and capabilities.

Packaging manufacturer

Packaging manufacturers, or licensees, use the technologies provided by Yangi or PulPac to produce the final packaging products. They are responsible for scaling the production process, ensuring product quality, and meeting client demands.

ThermoFibre, a UK-based company that has integrated PulPac's technology to expand its product offerings, including items such as food trays, lids, and cutlery.

Dart Container, an American company, which has become a PulPac licensee and is installing the first Dry Moulded Fibre production line in North America, known as the PulPac Scala. This strategic move aims to expand Dart's product portfolio to include sustainable packaging options, although specific product details have yet to be announced (Pulpac, 2024).

Distributors

In the moulded pulp packaging market, end-users typically buy packaging either through distributors or via direct supply agreements with moulded pulp packaging manufacturers (Markets and Markets, 2023). While distribution channels may vary by country, a deeper contextual analysis is not required here.

End-users

End-users of moulded pulp packaging typically fall into two categories:

- **Commercial food Service:** This category includes restaurants, caterers, cafeterias, and fast-food outlets. These establishments utilise moulded pulp products such as trays, clamshells, plates, bowls, and cups for serving and packaging food items.
- **Food Packaging Industry:** This category includes eggs, fruits, vegetables, meat, and fish suppliers. Moulded pulp trays and cartons are commonly used to protect these products during transportation and storage, offering cushioning and reducing damage.

4. Future Market with ZeroF solution for packaging

4.1 PESTEL analysis

ZeroF technology represents a significant shift toward PFAS-free moulded packaging and coating, driving both transformation within the existing value chain and broader market impact. To better understand the factors influencing the adoption of ZeroF packaging and coating, this paper presents a PESTEL analysis, examining the political, economic, social, technological, environmental, and legal drivers shaping this transition.

Political factors

Political priorities at the European level are increasingly aligned with the transition toward sustainable, non-toxic packaging solutions. A key element of this shift is the European Green Deal, which sets out a long-term vision for a circular, climate-neutral economy and supports the phase-out of harmful substances like PFAS in consumer products.

One of the clearest signs of this political direction is the **European Union's public funding** for research and innovation in sustainable materials. The ZeroF project, for example, is co-

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funded by the EU's Horizon Europe program, which backs the development of PFAS-free coatings and moulded fibre packaging technologies. Such funding initiatives not only support technological advancement but also de-risk innovation for companies, making it more feasible for industry players to transition away from PFAS-based systems. As these projects gain visibility and success, they help shape the policy agenda and accelerate industry-wide adoption of safer, more sustainable alternatives.

Economic factors

The transition to PFAS-free moulded packaging is influenced by several key factors, including consumer preferences, production costs, and competition from alternative materials, which can either drive or hinder the market transition.

Higher production costs of moulded pulp packaging

Despite its environmental advantages, PFAS-free moulded pulp packaging is often more expensive than plastic alternatives. This is due to higher equipment, material sourcing, and production costs. However, this cost gap may diminish as the industry scales, improves manufacturing efficiency, and benefits from economies of scale (Precedence Research, 2024).

Consumer willingness to pay a premium

Sustainability has become a priority to consumers, pushing brands to explore eco-friendly alternatives. A 2023 survey by GlobalData found that 74% of consumers are willing to pay a premium price for environmentally friendly packaging. This growing consumer demand acts as a strong economic driver, encouraging manufacturers to invest in PFAS-free and fibre-based packaging solutions.

Competition from plant-based plastics

The rise of plant-based biodegradable plastics presents a competitive challenge for pulp-based packaging. This sector is experiencing significant growth, offering brands an alternative solution that combines sustainability with material properties similar to traditional plastics. As these biodegradable plastics become more affordable and widely available, they may pose direct competition to fibre-based packaging solutions.

Social factors

Public health concerns over PFAS exposure

The presence of PFAS in food packaging has become a significant public health concern. Often referred to as "forever chemicals," due to their persistence in the environment and human body, PFAS are linked to serious health effects, including cancer, hormonal disruption, immune system suppression, and reproductive harm. Dietary exposure to PFAS, especially from fast food and processed foods packaged in PFAS-coated materials, has been shown to elevate serum concentrations in consumers (Susmann, Herbert; Schaider, L; Rodgers, K;, 2019). As scientific evidence continues to accumulate, public pressure on regulators and brands to eliminate PFAS from packaging is intensifying.

Growing consumer awareness

As consumers become increasingly aware of the environmental and health impacts of the products they use, demand is growing for sustainable, non-toxic alternatives to conventional plastics and PFAS-coated packaging. This societal shift is driving companies to invest in PFAS-free solutions and to communicate their sustainability commitments more openly and transparently.

Food delivery trends

The rapid growth of the food delivery and takeaway industry has significantly increased demand for packaging that is not only grease-resistant and durable but also sustainable. While this trend supports the adoption of PFAS-free alternatives, it also introduces challenges. Many consumers still expect the convenience and functionality associated with plastic or PFAS-coated packaging, such as leak-proof containers or heat resistance. As a result, there can be resistance to packaging alternatives that are perceived to be less effective. Nevertheless, expectations for sustainability are rising even in this sector, pushing brands to innovate and find PFAS-free solutions that meet performance standards without compromising convenience.

Technological factors

Technological capabilities play a critical role in determining whether PFAS-free packaging can meet market demands.

Grease and water resistance from PFAS-free solutions

A major technological challenge in replacing PFAS-based packaging is achieving equivalent levels of grease and water resistance. Plastic packaging and PFAS coatings typically perform well in this area, particularly for high-fat content foods. For PFAS-free coatings to be viable in demanding applications, they must achieve high KIT values, ideally KIT 7 or above. Reaching this level of performance would enable use in products such as butter wraps or fast-food packaging. The ZeroF technology aims to meet this threshold, but consistently achieving such performance remains difficult. Until these technical hurdles are overcome, plastic and PFAS-coated solutions may retain a competitive edge in certain applications.

Technological performance of bioplastics

Bioplastics, derived from renewable resources such as cellulose, starch, or vegetable oils, offer several technical advantages over moulded pulp alternatives. These include enhanced visual appeal, smoother surfaces, and better moisture resistance, which make them attractive to both brands and consumers. Additionally, bioplastics can be engineered to be biodegradable or compostable. Their versatility and improved performance characteristics pose a competitive challenge to fibre-based packaging technologies.

Environmental factors

Environmental concerns are among the most significant drivers influencing the shift away from PFAS-based and plastic packaging toward PFAS-free alternatives. These include not only the direct impacts of persistent chemicals like PFAS, but also the broader environmental footprint of materials and production processes used across the packaging industry.

PFAS environmental contamination

PFAS are known for their extreme persistence in the environment, earning the name "forever chemicals." They accumulate in soil, water, and living organisms, including humans, and are difficult to remove once released. Their widespread contamination, including in drinking water and ecosystems, has become a major environmental concern globally. The

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long-term impact of PFAS pollution is increasingly influencing public policy, industry standards, and consumer expectations, all of which are pushing toward PFAS-free packaging alternatives.

Carbon footprint of packaging materials

Reducing the carbon footprint of packaging is a key environmental driver supporting the transition to dry moulded fibre technologies. Compared to plastic, dry moulded fibre products often have a significantly lower climate impact. For instance, a 2025 study by RISE assessed the environmental performance of Dry Moulded Fibre spoons and found a climate impact of just 2.5 g CO_2eq per spoon, or 0.66 kg CO_2eq per kilogram of product. In contrast, a life cycle assessment (LCA) of polypropylene (PP) cutlery in Denmark reported an impact of 15 g CO_2eq per piece, or 4.2 kg CO_2eq per kilogram (Takou, 2019). These findings highlight the substantial climate benefit of switching to dry moulded fibre, especially when scaling up production. Notably, the main environmental impact comes from the input materials (e.g., fluff pulp and tissue), while the dry forming process itself accounts for just 7% of the total carbon footprint (Pulpac, 2025).

Land-use and resource sourcing

While fibre-based packaging offers many environmental benefits, land use and sourcing of raw materials remain important considerations. Moulded pulp can be derived from a variety of renewable resources, such as bagasse, bamboo, wood, and wheat straw. These materials vary in their geographic availability, farming intensity, and environmental trade-offs. For example, bagasse is a byproduct of sugarcane processing and considered a waste valorisation option, whereas wood pulp may involve more intensive land and forest use. The environmental impact of land use depends on sourcing practices, transportation, and local ecosystems. Ensuring responsibly sourced, certified raw materials is essential for maintaining the environmental integrity of PFAS-free packaging solutions.

Legal factors

A growing number of legal measures at the European level are accelerating the shift toward PFAS-free coatings and packaging solutions such as ZeroF. While many of these restrictions are still under development and may take several years to come into effect, the European Commission has made clear its intention to phase out PFAS in consumer products wherever possible. These upcoming regulatory changes are expected to have a significant impact on the food packaging sector. Key regulatory initiatives that are currently implemented include:

The **Ecodesign for Sustainable Products Regulation (ESPR)** and EU Ecolabel aim to significantly improve the sustainability of products placed on the EU market and , therefore, provide additional support to the adoption of sustainable packaging alternatives.

Moreover, the **European Union's Single-Use Plastics Directive** aims to reduce the ten most commonly found single-use plastic items on European beaches by 70% by 2025, reinforcing the political momentum toward fibre-based, PFAS-free solutions.

The EU is also in the process of revising its **Food Contact Materials (FCM)** regulation, with particular attention to PFAS and other harmful substances in packaging that comes into direct contact with food. The revision aims to harmonise safety standards across Member States and strengthen consumer protection. The Framework Regulation (EC) no 1935/2004 requires tat a new coating (Material) and/ or a new container (Article) do not:

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- Release their constituents into food at levels harmful to human health
- Change food composition, taste and odour in an unacceptable way

In addition to general regulations, more specific rules govern the development of coatings intended as alternatives to PFAS, as well as the final packaging itself. For coatings, a key regulation at the EU level is Regulation (EU) No 10/2011, which mandates that plastic materials and articles intended for food contact must undergo chemical characterisation. This process requires a complete identification and quantification of migrating substances to ensure safety. In contrast, there is currently no EU-level regulation specifically addressing the overall packaging of paper-based food contact materials (FCMs). As a result, companies must comply with national regulations in each country where their products are marketed.

For detailed information regarding the regulations surrounding packaging and coating, a dedicated deliverable D6.7, titled "Strategic certification/standardisation roadmap to achieve cost-effective certification compliance" will be published as part of the ZeroF project. This document will provide comprehensive insights into the relevant regulatory requirements and compliance measures.

4.2 SWOT analysis

In addition to identifying the range of drivers influencing the market uptake of ZeroF packaging, a SWOT analysis provides insight into the specific strengths, weaknesses, opportunities, and threats associated with the adoption of ZeroF technology. These are summarised in Table 2.

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Table 2. SWOT packaging

Strengths	Weaknesses
o PFAS-free, bio-based solution with both grease and water resistance, KIT Level 3 o Lower carbon footprint than plastics and wet moulded fibre o Strong EU project support o Strategic collaboration	o Still under development, higher KIT level not yet reached o Technical limitations: grease resistance and dry-moulded shapes o High production and scale-up costs compared to plastic or PFAS-based packaging o Uncertain recycling
Opportunities	**Threats**
o Rising consumer and brand demand for sustainable packaging o Regulatory drivers o Booming food delivery & takeaway market o Strategic collaborations within the food market (new partnerships & client segments)	o Regulatory uncertainty: Policy delays could slow market readiness o Price sensitivity in food and packaging sectors o Risk of underperformance or unmet technical goals o Growing competition from PFAS-free coating suppliers

Strengths

The ZeroF technology delivers several compelling advantages that position it as a leading solution in the shift toward PFAS-free packaging. Most notably, it offers a bio-based, PFAS-free alternative that aligns with emerging regulatory demands and addresses rising health concerns associated with fluorochemicals. Yangi is developing a grease-resistant range targeting low-demand food applications such as salads, takeaway meals, and meat, with current performance reaching KIT level 3.

In addition to its functionality, ZeroF is backed by a sustainable dry moulding process that consumes significantly less water and energy than traditional wet moulding and contributes to a lower carbon footprint and reduced environmental impact at end-of-life. These combined attributes reflect ZeroF's integrated packaging and coating approach, its alignment with EU sustainability goals, and its potential to serve as a scalable and compliant alternative in the evolving packaging market.

Weaknesses

Despite its promises, the ZeroF technology still faces several challenges that could limit its widespread adoption. One of the main technical hurdles is replicating the highest levels of grease resistance, which are required for more demanding food applications. So, while the technology has achieved KIT level 3, this may not yet meet the needs of high-fat or hot food packaging.

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Moreover, Yangi also identifies technical limitations in shaping certain formats, such as deep clamshell containers, which are difficult to achieve through dry moulding processes.

Costs also remain a main barrier, as dry moulding and bio-based coatings are currently more expensive than conventional plastic and PFAS-based packaging. This cost gap could limit uptake, especially in price-sensitive markets. ZeroF will also face market entry challenges as the technology will compete with well-established PFAS-based and plastic packaging solutions.

Furthermore, while the coatings may be biodegradable, some may not yet be compatible with mainstream recycling infrastructure, raising questions about end-of-life handling.

Opportunities

A variety of market and regulatory dynamics present significant opportunities for the adoption of ZeroF technology. Consumer preferences are shifting rapidly toward safer, more sustainable options, with recent studies showing that 74% of consumers are willing to pay more for environmentally friendly packaging.

At the same time, the regulatory landscape is tightening, with increasing bans on PFAS and growing restrictions on single-use plastics, creating strong incentives for food brands to transition to compliant alternatives.

The booming food delivery and takeaway sector further amplifies demand for grease-resistant and functional packaging that also meets sustainability expectations.

As ZeroF technology approaches commercial readiness (TRL 9), strategic collaboration with major food packaging brands and distributors offers a clear path to accelerate market entry, enhance visibility, and position the technology as a leading PFAS-free solution in both domestic and international markets.

Threats

Despite growing momentum for PFAS-free alternatives, several external factors could challenge the widespread adoption of ZeroF technology. Although regulatory pressure is increasing, legislative changes often take years to be fully implemented, potentially delaying industry-wide transitions and creating a period of uncertainty.

High production costs may further hinder adoption, particularly if competitors succeed in developing more affordable PFAS-free solutions.

In addition, other bio-based alternatives could appeal to the same sustainability-focused customer base, intensifying market competition. Several companies, including OrganoClick, Solenis, and others, are actively developing their own PFAS-free coatings for fibre-based packaging, which may reduce ZeroF's differentiation once these solutions reach the market.

Finally, the uncertainty surrounding scale-up timelines means that the first technology to achieve commercial viability at scale could capture a significant market advantage, posing a risk to slower-moving alternatives like ZeroF.

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4.3 New PFAS-free packaging value chain

Evolution of PFAS-free moulding and coating

As regulatory pressure and environmental concerns surrounding PFAS intensify, a growing number of organisations across the packaging value chain have and are actively developing PFAS-free alternatives. Both dry moulding technology providers and coating solution companies are investing in R&D to identify sustainable, high-performance materials. While several PFAS-free packaging solutions are already available on the market, they often fall short when it comes to combining both high grease and water resistance—a critical requirement for food-contact applications.

Yangi, a pioneer in dry moulded fibre packaging, is already committed to PFAS-free innovation, designing its technology and packaging concepts around renewable, recyclable, and non-toxic materials. However, like other players in the space, Yangi continues to explore ways to enhance the barrier performance of its packaging to meet the demanding standards of food service and takeaway use. Within the ZeroF project, Yangi is actively researching the development of a powder-based packaging specification. This innovative approach offers several advantages over traditional liquid emulsions, including extended shelf life, improved handling, and a significantly lower environmental impact compared to conventional plastics. Although powder applications are not new in the industry, they come with several challenges, such as achieving precise dosage control and ensuring an even distribution of the powder layer. The ZeroF project aims to overcome these challenges through innovative technology and application processes, which will be safeguarded by patent protection.

On the coating side, **Kemira** already offers PFAS-free solutions that achieve high levels of grease resistance. Within the ZeroF project, however, the company is working to develop a bio-based coating that delivers both superior grease and water resistance, a combination that is particularly difficult to achieve, as enhancing one often compromises the other. Kemira's goal is to create a low-carbon, biodegradable, and recyclable solution that matches or exceeds the performance of traditional PFAS-based coatings.

The ZeroF project brings these efforts together with the aim of creating next-generation PFAS-free food packaging that delivers a high level of both grease and water resistance, outperforming current PFAS-free alternatives.

The ZeroF technology is expected to reshape the packaging value chain by introducing new suppliers, customers, technology requirements, and production processes. Although the technology is still under development and has not yet reached its targeted performance level (KIT level 3), this section outlines the anticipated shifts within the value chain driven by the adoption of ZeroF's PFAS-free solutions. While this analysis focuses on Kemira and Yangi, two key players in the packaging supply chain involved in dry moulded fibre forming and coating, similar changes are expected across the industry, as other actors are likely to follow with comparable PFAS-free innovations. Figure 16 displays the changes in value chain for Kemira and Yangi with the new ZeroF technology.

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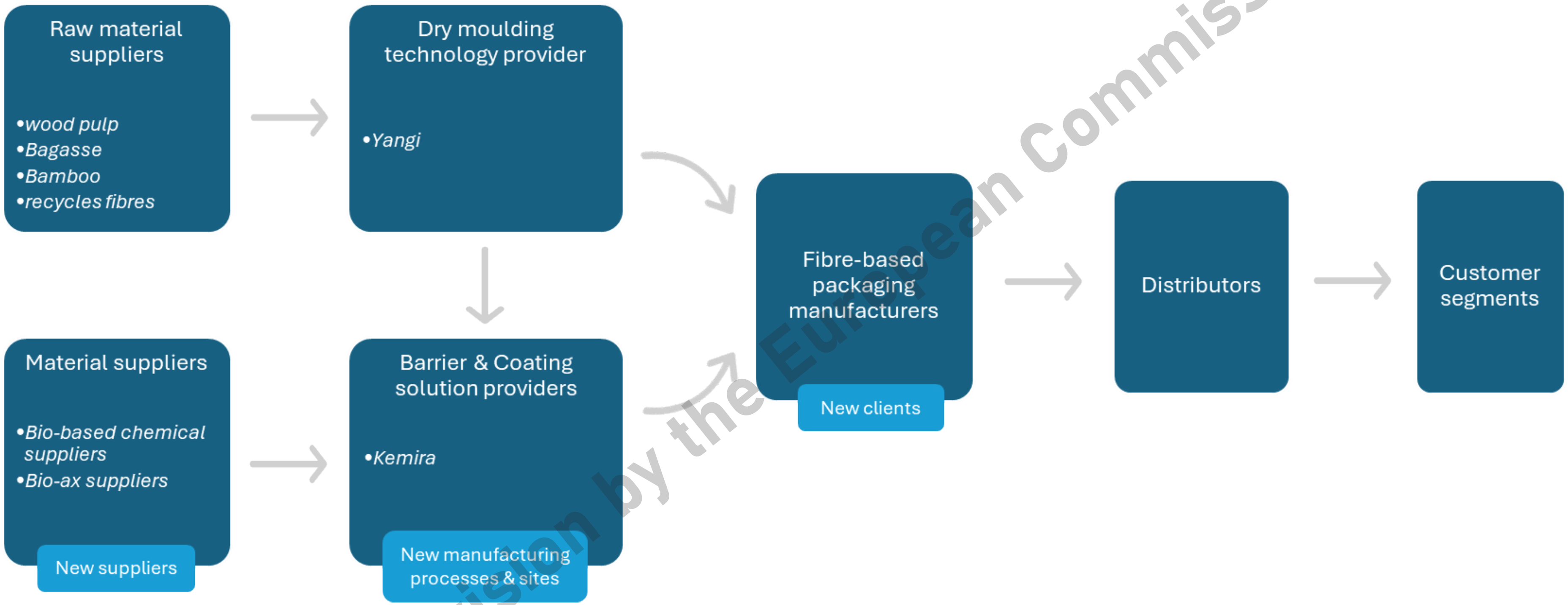

Figure 16. New dry-moulded packaging value chain

Kemira

The development of ZeroF technology has the potential to significantly transform Kemira's value chain. First, the shift toward bio-based chemistry will require Kemira to establish new supplier relationships. Secondly, the coating formulation and application processes will evolve. Integrating ZeroF's PFAS-free technology may require changes across Kemira's product formulations, development, and manufacturing operations. To scale up production and meet growing market demand for sustainable coatings, Kemira may need to invest in new production facilities, modify existing lines, or create dedicated infrastructure for bio-based coatings. This represents both a technological and logistical shift in their operations. Importantly, the adoption of ZeroF technology opens up new customer segments. While Kemira's traditional clients have primarily been paper and board packaging producers, PFAS-free barrier coatings designed for dry moulded fibre applications could position Kemira to serve a growing base of fibre-based moulded packaging manufacturers.

Yangi

Yangi is currently developing a new powdered moulding packaging application, where the powder is applied on top of the pressed material using manual sealing. Although this process is currently limited to a laboratory scale, Yangi aims to transition to machine testing to scale up production and achieve larger quantities. At present, Yangi remains in the lab testing phase. While this new powdered packaging specification will require Yangi to achieve several technical advancements, it does not significantly alter their existing value chain. The company's suppliers and clients are expected to remain largely unchanged. Once the powdered packaging application is successfully developed, Yangi intends to secure its technology through patent protection.

Despite these upstream and midstream changes, Kemira's and Yangi's downstream distribution model and end-customer segments, such as food brands and packaging converters, are likely to remain stable. As food companies and retailers increasingly seek compliant, PFAS-free packaging solutions, they are expected to follow the market shift and adopt more sustainable packaging materials developed through partnerships like ZeroF.

4.4 Recommendations to the Consortium

Scaling the PFAS free technology & packaging alternative

Focusing on cold food

To scale up the project, it is recommended to focus on cold food and other materials than clamshells. Focusing on salads, takeout meals, and cold food trays allows for quicker market entry while refining the coating's grease resistance capabilities.

Engaging with customers of Yangi and food manufacturers

Engaging early with end-users can be key to ensuring the product meets market needs. During the scale up of the ZeroF technology, it is important to consider conducting pilot programs with major food manufacturers or fast-food chains to gain real-world feedback before large-scale production.

Providing LCA comparable to plastic containers

When the technology has reached industrial scale, it is advised to compare the LCA of moulded pulp with plastic to understand the environmental benefits of dry moulded pulp.

Assessing the impact on waste management and recycling

Since PFAS-free coatings may still introduce recyclability challenges, it could be interesting to be working with waste management and recycling companies to assess and minimise the impact of ZeroF coating solutions on wastewater treatment processes.

Selling PFAS-free coating to the packaging industry

Expanding to High-barrier applications

It will be important to explore the opportunity of selling the coating technology for high-barrier applications such as ready-meal trays, pizza boxes, and baked goods packaging, where PFAS alternatives are still underdeveloped.

Collaboration with paperboard and paper manufacturers will be crucial. One example could be Ahlstrom, with the R&D centre in Pont-Êveque, and the mill in Rottersac, selling baking papers.

Expanding to Flexible Packaging applications

If the coating is successful on moulded pulp, the PFAS-free coating can generate value and revenues, by being sold for different applications, especially for flexible packaging:

- Wrapping papers: butter and margarine wrapping papers, snack packaging papers, hamburger wrapping paper or sweets wrap….
- bags (e.g., microwave pop-corn bags, French fry bags),
- sleeves,
- plates and containers for fast food and short shelf-life foods (salads, sandwiches, pastries, biscuits…)

Collaboration with major paper & packaging manufacturers will be important to integrate the coating into existing paper-based food packaging products. Ahlstrom's mill in Rottersac could be a potential user of the coating technology.

Selling PFAS-free coating to other industries

Partnering with scientific community

Partnering with the broader scientific community will be crucial to ensure the continuity and adaptability of PFAS-free coatings in other sectors, particularly within the OEM industry.

Identifying other segments

Identifying non-food applications where grease-resistant PFAS-free coatings are in demand, such as medical packaging, could be interesting for the ZeroF coating technology.

Implementing robust intellectual property on the coating technology

To accelerate market penetration without requiring direct production scaling, ZeroF should implement a robust intellectual property (IP) and **licensing strategy**. This approach will allow the owners of the ZeroF coating technology to generate revenue, expand market reach, and establish its coating as a standard in PFAS-free food packaging while minimising capital investment in manufacturing.

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5. Current market in grease resistant fabrics for upholstery textile

5.1 PFAS coatings in upholstery textile

5.1.1 Textile with PFAS

Per- and polyfluoroalkyl substances (PFAS) are widely used in the textile industry, including upholstery, due to their exceptional ability to repel water, oil, and stains. In the context of upholstery textiles, PFAS-based coatings contribute significantly to product longevity and functional performance, making them a common choice in residential, commercial, and institutional furniture.

Upholstery textiles are fabrics specifically designed to cover and pad furniture. Beyond their functional role in comfort and protection, they are central to interior design, contributing to the aesthetic value and ambiance of spaces in homes, offices, hotels, and public buildings. These textiles are manufactured using a wide range of materials, including natural fibres (e.g., cotton, wool, silk, linen) and synthetic fibres (e.g., polyester, nylon, acrylic). In many cases, blended fabrics that combine natural and synthetic fibres are used to optimise performance characteristics such as comfort, durability, cost-efficiency, and visual appeal. The selection of fabric type depends on the specific end use and desired properties, such as abrasion resistance, ease of maintenance, and long-term appearance retention (Reports and Data, 2024).

Within this context, PFAS are commonly applied to textiles to meet demanding performance standards (Textile World, 2021). The primary PFAS compounds used in textile applications include:

- **Polytetrafluoroethylene (PTFE)**, a PFAS polymer used to create vapor-permeable membranes that enable waterproofing while maintaining breathability.
- **Long-chain fluorinated polymers**, commonly referred to as C8 chemistries, which have historically been used for oil, stain, and water repellency.
- **Short-chain fluorinated polymers**, including C6 and C4 chemistries, which are increasingly adopted as alternatives to C8 compounds and serve the same repellency functions.

These substances are also used in other applications such as fire-fighting foams, paints, surgical instruments, electronics, and cable housing. However, their use in textiles remains significant due to the performance benefits they offer.

Despite their effectiveness, PFAS pose serious **environmental and health risks**. These substances are highly persistent in the environment and in the human body, where they accumulate over time. Long-chain PFAS such as PFOA and PFOS, which are terminal degradants or impurities associated with C8 chemistry, have been linked to adverse health effects. In response to these concerns, their production has been discontinued in several regions, including the United States, where short-chain PFAS have been introduced as substitutes. However, short-chain PFAS (e.g. PFHxA, linked to C6 chemistry) are also considered problematic due to their mobility in the environment, potential for human exposure, and continued environmental persistence, even if they bioaccumulate less than their long-chain counterparts.

The table below provides an overview of common textile-related PFAS materials, their functions, additional end-use examples, and regulatory status in the United States:

Table 3. Non-comprehensive list of textile-related PFAS materials

Name & Compound Type		Textile-Related Function	Other End-use Examples	Terminal Degradant, Impurity or Metabolite		Production Status in US
PTFE	PFAS Polymer	Vapor-permeable membranes for waterproofness	Electronics, surgical instruments, cable housing	-	-	**Ongoing**
Long-chain fluorinated polymer (C8)	PFAS Polymer	Oil, stain, and water repellency	Fire-fighting foam, paints, coatings	PFOA, PFOS	PFAS non-polymer	**Discontinued, replaced by short-chain alternatives**
Short-chain fluorinated polymer (C6 or C4)	PFAS Polymer	Oil, stain, and water repellency	Fire-fighting foam, paints, coatings	PFHxA	PFAS non-polymer	**Ongoing**

Given the regulatory pressure and the growing awareness of PFAS-associated risks, there is an urgent need to identify fluorine-free alternatives that meet the same functional requirements while adhering to the principles of safe and sustainable design (SSbD). The ZeroF project addresses this challenge by developing new coating chemistries intended to replace PFAS in the upholstery textile value chain, without compromising on performance.

5.1.2 Fabrics

As outlined in the previous section, PFAS are applied to upholstery textiles to enhance their resistance to water, oil, and stains. However, the effectiveness and relevance of such treatments can vary significantly depending on the underlying fabric to which they are applied. Upholstery textiles are manufactured using a wide variety of fibres, each offering distinct properties that influence not only performance but also aesthetic appeal, maintenance requirements, and suitability for specific environments or usage scenarios.

Upholstery fabrics can be broadly categorised into natural and synthetic fibres:

Natural fibres

- **Cotton** is one of the most commonly used and cost-effective natural fibres. It offers comfort, decent durability, and fade resistance, but it is prone to staining and may not be ideal for high-use environments.
- **Linen** is valued for its refined appearance and intricate patterns, making it popular in decorative, adult-oriented spaces. However, it wrinkles and stains easily and typically requires professional cleaning.
- **Silk**, a luxurious and expensive option, is best suited to formal settings with limited use. Like linen, it also demands professional cleaning and is sensitive to wear.

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- **Wool** is durable and resistant to fading, wrinkling, and soiling. For upholstery, wool is often blended with synthetic fibres to improve cost efficiency and performance.

Synthetic fibres

- **Acetate** was developed to mimic silk but lacks durability, being vulnerable to fading, wrinkling, and staining.
- **Acrylic** originated as an outdoor fabric due to its resistance to sunlight and mildew. It resists fading and soiling, although lower-quality versions may pill.
- **Modacrylic**, a modified version of acrylic, is known for its flame retardance and strong resistance to heat and wear, making it well-suited for public settings.
- **Nylon** is typically used in blends to improve the strength and resilience of fabrics. It prevents crushing but can fade under UV exposure and may pill over time.
- **Olefin** (e.g., polypropylene) is highly resistant to moisture, mildew, staining, and scratching. It is ideal for high-performance and outdoor use.
- **Polyester** is commonly blended with natural fibres like cotton to enhance wrinkle resistance and colourfastness, striking a balance between comfort and practicality.
- **Rayon** is strong and affordable, often used in casual settings or children's furniture, but it tends to wrinkle.

The fabric construction method also impacts the final properties of upholstery textiles. After fibres are spun into yarns, these yarns are typically converted into fabric by:

- **Weaving**, the most common method for upholstery, produces structured and durable textiles through the interlacing of warp and weft yarns at right angles. Common weaves include jacquard, velvet, and twill, each offering different textures and strengths.
- **Knitting**, while less frequent in upholstery, creates more flexible and stretchable fabrics by looping yarns. This method is suitable for certain soft furnishings that require elasticity or comfort.

In the context of ZeroF, the textile developments have primarily focused on **100% polyester (PES)** fabrics, widely used in **home textile applications**. Polyester offers an ideal balance between performance, durability, and compatibility with coating processes, making it a strategic choice for exploring PFAS-free alternatives.

The properties of these fabrics, including their resistance to wear, aesthetic appearance, and functional performance, are critical in determining their suitability for various end uses, which will be further explored in the next section.

5.1.3 End uses

As discussed in the previous section, upholstery textiles come in a wide range of fibres and constructions, each selected to meet specific performance and aesthetic requirements. These differences are not only technical but also deeply connected to the **end-use** context. The intended use of the textile strongly influences the choice of fibre, the need for specific surface treatments (such as PFAS-based repellents), and compliance with safety and durability standards.

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Upholstery textiles are employed across several key sectors, each with distinct needs in terms of functionality, comfort, and regulatory requirements. The primary end-use markets include residential, contracting, automotive, and marine applications, as illustrated in Figure 17.

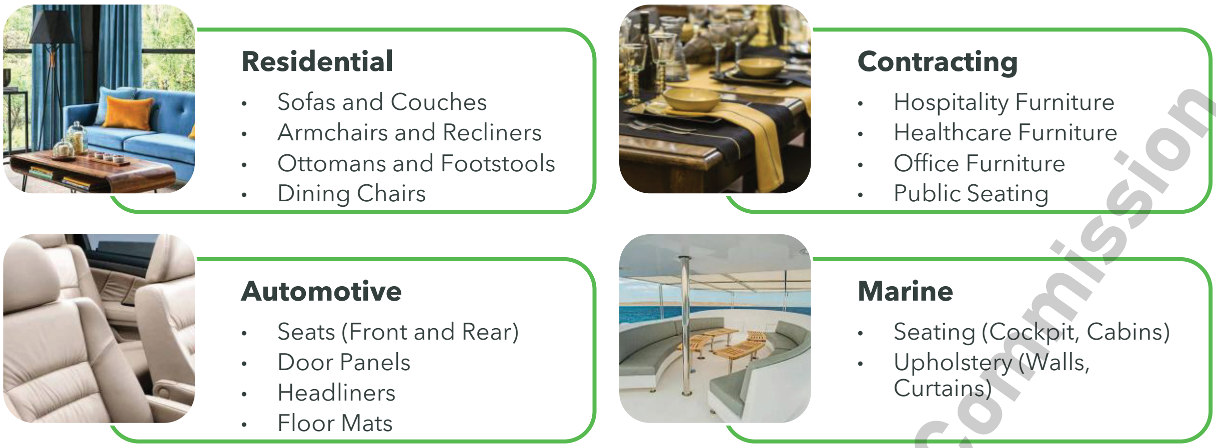

Figure 17. Upholstery textile end-uses

Residential

The residential segment in the upholstery textile market plays a pivotal role, driven by increasing consumer interest in home aesthetics, comfort, and customisation. Upholstery textiles in this segment include a variety of fabrics used for furniture coverings, such as sofas, chairs, cushions, and other residential furnishings.

With the growing trend of home decor and interior design, consumers are seeking high-quality, durable, and stylish textiles that align with their personal tastes and lifestyle. While rising inflation and stagnant wages have affected household budgets in many regions, there remains a strong consumer segment that continues to invest in premium and design-forward upholstery materials, particularly among homeowners prioritising comfort, longevity, and sustainability in their living spaces. Additionally, the growing influence of social media and home improvement shows has heightened awareness about interior design, further fuelling the demand for trendy and contemporary upholstery fabrics.

Sustainability is also becoming a crucial consideration for consumers in this segment. There is an increasing preference for organic or recycled materials, reflecting broader global concerns about environmental impact. Moreover, technological advancements have led to the development of performance fabrics that are stain-resistant, easy to clean, and highly durable, making them particularly attractive for residential use.

Contracting

Contracting textiles cater to commercial spaces such as hotels, offices, hospitals, and public buildings. These environments require high-performance fabrics that are durable, fire-retardant, and resistant to heavy use. The market is growing significantly due to the increased demand for aesthetically appealing and functional fabrics in public spaces. Contracting textiles must meet strict regulatory standards, particularly in terms of flame retardancy and health safety. These fabrics often incorporate stain-resistant and antimicrobial finishes to ensure longevity and cleanliness in high-traffic areas.

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Automotive

The automotive sector is another significant contributor to the growth of the upholstery textile market, the demand for high quality, durable, and aesthetically pleasing upholstery textiles for automotive interiors is rising. This demand is further bolstered by the growing trend towards electric vehicles, which often feature premium upholstery materials. The expansion of the automotive industry is driving demand for high-quality upholstery textiles.

Marine

Marine upholstery textiles are designed to withstand harsh environmental conditions such as saltwater, UV exposure, and temperature fluctuations. Fabrics used in boats and yachts need to be highly resistant to moisture, mold, and mildew while maintaining durability and ease of cleaning. The marine upholstery market also focuses on textiles that are water and stain-repellent, ensuring that the products can maintain their appearance and functionality over extended periods in challenging environments.

5.1.4 Properties

As outlined in the previous section, the wide variety of upholstery textile end-uses—from home interiors to marine and automotive settings—requires materials that not only align with aesthetic preferences but also deliver robust and reliable performance. Upholstery textiles are expected to endure intense physical and environmental stress while maintaining their appearance, comfort, and safety. As a result, the industry places a strong emphasis on fabric durability, resilience, protective functionality, and compliance with safety standards.

One of the defining features of upholstery fabrics is their **durability**, particularly in high-traffic and commercial environments. Properties such as abrasion resistance, tensile strength, and tear strength are critical to ensuring a long product lifespan. For example, the Martindale test is widely used to assess abrasion resistance; fabrics achieving 50,000 cycles are considered highly durable, while those surpassing 100,000 cycles are regarded as extremely durable, suitable for public seating and heavily used furniture (Tèxtils.CAT, 2024).

Another essential performance criterion is **resistance to fading**, especially for textiles exposed to sunlight in settings like residential or marine applications. Many fabrics incorporate UV-resistant finishes to preserve colour and integrity over time.

In parallel, **water and stain repellency** has become a central feature of high-performance upholstery textiles. In everyday use, spills, dirt, and moisture can rapidly degrade fabric condition. To counter this, manufacturers often apply protective finishes—such as PFAS-based treatments or newer alternatives—that repel liquids and resist staining. These treatments are especially valued in households with children or pets, in marine settings where moisture is omnipresent, and in hospitality environments where cleanliness is essential (Reports and Data, 2024).

Flame retardancy is another critical property, particularly for contract and transport applications where compliance with strict fire safety regulations is mandatory. Flame-retardant treatments, or the use of inherently flame-resistant fibres (e.g., modacrylic or treated PES), are commonly used to meet sector-specific standards. These properties are not optional, but rather required by legislation and certifications, especially in sectors like healthcare, public transport, and marine upholstery.

Ultimately, the fabric structure and composition, which are shaped during yarn spinning, weaving, or knitting processes, play a decisive role in determining performance characteristics. Both natural and synthetic fibres offer advantages, but their final suitability depends on the environment and intended use. Because of this, upholstery textiles on the market show a high degree of variation and tailoring—there is rarely a "one-size-fits-all" composition.

Taken together, these technical properties ensure that upholstery fabrics not only meet user expectations but also deliver long-term functional and aesthetic value across a range of demanding applications.

5.2 Upholstery market insights

As mentioned in previous sections, upholstery textiles represent a crucial and growing segment within the broader textile industry, with applications ranging from residential furniture to commercial and automotive interiors. The market is being reshaped by evolving consumer preferences, sustainability trends, and broader economic dynamics—particularly within the European Union, which is the primary focus of this study.

Across the EU, upholstery textiles have become a strategic segment of the textile industry. This momentum is driven by rising disposable incomes, continued urbanisation, and the growing popularity of home renovation and interior design. These trends are further amplified by the convenience of e-commerce, which has expanded consumer access to a wider variety of upholstery fabrics (as further discussed in section 7.1 PESTEL Analysis).

While market estimates vary between sources, they consistently indicate strong and sustained growth. Globally, the upholstery textile market was valued at approximately €41.8 billion in 2023 (converted from USD), with projections indicating a compound annual growth rate (CAGR) of 4.7% through 2033 (Reports and Data, 2024). Within the global textile market, upholstery textiles are expected to account for around 38% of the projected overall €1.42 billion growth by 2030. As outlined in the ZeroF project's Description of Action (DOA), this growth offers a strategic entry point for sustainable, PFAS-free alternatives: assuming ZeroF technologies could reach 25% of the upholstery segment, they would influence over €130 million of this global increase in value.

Within the European Union, several subsegments offer specific market opportunities for innovation:

- **Residential textiles** are expected to retain a dominant role, driven by a growing preference for personalisation and comfort in living spaces. The rise of customised furniture and environmentally conscious home design further reinforces demand in this sector.
- **Contracting textiles**, including those used in hospitality, healthcare, and office spaces, account for approximately 80% of the €3.2 billion EU contracting market. This segment is projected to grow at a CAGR of 3.6% through 2025, reflecting increased investment in functional, high-quality interior environments.
- **Automotive upholstery textiles** represent an additional €1.3 billion in EU market value, with a projected CAGR of 4.8% between 2021 and 2026. The increased adoption of electric and premium vehicles is contributing to demand for high-performance, durable, and sustainable fabrics in this segment.

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Together, the contracting and automotive sectors provide a healthy EU market foundation of approximately €4.3 billion, with consistent and stable growth prospects. These segments are of particular interest to ZeroF, as they offer ideal conditions for deploying innovative upholstery textile technologies, including PFAS-free coatings, at competitive price points. The project's current price target of 14.60 €/ml is aligned with prevailing market rates. According to the DOA, ZeroF-coated textiles are expected to gain between 10% and 25% of the market share over the next decade.

Finally, consumer and regulatory interest in sustainable and eco-friendly textiles continues to reshape the market landscape. As mentioned previously, natural and recycled fibres are gaining traction, and governmental bodies (such as the U.S. EPA) are promoting sustainable manufacturing practices. While these initiatives are global, they resonate strongly within the EU policy context, particularly in light of the EU Green Deal and Circular Economy Action Plan, and are likely to further accelerate the transition to PFAS-free, sustainable upholstery textiles.

5.3 Benchmark of PFAS-free textile application

While PFAS-based coatings have long dominated the textile industry due to their strong water, oil, and stain repellency, they are increasingly scrutinised for their persistence and potential health risks. As regulatory pressure mounts and consumer demand shifts toward safer alternatives, a variety of PFAS-free technologies are emerging to meet performance needs in applications such as residential, contract, and automotive upholstery. These alternatives can be broadly categorised into physical approaches, which modify the fabric surface or structure without chemical coatings, and chemical substitutes, which rely on new or adapted compounds to replicate PFAS functionality. Each approach offers distinct advantages and challenges in terms of repellency performance, durability, and market readiness.

5.3.1 Physical alternatives without PFAS

Physical alternatives to PFAS in upholstery and home textiles rely on modifying the surface properties of fibres without applying chemical finishes or coatings that remain on the fabric as a separate layer, such as PFAS or silicone-based treatments. Techniques like plasma treatment and nanostructuring change the fabric at the microscopic level to enhance water and oil repellency. Even when precursor gases are used, the amount of deposited material is minimal, often in the nanometre range, and the process remains physically driven rather than based on chemical deposition. These methods are typically dry, non-toxic, and more sustainable, though they may not yet match the full performance of chemical alternatives.

Plasma Treatment

Plasma treatment is a surface modification technique that alters the outermost layer of textile fibres using an ionised gas. By exposing the fabric to a plasma field, its surface energy changes, enabling properties like hydrophobicity or improved adhesion without applying a traditional chemical coating. This dry, solvent-free method reduces water and chemical use, offering a more sustainable alternative to PFAS-based finishes (Raslan, El-Halwagy, & El-Sayad, 2020).

Recent developments have shown promising results. The Swiss research institute Empa has developed a plasma coating method that deposits a thin, highly cross-linked siloxane layer

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on textile fibres, providing durable water repellency even after multiple washes. While the technology is still being scaled for broader application, it shows strong potential for integration into PFAS-free textile finishing processes relevant to interior and home textile markets (The Textile Think Tank, 2024).

Commercial plasma solutions are also gaining traction. Companies like Henniker Plasma offer vacuum plasma systems for textiles to improve surface wettability or impart water-repellent properties (Henniker Plasma, 2020). Plasmatreat, with its Openair-Plasma® technology, provides atmospheric plasma systems that allow continuous processing and chemical-free fabric treatment (Plasmatreat, 2023).

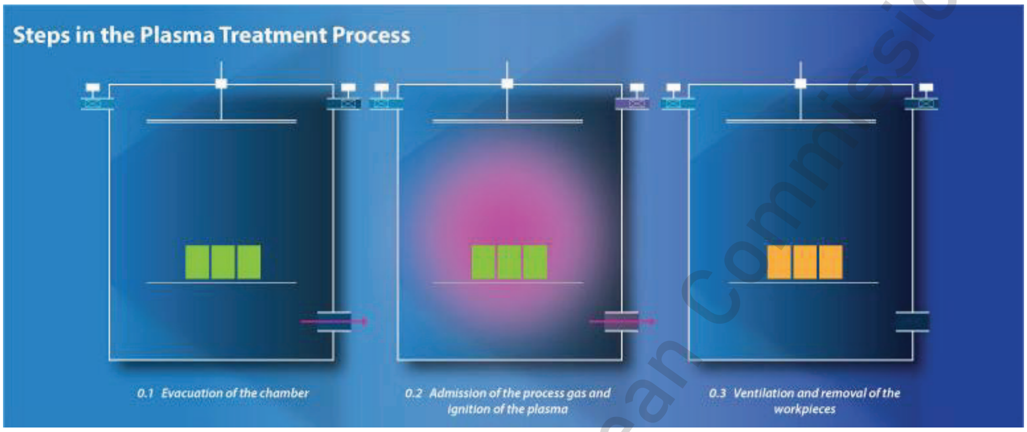

Figure 18. Steps in the Plasma Treatment Process (Henniker Plasma, 2020)

While plasma treatment offers clear environmental advantages and growing industrial interest, it has limitations in achieving oil repellency. Unlike PFAS, which lowers surface energy enough to repel both water and oils, most PFAS-free plasma treatments only achieve water repellency. Repelling oils typically requires extremely low surface energy, which is difficult to attain without fluorinated chemistries. Scalability, equipment cost, and uniform treatment across large textile surfaces also remain challenges. However, as adoption increases and equipment becomes more accessible, plasma treatment is emerging as a viable PFAS-free finishing technology for water-repellent applications.

Nanostructured surfaces

Nanostructured surfaces draw inspiration from natural phenomena like the lotus leaf, which exhibits remarkable water repellency due to its micro- and nanoscale surface textures. By engineering similar structures onto textile fibres, it's possible to achieve superhydrophobic properties without relying on chemical coatings (Wang, et al., 2022).

These surfaces are typically created through techniques such as plasma etching, laser patterning, or the application of nanoparticles that form hierarchical structures on the fabric. The resulting textures reduce the contact area between water droplets and the fabric, causing liquids to bead up and roll off easily (Ghosh & Paul, 2024).

While nanostructured surfaces offer excellent water repellency and self-cleaning capabilities, achieving oil repellency remains a challenge. Oil molecules have lower surface tension than water, making it harder for purely physical structures to repel them effectively without additional chemical treatments.

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In terms of market readiness, several companies and research institutions are exploring nanostructured coatings for textiles. For instance, Nano-Care offers Tex 5, a water-repellent textile coating that leverages nanotechnology to provide durable protection against liquids (nanoCare, 2021).

Overall, nanostructured surfaces present a promising avenue for PFAS-free water-repellent textiles, especially in applications where oil repellency is not a primary requirement. Ongoing research and development efforts continue to enhance the durability and functionality of these coatings, aiming to broaden their applicability in the textile industry.

5.3.2 Chemical alternatives without PFAS

Unlike physical treatments, which rely on surface modification without added substances, chemical alternatives to PFAS involve applying new types of coatings or finishes that aim to replicate water and oil repellency while eliminating the health and environmental risks of fluorinated compounds. These alternatives use non-fluorinated chemistries designed to meet growing regulatory requirements and sustainability goals, with varying degrees of performance and durability.

Although many of these coatings achieve effective water repellency, matching the oil repellency and long-term durability of PFAS remains a key challenge. The options currently available or in development include silicone-based finishes, polyurethane coatings, dendrimers, bio-based formulations, and sol-gel coatings. Each presents unique advantages and trade-offs, making them suitable for different use cases within upholstery textiles.

Silicone-based coatings

Silicone-based finishes, typically made from polydimethylsiloxane (PDMS) or its derivatives, are among the most common PFAS-free alternatives used to provide water repellency in textiles. These coatings create a hydrophobic barrier on the fabric surface, causing water to bead and roll off, while preserving the fabric's softness and breathability , key characteristics for upholstery and home textile applications.

However, one of the main limitations of silicone-based treatments is their lack of oil repellency. Achieving oil resistance requires a much lower surface energy than silicone can provide, making them less suitable for applications where oil-based stains are a concern.

An example of a commercial upholstery application is Supreen®, a performance fabric that uses a silicone-based stain repellent applied through a proprietary process. The silicone is embedded into the fibre structure, offering water resistance and stain protection while remaining free from PFAS chemicals (Supreen, 2023).

Silicone-based finishes are a mature and widely adopted solution for PFAS-free water repellency, though their performance limitations with oils must be taken into account depending on the intended use.

Polyurethane (PU)-Based Finishes

Polyurethane (PU)-based finishes are a common PFAS-free option for adding water repellency to textiles. They create a thin, flexible film on the fabric that resists water while preserving softness and breathability

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Waterborne PU formulations are especially valued for their low environmental impact, as they reduce solvent use and VOC emissions. However, PU finishes generally lack oil repellency, making them less suitable where protection against oil-based stains is needed.

An example of a commercial application is PolyCore Technologies' Eco-Coating, a high-performance coating designed to enhance mechanical properties while minimising environmental impact. This coating has demonstrated increased abrasion resistance and improved tear strength, showcasing its potential for durable textile applications.

Dendrimer-based coatings

Dendrimer-based coatings utilise hyperbranched polymers that form tree-like structures on textile surfaces, creating a durable, water-repellent barrier without the use of fluorinated compounds. These structures can self-organise and crystallise, enhancing the fabric's resistance to water while maintaining breathability and softness.

A notable commercial example is BIONIC-FINISH® ECO by the Rudolf Group. This technology employs dendrimer-based formulations to provide fluorine-free water repellency suitable for various textiles, including those used in upholstery. The finish is designed to be durable, withstanding household and industrial laundering, and is compliant with environmental standards such as bluesign® and ZDHC (Rudolf Group, 2021).

While dendrimer-based coatings offer excellent water repellency, achieving oil repellency remains a challenge without incorporating fluorinated compounds.

Bio-based or Wax-based formulations

Bio-based and wax-based coatings offer PFAS-free water repellency by leveraging natural materials such as plant-derived fatty acids, waxes, and biopolymers. These formulations aim to provide effective water resistance while aligning with sustainability goals, as they are often biodegradable and derived from renewable resources.

One notable example is OrganoTex®, developed by Swedish company OrganoClick. This technology utilises natural fatty acids and organocatalysis to mimic the water-repellent properties found in nature, such as those of the lotus leaf. OrganoTex® products are 100% biobased, biodegradable, and free from PFAS, fossil-based plastics, and synthetic waxes. They are also eco-labelled with certifications like OEKO-TEX® Eco Passport and USDA Certified Biobased Product (OrganoClick, 2023).

Another innovation is EMPEL®, developed by Green Theme Technologies (GTT). EMPEL® is a waterless and PFAS-free textile finishing platform that applies protective polymers directly onto fibres, forming covalent bonds through thermal curing. This method reduces water usage and eliminates harmful chemicals, offering durable water repellency suitable for various textile applications (Green Theme Technologies Inc., 2022; Green Theme Technologies Inc., 2024).

While these bio-based and wax-based formulations excel in providing water repellency and environmental benefits, achieving oil repellency remains a challenge without incorporating fluorinated compounds.

In summary, bio-based and wax-based coatings present sustainable and PFAS-free alternatives for water repellency in upholstery and home textiles, with ongoing developments aimed at enhancing their performance and durability.

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Sol-gel coatings

Sol-gel coatings utilise a hybrid organic–inorganic network formed through the sol-gel process, where metal alkoxides undergo hydrolysis and condensation reactions to create a silica-based matrix. This thin, durable layer can be applied to textiles, imparting water repellency, UV resistance, and antimicrobial properties without the use of PFAS.

These coatings are typically applied using methods like dip-coating or spray-coating, followed by curing at moderate temperatures. The resulting film is often less than 100 nanometres thick, preserving the fabric's breathability and flexibility.

While sol-gel coatings offer excellent water repellency, achieving oil repellency remains a challenge without incorporating fluorinated compounds. Therefore, their effectiveness against oil-based stains may be limited compared to traditional PFAS-based treatments.

In terms of market readiness, sol-gel coatings are being explored in various applications. For instance, the BIO-SUSHY project, funded by the EU's Horizon Europe program, is currently developing bio-based, PFAS-free sol-gel coatings for textiles, aiming to provide sustainable alternatives with hydrophobic and oleophobic properties (Bio-sushy, 2023).

5.4 Performance of PFAS-free textile

The previous section presented the current landscape of PFAS-free alternatives for textile applications, highlighting a variety of chemical and physical approaches emerging from research and the market. These alternatives differ not only in formulation, but also in functional performance which is an important factor for their practical adoption.

The table below, adapted from Archroma (Lassen, Jensen, & Warming, 2015; Pandit, 2024), compares fluorinated and non-fluorinated impregnation agents across six key textile performance parameters: water repellency, oil repellency, alcohol repellency, stain release, abrasion resistance, and self-cleaning.

Table 4. Comparison of performance of impregnating agents as described by the Archroma, adapted from (Lassen, Jensen, & Warming, 2015; Pandit, 2024)

Performance	Water repellency	Oil repellency	Alcohol repellency	Stain release	Abrasion resistance	Self cleaning
Fluorinated						
F-(Meth)Acrylates	+	+	+	+	+/-	-
F-Urethanes	+	+	+	+	+	-
F-Silicones	+	+	+	+	-	-
F-Particle	+	+	+	-	+	+
Non-fluorinated						
(Meth)Acrylates/ Urethanes	+	-	-	+/-	+/-	-
Silicones	+	-	-	-	-	-
Waxes	+	-	-	-	-	-
Dendrimers	+	-	-	-	+/-	-
Particle	+	-	-	-	+	+

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These results confirm the general consensus that non-fluorinated alternatives can achieve durable water repellency but do not provide resistance to oil or alcohol-based substances. In contrast, PFAS-based agents continue to outperform across the full range of functional metrics.

Thus, no current PFAS-free alternatives match PFAS-based repellents on all performance criteria. Non-fluorinated options show promising performance in water repellency and abrasion resistance but fall short when oil and alcohol resistance is required. Additionally, for most non-fluorinated impregnating agents, limited public information is available regarding the full formulation, ingredient toxicity, or environmental impact, particularly concerning raw material residues or degradation by-products (Lassen, Jensen, & Warming, 2015).

This reality underlines the importance of the ZeroF project, which aims to develop a high-performance, PFAS-free formulation that ensures functional durability while providing transparency and safety in terms of environmental and human health impacts, as well as economic feasibility.

Oil repellency: Rethinking performance requirements

Oil repellency remains one of the most challenging performance parameters for PFAS-free alternatives. Yet, for textile applications such as residential upholstery, which is the primary use case for ZeroF, the required level of oil repellency may not be as demanding as in industrial or protective gear applications.

The ability of a fabric to repel oil is directly related to the concept of surface tension. Surface tension refers to the cohesive force at the surface of a liquid that makes it tend to minimise its surface area. Liquids with low surface tension spread and penetrate surfaces more easily, while those with higher surface tension are more likely to bead up and remain on the surface. In this context, a textile that can repel a low surface tension oil will automatically repel any oil with a higher surface tension.

To assess oil repellency, the ISO 14419 standard is commonly used. This test assigns a numerical oil repellency grade based on the lowest surface tension oil that does not wet the fabric. The higher the grade, the lower the surface tension of the oil being repelled. Table 5 below provides surface tension values of oils used in the ISO 14419 scale:

Table 5. Oil number reference for ISO 14419 and corresponding surface tensions at 25°C

Oil number	Composition	Surface tension (25°C)
1	White mineral oil	31,5 mN/m
2	65:35 white mineral oil: n-hexadecane	29,6 mN/m
3	N-hexadecane	27,3 mN/m
4	N-tetradecane	26,4 mN/m
5	N-dodecane	24,7 mN/m
6	N-decane	23,5 mN/m
7	N-octane	21,4 mN/m
8	N-heptane	14,9 mN/m

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Separately, Table 6 below lists the surface tension of common household cooking oils.

Table 6. Surface tensions of main cooking oils (20°C)

Composition	Surface tension (20°C)
Castor Oil	39,0 mN/m
Peanut Oil	35,5 mN/m
Cottonseed oil	35,2 mN/m
Sunflower Oil	33,7 mN/m
Coconut Seed Oil	33,4 mN/m
Palm Oil	33,2 mN/m
Olive Oil	33,0 mN/m

As seen above, household cooking oils exhibit surface tensions between 33.0 and 39.0 mN/m. In comparison, white mineral oil, which defines oil repellency grade 1 in the ISO 14419 standard, has a lower surface tension of 31.5 mN/m. Surface tension is a key factor in oil repellency because it determines whether a liquid can penetrate or spread across a treated textile surface. In general, liquids with higher surface tensions are less likely to wet or soak into a fabric that repels lower-surface-tension substances. This means that if a textile can repel white mineral oil, it will also repel any liquid with a higher surface tension, including all common household cooking oils.

This detail has important practical implications. In the context of residential upholstery, the oils most likely to come into contact with furniture surfaces are those used in everyday cooking. Therefore, achieving an oil repellency grade of 1 is already sufficient to protect against the types of oils typically found in households.

Recognising this threshold invites a reconsideration of how performance targets are set. Pursuing higher oil repellency grades may be unnecessary for many applications and could result in trade-offs, especially if achieving those higher grades involves introducing substances with undesirable environmental, health, or cost implications.

At the time of writing, the ZeroF project has achieved oil repellency grades of 2 in its textile coating formulations. As mentioned, this level is considered adequate for most residential upholstery applications. However, further efforts to improve repellency are ongoing.

Flame retardancy

Flame retardancy is a key requirement in certain textile applications, particularly in public spaces and transport settings. PFAS coatings are not inherently flame retardant, but they can coexist, up to a point, with flame retardant additives. In current market formulations, this compatibility enables some degree of flame resistance, though typically at modest levels and often with trade-offs in water or oil repellency.

When it comes to PFAS-free alternatives, most existing solutions struggle to achieve high flame-retardant performance. The chemical interactions between non-fluorinated coatings and flame-retardant additives can be limiting, and few market-ready formulations offer strong dual performance.

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6. Current textile coating value chain

This section focuses on the value chain for PFAS-coated upholstery textiles. As the upholstery sector transitions toward PFAS-free solutions, understanding the structure and stakeholders of the current value chain is essential. The upholstery textile industry comprises a complex network of actors, from raw material and chemical suppliers to textile and upholstery manufacturers, distributors, and end-users, each playing a role in how PFAS-based coatings are applied, marketed, and regulated.

The value chain spans from the sourcing of raw materials, whether natural fibres such as cotton, wool, and leather, or synthetic fibres like polyester, to their transformation into yarns and fabrics through spinning, weaving, or knitting processes. These base textiles then undergo various finishing treatments, including dyeing, printing, and coating, to improve visual appeal and functional properties such as durability, stain resistance, and fire retardancy. These treatments are usually taken care of by coating technology providers using chemical formulations that confer these specific functionalities. Treated fabrics are integrated into upholstered goods like furniture coverings and automotive interiors, which are then distributed through wholesale and retail channels to furniture retailers, car manufacturers, and interior designers. Finally, these products reach end users through stores, e-commerce platforms, or direct sales.

In parallel, a range of transverse actors, including regulatory bodies, standards organisations, research institutions, and advocacy groups, play a critical role in shaping industry practices and accelerating the shift toward safer, PFAS-free alternatives.

Figure 19 provides a visual overview of these stages and actor categories. The following pages break down each stage of the value chain in more detail, highlighting key functions and representative stakeholders.

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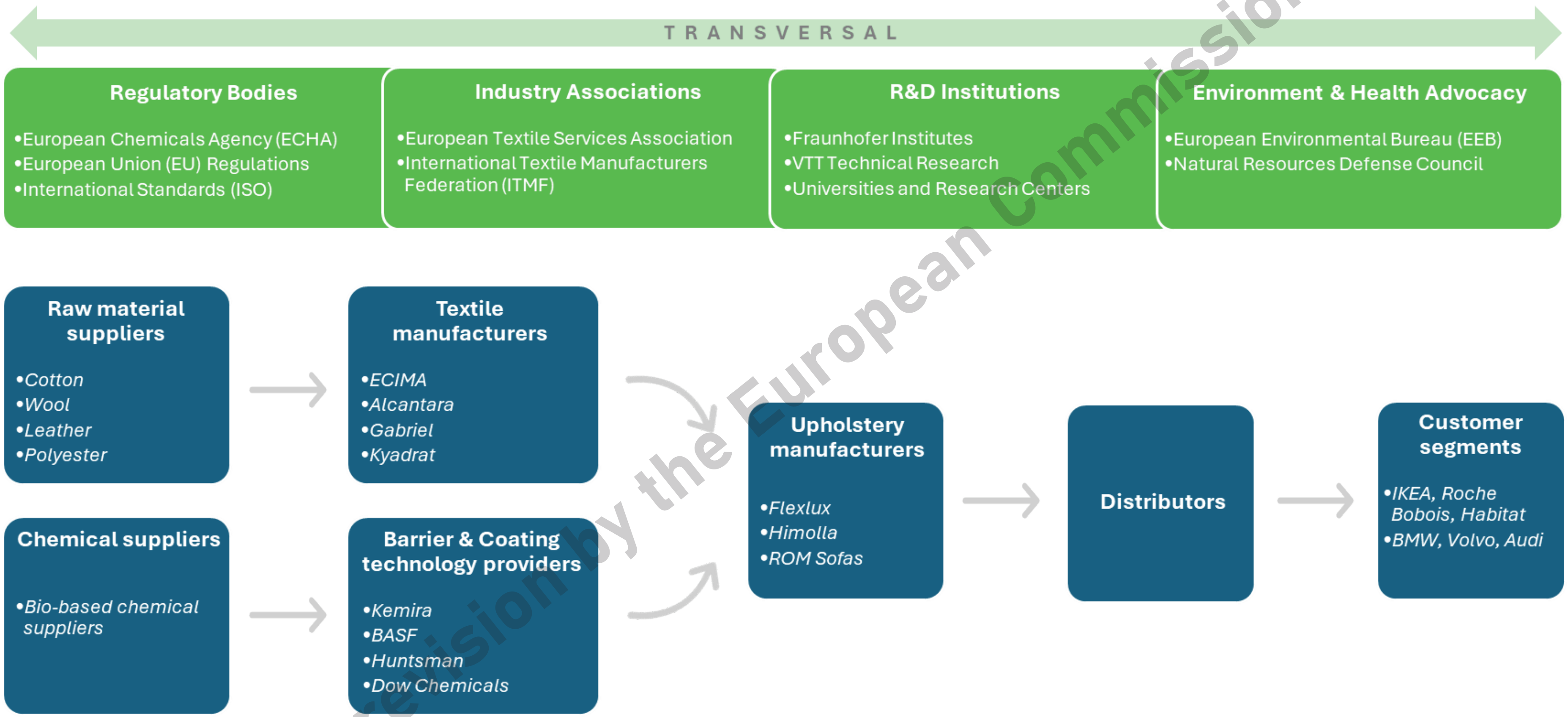

Figure 19. Current textile coating value chain

Raw Materials suppliers

The first stage of the upholstery textile value chain involves sourcing raw materials, including natural fibres such as cotton, wool, and leather, as well as synthetic fibres like polyester and nylon. Natural fibres are valued for comfort and aesthetic appeal, while synthetics are preferred for their durability and performance in demanding settings such as automotive interiors. These fibres form the base substrates for coated textiles and are processed into yarns and fabrics through spinning, weaving, or knitting.

The origin and type of fibre can significantly influence the fabric's compatibility with coatings, including PFAS-free alternatives. For instance, synthetic fibres may bond differently with coatings than natural ones, impacting performance. Increasingly, sustainability concerns, ranging from water use and pesticide exposure in cotton to microplastic pollution from synthetics, are driving demand for recycled or certified materials. While raw material suppliers do not apply coatings themselves, the materials they provide shape the downstream feasibility and effectiveness of safer, PFAS-free solutions.

Textile manufacturer

Once raw fibres are sourced, they are processed and converted into yarns and fabrics through well-established techniques such as spinning, weaving, or knitting. This stage forms the backbone of the upholstery textile supply chain, as it determines the structural characteristics of the material, such as strength, texture, breathability, and weight, which ultimately influence both the comfort and performance of the final upholstered products.

A number of textile manufacturers play a key role in this segment, producing base fabrics made from cotton, polyester, and various blends suitable for upholstery applications. Notable European players include Alcantara (Italy), known for its high-end microfibre materials used in automotive and furniture sectors; Gabriel (Denmark), which specialises in sustainable upholstery fabrics; and Kvadrat (Denmark), a major supplier of innovative and design-driven textile solutions. These companies often work closely with designers, product developers, and coating specialists to ensure compatibility with downstream treatments such as dyeing, printing, and performance coatings.

Chemical suppliers and barrier/coating technology providers

Chemical suppliers and coating technology providers play a central role in enabling the performance characteristics of upholstery textiles. These actors develop and supply chemical formulations—including repellents, binders, and finishing agents—that are applied to fabrics to enhance properties such as stain resistance, water repellency, and durability. Traditionally, many of these formulations have relied on PFAS compounds; however, growing regulatory and market pressures are accelerating the shift toward safer alternatives.

Large chemical producers such as BASF (Germany), Huntsman (Switzerland), and Dow Chemicals (USA) are key players in developing next-generation, PFAS-free formulations tailored to textile applications. In parallel, coating specialists like Schoeller Textil AG and HeiQ (both based in Switzerland) focus on the application of these technologies, often using proprietary methods to optimise performance, durability, and sustainability. Their expertise is critical to ensuring that alternative coatings meet the required functional standards while complying with evolving health and environmental regulations.

Upholstery manufacturers

Upholstery manufacturers are responsible for converting coated textiles into finished products such as furniture coverings, cushions, and vehicle interiors. This stage bridges material functionality and end-user expectations, integrating treated fabrics into applications that require both aesthetic appeal and high performance. Upholstery producers must ensure that the materials, which are often enhanced with stain- or water-repellent coatings, retain their desired properties under use conditions.

European players in this segment include Flexlux (Denmark), which produces upholstered furniture for various brands and retailers; Himolla (Germany), known for its high-quality recliners and sofas; and ROM Sofas (Belgium), which specialises in customisable upholstered seating. In the automotive sector, companies like Faurecia (France) supply OEMs with textile-covered seating systems and interior modules that incorporate performance-coated fabrics.

As demand grows for PFAS-free solutions, upholstery manufacturers are playing an increasingly strategic role in testing, validating, and mainstreaming alternative coatings—especially those that must meet stringent automotive or commercial standards.

Distributors

Distributors serve as the logistical link between upholstery manufacturers and final customers, handling warehousing, transportation, and order fulfilment. While distribution channels may vary by country and product type, a deeper contextual analysis is not required here. In some cases, manufacturers distribute directly, while in others, third-party wholesalers or agents, such as Actona Company (Denmark) or Eurodiffusions (France), support the flow of goods toward retail and commercial markets.

End-users

The final stage of the value chain includes the companies and consumers that purchase and use upholstered textile products. In the furniture sector, retailers and brands such as IKEA (Sweden), Roche Bobois (France), and Habitat (UK) offer a wide range of upholstered products, including models marketed as PFAS-free. In the automotive sector, original equipment manufacturers (OEMs) like BMW (Germany), Volvo (Sweden), and Audi (Germany) incorporate upholstered textiles into vehicle interiors, often in collaboration with Tier-1 suppliers. Ultimately, the final consumers—individuals furnishing homes or purchasing vehicles—are the end users of these textile products.

Transversal actors

Across the upholstery textile value chain, a diverse set of transversal actors influences the development, application, and regulation of PFAS-coated products. These include regulatory bodies, standard-setting organisations, industry associations, research institutions, and advocacy groups—all of which play a key role in accelerating the transition toward PFAS-free alternatives.

Regulatory and standardisation bodies such as the European Chemicals Agency (ECHA) and the broader EU regulatory framework—notably through REACH (Registration, Evaluation, Authorization and Restriction of Chemicals)—set the legal boundaries for chemical use in textiles across Europe. International bodies like the International Organization for Standardization (ISO) also contribute by establishing quality and safety benchmarks for textiles. Meanwhile, consumer advocacy groups such as Consumers International help raise awareness about health and environmental risks associated with PFAS and promote more transparent labelling and safer alternatives.

Industry associations provide a platform for dialogue, knowledge exchange, and sectoral alignment. Key examples include the European Textile Services Association (ETSA), which represents textile service providers in Europe; the International Textile Manufacturers Federation (ITMF), which connects global textile producers; and the Sustainable Furnishings Council, which promotes environmental responsibility in the furniture and home textiles sector.

Research and innovation institutions play a pivotal role in developing PFAS-free coating technologies. The Fraunhofer Institutes, particularly Fraunhofer ISC in Germany, and the VTT Technical Research Centre of Finland, which coordinates the EU-funded ZeroF project, are at the forefront of scientific efforts to substitute PFAS in textiles. Universities and public research centres across Europe also contribute through applied materials research and performance testing of alternative coatings.

Finally, environmental and health advocacy organisations such as the Green Science Policy Institute, the European Environmental Bureau (EEB), and the Natural Resources Defense Council (NRDC) actively campaign for stricter chemical regulations and help build momentum for systemic change within the industry.

7. Future Value Chain with ZeroF solution for textile

Building on the value chain mapping presented in Section 6, this section looks ahead to assess how the development and deployment of PFAS-free textile coating solutions, specifically the ZeroF innovation, could reshape the upholstery textile industry. As regulatory pressures intensify and demand for safer, more sustainable materials grows, solutions like ZeroF offer a promising alternative to PFAS-based coatings.

7.1 PESTEL analysis

ZeroF technology represents a significant shift toward PFAS-free textile coatings, offering a safer and more sustainable alternative for the upholstery sector. Its adoption has the potential to reshape the value chain and influence market practices across industries such as furniture and automotive interiors. As the sector navigates this transition, it is important to first understand the external political, economic, social, technological, environmental, and legal factors that will shape the demand, development, and deployment of PFAS-free textile solutions.

Political and Legal factors

The transition toward PFAS-free textile coatings is strongly influenced by evolving political agendas and legal frameworks that are reshaping the regulatory landscape of the European textile industry. At the forefront is the European Union's Circular Economy Action Plan, which promotes not only recycling and resource efficiency, but also the adoption of sustainable, low-impact materials throughout the textile value chain (Reports and Data, 2024). This policy framework encourages a shift toward natural fibres such as cotton, linen,

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and wool, as well as recycled and upcycled materials, setting the stage for innovation in eco-friendly upholstery textiles.

Simultaneously, regulatory pressure to eliminate hazardous substances, particularly per- and polyfluoroalkyl substances (PFAS), is accelerating. The European Green Deal and the Chemicals Strategy for Sustainability exemplify the EU's commitment to fostering the substitution of toxic substances with safer alternatives. These strategies are particularly relevant to coating formulations used in upholstery, where conventional PFAS-based chemistries are coming under increasing scrutiny.

In addition to EU-level initiatives, national governments are stepping up their efforts to enforce sustainable practices and to incentivise the development and uptake of environmentally responsible products. This regulatory momentum is creating both compliance challenges and strategic opportunities for industry actors engaged in innovation, such as the ZeroF consortium.

To better understand this regulatory transition, Deliverable D6.7 of the ZeroF project "Strategic certification/standardisation roadmap to achieve cost-effective certification compliance", provides a comprehensive overview of the current legislative, certification, and standards landscape for coating applications. It identifies key gaps and proposes a forward-looking roadmap to align ZeroF solutions with emerging sustainability criteria. For a more detailed understanding of the evolving compliance environment and its implications for textile coatings, readers are encouraged to consult this deliverable.

Economic factors

The economic landscape surrounding the upholstery textile sector presents both growth opportunities and cost-related challenges that influence the adoption of PFAS-free solutions like ZeroF.

On the demand side, the global furniture market is experiencing steady growth, driven by rising urbanisation, increasing disposable incomes, and demographic changes such as population growth. According to the United Nations Industrial Development Organization (UNIDO), the furniture sector is projected to grow at a compound annual growth rate (CAGR) of approximately 4.5% between 2023 and 2028 (Reports and Data, 2024). In addition to these drivers, evolving lifestyle patterns—such as more frequent residential moves and the growing preference for flexible living arrangements—are contributing to a sustained need for new and affordable furniture, thereby boosting the demand for upholstery textiles.

However, this market potential is tempered by significant economic constraints, particularly in relation to material costs. Natural fibres, which are often favoured for their environmental profile, remain relatively expensive, and their prices are subject to volatility. Meanwhile, cheaper synthetic alternatives continue to dominate large segments of the market due to their affordability and visual appeal. While these materials can mimic the look and feel of natural fibres, they do not inherently provide critical performance characteristics such as flame retardancy, water repellency, or stain resistance. These properties typically require additional treatments, many of which have historically involved PFAS chemistries. As such, price competition, combined with tightening safety and sustainability requirements, places considerable pressure on manufacturers of PFAS-free textiles to innovate and reduce production costs while still delivering on performance and compliance.

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Social factors

The growing public concern around PFAS and their health implications is becoming a significant social driver in the transition toward safer alternatives like ZeroF. PFAS substances have gained heightened visibility in the media due to their persistence in the human body and links to serious health effects, including hormonal disruption, immune system impairment, and certain cancers (European Environment Agency, 2024; Agency for Toxic Substances and Disease Registry, 2024). This increased media coverage and public discourse, including recent documentaries, NGO campaigns, and investigative journalism, has raised consumer awareness and scrutiny of products containing hazardous chemicals.

This societal shift is particularly impactful in the upholstery textile sector, where products are used in close proximity to human contact, such as on sofas, chairs, and car interiors. As a result, consumers are increasingly demanding sustainable and non-toxic textiles, with a clear preference for materials that are free from harmful substances like PFAS. This trend is not only shaping retail behaviour but is also influencing procurement strategies in institutional and commercial settings. In sectors such as hospitality, healthcare, education, and public infrastructure, there is a growing emphasis on health, safety, and sustainability, driving the adoption of durable and environmentally friendly upholstery textiles that can meet stringent hygiene and safety requirements (Reports and Data, 2024).

At the same time, the growth of online retail and digital marketing platforms is reshaping how consumers access and select upholstery products. E-commerce platforms provide greater visibility and comparison of product attributes, including eco-labels, chemical disclosures, and certifications. This increased transparency empowers consumers to make more informed, values-driven purchasing decisions, and facilitates the market penetration of PFAS-free textile innovations (Štofejová, 2023; Kabaja, Wojnarowska, & Varese, 2023).

Technological factors

Key technological trends in the upholstery textile market include the adoption of advanced manufacturing technologies, such as digital printing and nanotechnology, which are transforming textile production. Digital printing enables greater customisation and design flexibility, allowing manufacturers to cater to specific consumer preferences. Meanwhile, nanotechnology is enhancing the functional properties of textiles, including stain resistance and durability. These innovations are expected to drive growth and innovation in the upholstery textile market in the coming years (Reports and Data, 2024).

Additionally, advancements such as stain-resistant, fire-retardant, and antimicrobial fabrics are enhancing the appeal of upholstery textiles. The integration of smart textiles, which incorporate embedded sensors or conductive fibres, is unlocking new functionalities. Furthermore, the expanding use of natural and organic fibres, such as hemp and bamboo, aligns with increasing demand for sustainable materials. Innovations in eco-friendly dyeing and finishing processes are contributing to the sector's environmental sustainability.

Finally, the growth of online retail channels for upholstery textiles is expanding market access and driving increased demand.

In the context of the ZeroF project, upholstery and contract fabrics treated with new hydrophobic/oleophobic inorganic-organic coatings will undergo various finishing processes. Traditional methods such as impregnation by padding, bath exhaustion, and coating techniques will be used to apply these innovative coatings. These methods,

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previously used for inorganic sol-gel coatings, will be adapted to the characteristics of the selected fabrics. Treated fabrics will be evaluated for their water and oil repellence properties to ensure the effectiveness of the coatings developed in the project.

Environmental factors

The growing environmental scrutiny of PFAS substances is a major driver of change in the textile industry. PFAS are known for their extreme persistence in the environment, resisting natural degradation processes and accumulating in soil, water, and living organisms over time. These substances have been detected in remote ecosystems and even in drinking water sources, raising alarm about their long-term ecological impact. Their release during production, use, and end-of-life incineration of treated textiles contributes to widespread contamination, prompting urgent calls for cleaner alternatives.

This environmental legacy has triggered intensified regulatory action and consumer advocacy, spurring a shift towards sustainable, PFAS-free materials in upholstery and other textile applications. In response, both manufacturers and designers are rethinking materials and processes to minimise ecological harm.

One major trend is the increased use of natural and biodegradable fibres, such as hemp, bamboo, organic cotton, and wool. These materials are not only renewable and less resource-intensive but also more likely to break down naturally at end-of-life, reducing their burden on landfills and ecosystems. Hemp, for example, grows quickly without the need for pesticides and enriches the soil, making it an attractive sustainable alternative.

At the same time, recycled and upcycled materials, such as polyester derived from post-consumer plastic waste, are gaining traction as a way to reduce reliance on virgin resources and curb textile waste. Innovative companies are also developing next-generation fibres from low-impact feedstocks like wood pulp or agricultural residues, often using closed-loop or low-emission processes.

Production technologies are evolving as well. New eco-friendly dyeing and finishing techniques are being adopted to reduce water and chemical use. Plasma surface treatments, for instance, improve coating adhesion without relying on harmful solvents, making them well-suited for the application of sustainable coatings like those in ZeroF.

Together, these developments point to a deeper industry-wide transformation toward sustainability, where the goal is not only to replace toxic chemistries like PFAS but to embed circularity and environmental responsibility throughout the textile lifecycle.

A shifting landscape: a favourable climate for PFAS-free innovation

The analysis of political, economic, social, technological, environmental, and legal factors reveals a clear and converging trend: the macro-environment is becoming increasingly favourable to the development and adoption of PFAS-free textile coatings such as those proposed by the ZeroF project.

Political and legal frameworks, particularly within the European Union, are rapidly evolving to phase out harmful substances like PFAS while promoting sustainable innovation through the Circular Economy Action Plan and Chemicals Strategy for Sustainability. Economic conditions, though marked by cost pressures and competition from synthetics, also show promising demand growth, especially in the furniture and automotive sectors, opening space for high-performance, sustainable alternatives.

On the societal front, consumer awareness of PFAS-related health risks is surging, particularly as media coverage and institutional procurement standards spotlight the dangers of toxic substances in indoor environments. This shift in public perception is fuelling demand for non-toxic, environmentally responsible products. Technological advancements in coating application, material processing, and performance enhancement provide the tools needed to deliver PFAS-free solutions at competitive quality and functionality levels. Environmental imperatives further reinforce this direction, as the textile sector faces mounting pressure to reduce pollution and improve biodegradability.

Taken together, these factors define a critical window of opportunity for the ZeroF solution. The alignment of regulatory incentives, market demand, consumer values, and technological readiness creates an environment that not only supports but actively calls for the market entry and scale-up of PFAS-free coatings. By anticipating these trends and positioning itself accordingly, ZeroF is well-placed to reach market maturity and play a pivotal role in transforming the future of upholstery textiles.

7.2 SWOT analysis

With the external environment increasingly favouring PFAS-free alternatives, it is crucial to assess how the ZeroF solution is positioned to respond. This SWOT analysis highlights the main strengths, weaknesses, opportunities, and threats that will influence its ability to reach the market and deliver impact in the transition away from PFAS-based coatings. The key insights are summarised in Table 7 below.

Table 7. SWOT textile

Strengths	Weaknesses
o PFAS-free and regulation-ready o Hybrid technology with oil and water repellency o First-in-market oil repellency among PFAS-free coatings o Sustainable and EU compliant o Recyclable without PFAS-related risks	o Up to 20% higher production cost o Oil repellency lower than PFAS, but sufficient for residential use o Abrasion resistance still untested o Flame retardancy compatibility not yet achieved
Opportunities	**Threats**
o Strong market growth in upholstery textiles o EU regulations promote PFAS-free innovation o Rising demand for sustainable materials o Growing consumer preference for non-toxic fabrics	o Industry reluctance to adopt PFAS-free coatings o Technical challenge to match PFAS performance o Competition from low-cost synthetic alternatives o Pressure to innovate rapidly and meet evolving expectations

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Strengths

One of the core strengths of the ZeroF solution lies in its ability to offer a PFAS-free formulation that directly addresses growing health and environmental concerns. This aligns with international regulatory trends, particularly in the EU, where the use of PFAS in textiles is being increasingly restricted. By offering a non-toxic alternative, ZeroF is well positioned to meet compliance requirements and appeal to health-conscious and environmentally aware buyers.

Another major advantage is ZeroF's advanced hybrid technology, which leverages a combination of organic and inorganic polymers to achieve both water and oil repellency. This technical innovation distinguishes ZeroF from many other PFAS alternatives that typically offer water resistance but fall short in protecting against oil-based stains, as mentioned in Section 5.4.

In fact, a notable technical milestone is ZeroF's current ability to achieve oil repellency grades of 1–2. While the original project target was to reach grades 4–6, and the ongoing goal is now 2–3, this initial performance already meets the needs of most residential upholstery applications. More importantly, this technical progress is being pursued with a deliberate focus on balance—ensuring performance does not come at the expense of safety, sustainability, or feasibility. The project's approach favours thoughtful iteration rather than replicating PFAS-like properties at all costs.

ZeroF also demonstrates a strong commitment to sustainability and safety, aiming to reduce the environmental impact of its coatings by at least 25% compared to conventional products. This positions the solution in line with the European Green Deal and the Chemicals Strategy for Sustainability, offering a clear value proposition for eco-conscious markets.

Finally, recyclability is a key consideration in the product's development. While recyclability testing is still ongoing—both within the project and through external efforts—the coating's physical similarity to PFAS suggests that mechanical recycling processes should not be negatively affected. Although chemical recycling viability is still being assessed, one important environmental advantage is clear: ZeroF-coated textiles will not release PFAS when recycled, reducing contamination risks.

Weaknesses

One of the current challenges for the ZeroF solution lies in its higher production costs. Early estimates suggest a potential cost increase of up to 20% compared to conventional PFAS-based coatings. However, it is important to note that this refers specifically to the cost of the coating formulation, which typically represents only a small fraction, often less than 5%, of the total cost of the final upholstery product (such as a sofa or seat). As a result, even a notable increase in formulation cost may translate to only a minor impact on the end-product's retail price. While this may still affect purchasing decisions in highly cost-sensitive markets, the overall price differential at consumer level is likely to be less significant than it might initially appear, especially for buyers prioritising health, sustainability, and compliance.

In terms of performance, although ZeroF has demonstrated promising oil repellency, it does not yet match the high levels achieved by PFAS-based coatings. However, this limitation should be interpreted in light of actual use cases. For example, as mentioned in Section 5.4, residential upholstery textiles are rarely exposed to low-surface-tension oils like petroleum-based fluids, and grade 1 oil repellency is generally sufficient to repel common household substances such as cooking oil. The need for high-grade oil repellency is therefore highly application-dependent, and PFAS-level performance may not be necessary for most target scenarios.

Another area of uncertainty is the abrasion resistance of the ZeroF coating. While PFAS coatings are known for their durability under friction, abrasion testing for ZeroF-treated fabrics has not yet been completed. Given that upholstery fabrics endure repeated contact and wear, durability will be a critical factor and is planned for testing before the project concludes, subject to time and resource availability.

Additionally, the current ORMOCER-based formulation is not yet compatible with flame retardant treatments. This is due to a performance trade-off: adding flame retardant chemicals has been found to hinder water repellency. Importantly, it should be noted that PFAS themselves are not flame retardant, and flame retardant PFAS-based coatings are relatively uncommon. While this means the current formulation does not fall behind PFAS in this regard, achieving compatibility with flame retardants remains an open technical challenge. It is an area the ZeroF project plans to explore during the pilot testing phase.

Opportunities

The ZeroF solution is well-positioned to capitalise on the growing demand for sustainable alternatives in the upholstery textile sector. As public awareness of the environmental and health risks associated with PFAS increases, industries and consumers are actively seeking safer and greener options. This shift is creating tangible market pull for PFAS-free solutions, particularly in sectors like residential furniture, contract textiles, and automotive interiors.

Forecasts indicate that the global upholstery textile market is expected to expand by more than €115 million by 2030 (Reports and Data, 2024), opening new commercial opportunities for innovative materials that align with sustainability goals. Within this growing market, ZeroF stands out by offering a formulation that combines safety, performance, and regulatory alignment.

ZeroF also benefits from a favourable regulatory landscape, particularly within the European Union, where policies such as the Circular Economy Action Plan and the Chemicals Strategy for Sustainability are actively promoting the substitution of hazardous substances with safer alternatives. These regulatory signals not only push PFAS-based products out of the market but also create a strategic advantage for early movers like ZeroF.

In parallel, there is a steady rise in consumer preference for eco-friendly, non-toxic fabrics, especially among environmentally conscious buyers and public procurement bodies. This evolving preference supports the long-term uptake of PFAS-free coatings and helps strengthen the business case for ZeroF in both B2B and B2C contexts.

Threats

Adoption of PFAS-free coatings still faces hesitancy from industry and consumers, driven by concerns about performance and cost. Many remain uncertain whether non-fluorinated solutions can fully match the durability, water, and oil repellency of traditional PFAS-based coatings, which can delay uptake.

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Technical challenges also persist. Achieving comparable functionality without compromising safety or sustainability remains a complex task, especially when trying to replicate PFAS's multi-functional performance.

The market is further pressured by intense competition from low-cost producers, particularly in Asia. These suppliers offer affordable synthetic textiles that, while not PFAS-free, often deliver similar aesthetics and perceived durability, making them attractive to price-sensitive buyers.

Finally, the need to continuously innovate to meet evolving consumer expectations adds pressure. Success will depend not only on sustainability, but also on delivering high performance at a competitive cost.

7.3 New PFAS-free textile value chain

Evolution of PFAS-free coating for textile

The introduction of PFAS-free coatings such as ZeroF marks a pivotal shift in the textile value chain, particularly for upholstery applications. While the core structure of the value chain remains intact, the roles, expectations, and decision-making dynamics among key actors are beginning to evolve. Driven by growing regulatory pressure, rising consumer awareness, and stronger certification standards, PFAS-free coatings are no longer niche alternatives but emerging market requirements. This section revisits the value chain presented earlier and explores how each step, from chemical supply to end-user engagement, is adapting to accommodate the transition toward safer, more sustainable textile finishes.

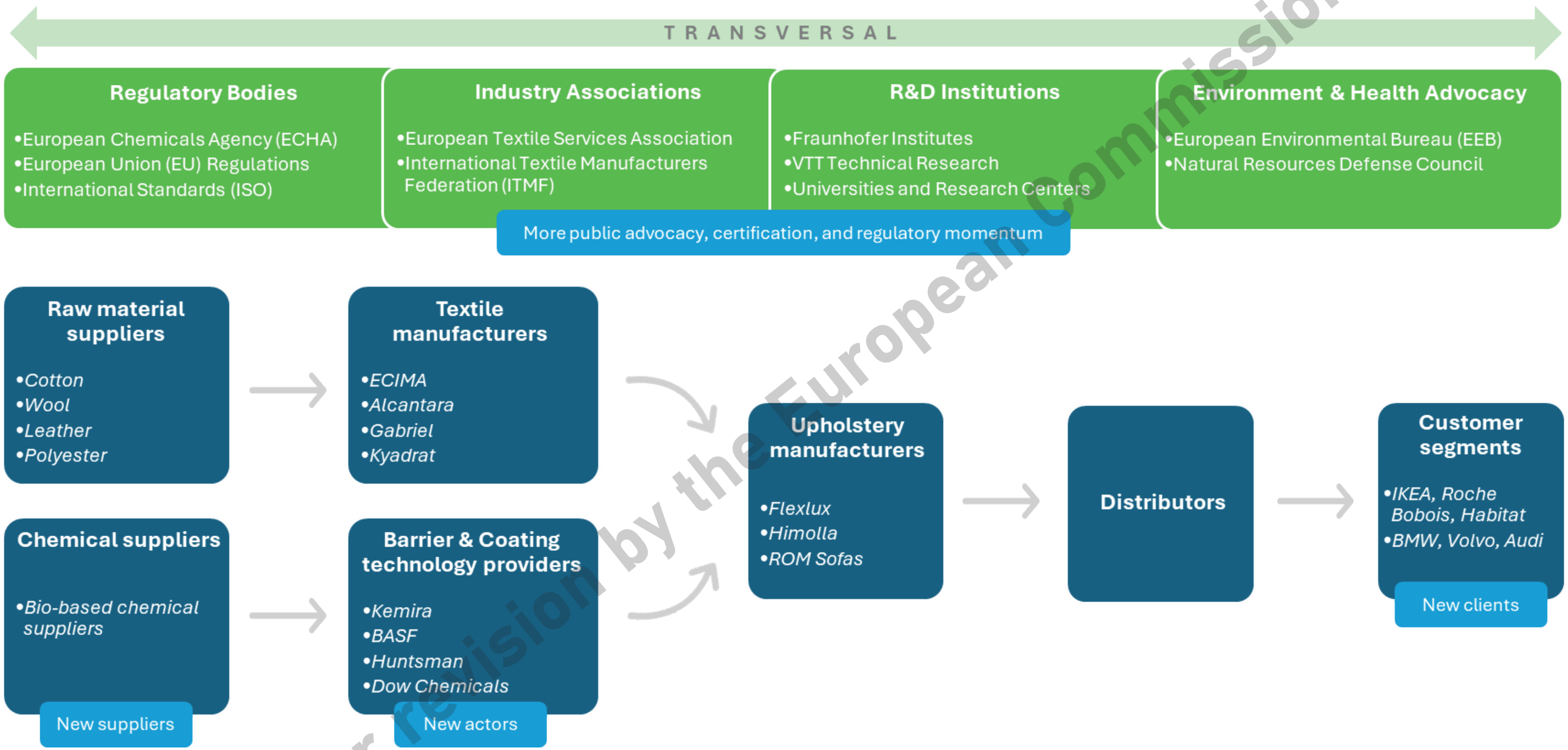

Figure 20. Future Textile Coating Value Chain Integrating PFAS-Free Technologies

Chemical Suppliers and Barrier & Coating Technology Providers

The shift to PFAS-free coatings like ZeroF is prompting changes in the chemical supply landscape. While application methods remain the same, the introduction of new inorganic-organic hybrid formulations opens the door for bio-based chemical suppliers and new entrants focused on safer alternatives.

At the same time, established players (e.g., BASF, Huntsman, Dow) may respond by expanding their product lines to include PFAS-free technologies, aiming to retain market share and meet growing regulatory and customer demands.

ZeroF exemplifies this transition—offering a performance-oriented, sustainable alternative that challenges suppliers to deliver on functionality, safety, and cost-efficiency. As the market evolves, success will depend on the ability to combine technical performance with regulatory compliance and sustainability goals.

Textile Manufacturers

While textile manufacturers continue to play the same technical role in the value chain—producing and finishing fabrics—their strategic position is shifting. With growing pressure from downstream clients and certification bodies, they are increasingly expected to source PFAS-free coatings and ensure compliance with evolving standards.

The coating processes and equipment remain unchanged, meaning no investment in new infrastructure is required. However, textile manufacturers must be able to validate that the fabrics treated with new formulations like ZeroF meet performance and regulatory expectations, especially in terms of repellency and safety.

In this context, their role becomes more about adapting sourcing and quality control strategies, rather than overhauling technical operations.

Upholstery Manufacturers

Upholstery manufacturers are among the most directly affected actors in the value chain as the shift toward PFAS-free coatings accelerates. Increasingly, these manufacturers face pressure from both regulators and consumers to deliver products that are safe, sustainable, and compliant with certifications like OEKO-TEX or EU Ecolabel.

To meet these expectations, many are pushing their textile suppliers to provide PFAS-free fabrics, which has a cascading effect upstream in the value chain. This shift is not only about regulatory compliance—it is also about brand positioning and responding to growing consumer demand for non-toxic, environmentally friendly products.

Importantly, the use of ZeroF coatings does not require changes in upholstery design or fabrication processes, allowing manufacturers to integrate compliant textiles without disrupting production. This makes the transition technically feasible, even if initial costs may be slightly higher. However, since the coating represents only a small fraction of the final product's cost, the impact on end-product pricing remains minimal.

For some manufacturers, this shift also creates a market opportunity to differentiate their offerings and appeal to new customer segments that prioritise health and sustainability.

End-users

The types of clients and end users—furniture brands, contract buyers, and consumers—remain the same, but their expectations are shifting. Professional buyers are increasingly requiring PFAS-free fabrics to comply with certifications and meet ESG goals.

On the consumer side, awareness of PFAS health risks is growing, especially in indoor settings. While price sensitivity persists, more buyers are willing to pay a small premium for safer, more sustainable products—much like they do for organic cotton or recycled textiles.

Though ZeroF coatings may cost up to 20% more at the formulation level, this increase represents a small fraction of the final product's cost, meaning the impact on retail price is minimal.

This evolving mindset is also opening up new customer segments actively seeking PFAS-free alternatives aligned with health and environmental values.

Transversal actors

Transversal actors, such as regulators, certification bodies, NGOs, and media, are driving the shift toward PFAS-free textiles. Regulations are tightening, and certifications increasingly exclude PFAS, pushing the industry to adapt.

At the same time, public advocacy and media coverage are raising awareness about PFAS risks, helping consumers make more informed choices and increasing tolerance for modest price premiums when backed by sustainability and safety.

Together, these actors are creating momentum for change, shaping demand, and enabling the adoption of solutions like ZeroF.

7.4 Recommendations to the Consortium

Diversifying Within Upholstery Applications

Beyond residential furniture, ZeroF should consider targeting contract textiles, public transport interiors (bus, train, aircraft), marine furnishings, and office chairs. Each of these markets presents a promising opportunity, but also comes with specific technical requirements, especially in terms of abrasion resistance, flame retardancy, and oil repellency. Adapting the formulation to meet these demands will be essential for market entry. Product customisation and application-specific testing should be prioritised as part of this expansion strategy.

Exploring New Markets Beyond Upholstery

The ZeroF coating technology also holds potential beyond the upholstery sector. It is recommended to explore other industries requiring repellency and barrier properties, such as medical packaging, industrial textiles, and technical wipes. These sectors often face pressure to eliminate hazardous substances and may offer faster adoption pathways. Identifying and piloting use cases in these adjacent markets could help accelerate impact and diversify revenue streams.

Advancing Performance Testing for Market Readiness

To support broader adoption, it is recommended to prioritise advanced durability testing, particularly abrasion resistance, which is critical for high-use textile applications. Additional

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work should be done to explore recyclability, especially the coating's behaviour in mechanical and chemical recycling processes. Strengthening the environmental profile through such testing will be key to meeting circular economy standards and buyer expectations.

Leveraging Academic and Industry Partnerships

Strategic collaborations with academic institutions, OEM partners, and testing labs can support formulation refinement, regulatory preparation, and real-world performance validation. Partnerships will be especially valuable for entering highly regulated sectors or those requiring specific technical certifications.

Protecting and Scaling Through Licensing

As the technology nears market readiness, the consortium should implement a robust IP and licensing strategy to ensure that the ZeroF coating can be deployed at scale without requiring direct investment in manufacturing. Licensing the formulation to established textile finishers or chemical suppliers would support rapid adoption and international reach, while allowing the consortium to remain focused on innovation, optimisation, and technical support.

This recommendation aligns with the objectives of Task T7.4 of the ZeroF project, which includes coordinated efforts to explore IP protection and exploitation pathways. During the final phase of the project (M30–M36), partners will work on defining long-term sustainability strategies for project outcomes. As part of this, licensing models and IPR options may be considered to support the transition from project results to market-ready applications.

Raising Technology Readiness and Securing Market Entry

To reach commercialisation, the project should continue efforts to raise the TRL through pilot-scale production, industrial validation, and early collaboration with selected market players. In parallel, ZeroF consortium partners, individually or in small groups, should consider actively pursuing funding opportunities, including EU innovation programs and sustainability-focused investment schemes, to support scale-up, performance optimisation, and certification. These efforts will be essential for de-risking the technology and enabling a smooth transition from project development to market deployment.

8. Conclusion

The findings of this impact study highlight the transformative potential of ZeroF technology in reshaping value chains within the food packaging and upholstery textile sectors. Both industries have long relied on PFAS-based chemistries for critical performance functions, namely grease, oil, and water resistance. However, growing regulatory constraints, heightened consumer awareness of PFAS-related health risks, and the environmental urgency to phase out persistent pollutants have created strong momentum for safer, more sustainable alternatives. The study confirms that ZeroF can respond to these pressures by offering an innovative, PFAS-free coating technology that is not only aligned with future regulatory frameworks but also addresses increasing market demand for non-toxic, eco-friendly solutions.

Through detailed value chain mapping, SWOT and PESTEL analyses, and stakeholder interviews, we identify that ZeroF's successful adoption could lead to significant shifts in

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supply chain structures, stakeholder roles, and product development strategies. Notably, ZeroF's alignment with dry-moulded pulp packaging and its ongoing compatibility with high-performance polyester textiles positions the partners as a frontrunner in the transition to sustainable material.

Key outcomes of the study include:

- **Validation of market demand**: Stakeholder engagement and market analysis confirm a strong interest in PFAS-free packaging and textiles, especially in food service and residential upholstery contexts.
- **Performance feasibility**: While technical challenges remain, such as achieving higher KIT levels or ensuring abrasion resistance, the current performance of ZeroF coatings is already suitable for selected applications (e.g., cold food trays, household textiles).
- **Policy and regulatory readiness**: ZeroF aligns closely with EU Green Deal priorities, the Circular Economy Action Plan, and forthcoming PFAS restrictions, making it well positioned to meet upcoming restrictions and legal pressures.
- **Value chains will be reconfigured**: The shift to PFAS-free coatings entails adjustments in supplier relationships, product development cycles, and manufacturing requirements. New actors are likely to emerge, while traditional partners must adapt processes and sourcing strategies.
- **Strategic roadmap for scale-up**: Recommendations include focusing initial adoption on lower-barrier applications, engaging early with industrial partners, and exploring licensing models to enable wide-scale deployment without requiring in-house production expansion. Rather than internal production scaling, partners should pursue licensing agreements with established coating and packaging providers. This approach can accelerate deployment and broaden reach while controlling investment risk.
- **Uncertain recycling and waste management compatibility**: While ZeroF coatings are PFAS-free, their impact on mainstream recycling and wastewater treatment systems remains to be fully understood. Engagement with recycling stakeholders is essential to ensure compatibility and avoid unintended barriers to circularity.

The ZeroF project offers a compelling model for safe and sustainable-by-design innovation. But to move from potential to widespread impact, partners must actively manage performance optimisation and scale-up strategies which requires strong collaboration between key value chain players.

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