

After PFAS: The Hidden Food-Safety Challenge in Europe's New Packaging Era

Why replacing fluorinated barriers is not enough — and why the next innovation frontier is performance-preserving, migration-aware packaging

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Executive Abstract

Europe's Packaging and Packaging Waste Regulation (PPWR) has moved food-contact packaging into a new regulatory era. Since 12 August 2026, packaging placed on the EU market may not contain PFAS at or above three concentration thresholds set by Article 5(5) of Regulation (EU) 2025/40. The immediate compliance problem is analytical and documentary, but the deeper industrial problem is functional: PFAS were used because they provided unusually effective resistance to grease, oil, water and heat. Replacing them without degrading food protection, shelf life, recyclability or chemical safety is therefore a materials-engineering problem, not merely a substitution exercise. Recent literature on fluorine-free, bio-based and fibre-compatible coatings shows substantial progress, but also persistent gaps in convertibility, moisture barrier, migration assessment, real-food shelf-life validation and non-intentionally added substances (NIAS). This article argues that the post-PFAS opportunity is a new discipline of "barrier-by-design": packaging developed simultaneously around food preservation, chemical migration, circularity, processability and regulatory evidence. The strategic prize is not simply PFAS-free packaging, but safer packaging whose replacement chemistry does not create the next regulatory problem.

1. The Regulatory Event Is Already Here

On 12 August 2026, the general application date of Regulation (EU) 2025/40 on packaging and packaging waste (PPWR), a particularly consequential provision for food businesses became operative. Article 5(5) restricts PFAS in food-contact packaging placed on the Union market.

The thresholds are unusually demanding. Food-contact packaging must not be placed on the market if it contains: 25 ppb or more of any individual PFAS measured by targeted analysis, excluding polymeric PFAS from that quantification; 250 ppb or more for the sum of targeted PFAS, again excluding polymeric PFAS; or 50 ppm or more of PFAS including polymeric PFAS. Where total fluorine exceeds 50 mg/kg, operators may need to demonstrate what fraction derives from PFAS and what fraction derives from non-PFAS fluorine so that the technical documentation can be established.

The legal trigger is placing on the market, not merely manufacture. The European Commission has also made clear that the PPWR creates a harmonised packaging framework across the Single Market, replacing the previous directive-based architecture.

For food companies, this is not a niche packaging-law issue. Food-contact packaging is part of the food-safety system. Regulation (EC) No 1935/2004 remains the general EU framework for materials and articles intended to come into contact with food, and Commission Regulation (EC) No 2023/2006 imposes good manufacturing practice. Packaging must not transfer constituents to food in quantities capable of endangering human health, causing unacceptable compositional change, or deteriorating organoleptic characteristics.

The PPWR therefore adds a new substance-of-concern constraint to an already demanding food-contact safety architecture. The result is not "PFAS law" on one side and "food-contact law" on the other. Companies must satisfy both simultaneously.

2. Why PFAS Were Used in the First Place

The easiest mistake in chemical substitution is to treat the restricted substance as if it had no engineering function.

PFAS were attractive in fibre-based food packaging precisely because fluorinated chemistries can produce low-surface-energy barriers with strong resistance to oil, grease and moisture. They were particularly useful in takeaway containers, fast-food wrappers, bakery papers, pizza packaging and similar applications in which uncoated cellulose performs poorly.

Paper and paperboard have many sustainability advantages, but untreated fibre is hydrophilic and porous. It can absorb water and fats; it can lose mechanical integrity; and it often has inadequate oxygen, water-vapour or grease barrier properties for demanding foods. The 2024–2025 literature on fibre-based packaging repeatedly identifies this functional deficit.

That means the post-PFAS problem is not solved by removing fluorine. A replacement package must still perform the primary functions of packaging: contain the food, prevent leakage, preserve quality, protect against environmental contamination and, where relevant, support shelf life.

A technically weak substitution can therefore create secondary food-safety or sustainability costs: increased oxidation, moisture transfer, microbial spoilage, leakage, food waste, heavier material use or a return to less recyclable multilayer structures.

The correct design target is consequently not “PFAS-free”. It is “PFAS-compliant while preserving the required food-protection function”.

3. The Substitution Paradox: Safer Chemistry Can Produce Worse Food Protection

This creates what may be called the substitution paradox.

A packaging reformulation can reduce one chemical hazard while unintentionally increasing another risk elsewhere in the food-packaging system. A coating with inferior grease resistance can fail in service. A hydrophilic biopolymer may lose barrier performance at high relative humidity. A new crosslinker can introduce migration concerns. A multilayer solution can improve barrier performance while impairing recyclability. A thicker package can meet functionality but increase material intensity. A bio-based formulation can still contain hazardous intentionally added substances or generate NIAS during manufacture, storage or thermal processing.

The paradox matters because regulatory and sustainability objectives are increasingly being imposed simultaneously.

The PPWR is not only a PFAS restriction. It is a circular-economy regulation that progressively introduces recyclability, recycled-content, minimisation, reuse and other packaging obligations. A substitute that solves Article 5 but frustrates later recyclability requirements may be commercially short-lived.

This is why substitution should be evaluated through at least five coupled dimensions:

1. chemical safety;
2. food-protection performance;
3. industrial convertibility;
4. circularity and end-of-life compatibility;
5. regulatory evidence.

Optimising only one dimension is no longer sufficient.

4. What the Science Says About Fluorine-Free Alternatives

The scientific literature shows that there is no single universal PFAS replacement.

Promising barrier systems include polysaccharides, proteins, lipids, polyesters, nanocellulose, chitosan, lignin-containing systems, inorganic nanosheets and multilayer architectures. Their performance varies substantially with substrate, coating weight, humidity, food type, temperature, contact time and conversion process.

A 2024 Green Chemistry critical review of sustainable biodegradable coatings concluded that many biodegradable polymers still underperform conventional petroleum-derived barriers in water-vapour or oxygen protection, although coating technologies can materially improve performance. The review also highlighted industrial challenges including scale-up, delamination, heat sealability and migration.

A 2025 semisystematic review in Packaging Technology and Science reached an equally important conclusion: the research literature often concentrates on coating formulation and laboratory barrier measurements while giving less attention to conversion, real-food preservation and full environmental assessment. Film formation and convertibility remain obstacles to scale-up, and claims such as “sustainable” or “biodegradable” are frequently used more confidently than the supporting evidence warrants.

Individual studies demonstrate genuine technical progress. For example, highly deacetylated chitosan coatings have been investigated for water- and oil-resistant disposable meal boxes, while cellulose-nanofibril multilayer systems have been developed for oil- and water-resistant food containers.

These are important signals of feasibility. They are not evidence that the substitution problem has been solved across industrial food packaging.

5. The Underappreciated Variable: Relative Humidity

Many bio-based barriers look excellent under one laboratory condition and substantially worse under another. This is particularly important for hydrophilic materials. Polysaccharides and proteins can provide good oxygen barriers under dry conditions, yet absorb moisture as humidity rises. Water plasticises the matrix, increases molecular mobility and can sharply degrade barrier performance.

Food packaging does not operate at a single laboratory humidity. A chilled ready meal, dry bakery product, oily snack, fresh produce item and frozen food create very different moisture and temperature environments. Distribution adds further variability. A credible PFAS-replacement programme should therefore avoid relying on a single grease-kit value or a single water-vapour transmission measurement. Performance should be mapped across realistic environmental conditions.

The more useful question is not: “Does the coating resist oil?” It is: “Does the complete converted package retain the required oil, water-vapour, oxygen and mechanical barrier throughout the product’s actual supply-chain conditions?”

That distinction separates materials screening from packaging validation.

6. NIAS: The Risk That Can Appear After a Successful Substitution

Removing PFAS does not eliminate chemical migration.

Food-contact materials contain intentionally added substances (IAS) and can also contain non-intentionally added substances (NIAS): reaction products, degradation products, impurities, contaminants or compounds generated during manufacturing and use.

A 2025 review in Food Research International emphasised the analytical challenge of identifying and quantifying IAS and NIAS in biodegradable food packaging and the importance of migration conditions, food type, contact time, temperature and polymer matrix.

This is particularly relevant to new coating systems because innovation frequently introduces unfamiliar combinations of polymers, crosslinkers, catalysts, surfactants, pigments, adhesion promoters and processing conditions.

The regulatory trap is obvious, since a company can successfully remove fluorinated chemistry and still introduce a migration profile that has not been adequately characterised.

This is why “PFAS-free” must never be treated as synonymous with “chemically safe”. Food-contact safety remains an independent requirement.

7. The Analytical Problem: One PFAS Test Is Not Enough

Article 5(5) creates three different compliance questions.

Targeted analysis addresses individual PFAS and the sum of specified PFAS. Polymeric PFAS are excluded from those targeted quantifications. The 50 ppm threshold, by contrast, includes polymeric PFAS. This matters analytically because total fluorine, extractable organic fluorine, targeted LC-MS/MS analysis and polymer-sensitive approaches do not answer exactly the same question. A low result in a targeted PFAS panel cannot automatically demonstrate compliance with the polymer-inclusive limit. Conversely, elevated total fluorine does not by itself prove that the fluorine derives from PFAS; fluorine may have other sources.

The PPWR itself recognises this distinction by requiring evidence on the origin of fluorine when total fluorine exceeds the specified level. The practical implication is that food companies need an evidence strategy, not merely a laboratory certificate.

That strategy should define:

- what packaging components are in scope;
- which PFAS question each analytical method answers;
- detection and quantification limits;
- supplier declarations;
- sampling plans;
- change-control triggers;
- treatment of inks, coatings, varnishes and adhesives;
- documentary retention;
- escalation when total fluorine and targeted results disagree.

The compliance unit is the food-contact packaging, not merely the base paper.

8. Paper and Board Remain a Regulatory Weak Point

There is another structural issue that deserves attention.

Unlike plastics, which are subject to extensive EU-specific harmonised rules, paper and board food-contact materials still rely significantly on national measures, standards and scientific guidance alongside the general requirements of Regulation (EC) No 1935/2004. A 2024 critical review by Störmer, Hetzel and Franz concluded that compliance testing for paper and board can be challenging and that conventional extraction or migration approaches may either overestimate or underestimate real transfer to food depending on the application.

This regulatory fragmentation becomes more consequential as fibre-based packaging expands. The PPWR encourages circularity and can indirectly accelerate movement toward paper and fibre solutions, yet the chemical-safety framework for those materials is not as fully harmonised as the framework for plastics.

Europe is therefore creating an interesting regulatory asymmetry: increasingly harmonised environmental packaging law operating alongside partially non-harmonised food-contact rules for one of the material classes likely to gain importance.

That is a genuine policy and innovation white space.

9. Recycled Fibre Adds a Second Layer of Complexity

Circularity can increase chemical complexity.

Recycled fibre can contain printing-ink constituents, mineral oils, adhesives, legacy additives and contaminants originating from previous material cycles. New barrier coatings may be applied on top of this chemically heterogeneous substrate.

The regulatory objective is therefore not merely to design a safe coating. It is to demonstrate that the coating-substrate-conversion system remains safe. This is where functional barriers, migration modelling, screening analytics and supplier-chain traceability become increasingly important. Circularity should not be framed as the opposite of chemical safety. The engineering objective is to make them compatible.

The PPWR makes that compatibility economically urgent.

10. Shelf Life Must Become Part of Substitution Safety

Packaging is an intervention in food preservation.

If replacing a PFAS-containing grease barrier shortens shelf life, increases moisture uptake or accelerates oxidation, the substitution has a food-system consequence. That consequence may be microbiological, chemical, sensory, nutritional or environmental. Food waste is especially important. A package with a lower material footprint can produce a higher system footprint if it causes significantly more food loss.

Yet the 2025 review of bio-based barrier coatings found limited direct evidence comparing novel materials with conventional packaging using real-food shelf-life outcomes. This is a major research gap. Future packaging assessment should connect material properties to food outcomes:

oxygen transmission -> lipid oxidation;

water-vapour transmission -> texture and microbial ecology;

grease barrier -> package integrity;

light barrier -> vitamin and pigment stability;

seal integrity -> microbial protection;

mechanical resistance -> distribution losses.

The correct unit of sustainability is not the empty package. It is the packaged food system.

11. EU, United States and Great Britain: Similar Direction, Different Legal Routes

The international direction is broadly convergent, but the legal mechanisms differ.

In the European Union, the PPWR now imposes explicit concentration thresholds for PFAS in food-contact packaging. These requirements coexist with the general EU food-contact-material framework and will interact with wider chemicals legislation.

In the United States, FDA announced in February 2024 that PFAS-containing grease-proofing substances were no longer being sold for paper and paperboard food-contact use following voluntary industry phase-outs and regulatory action. In January 2025, FDA determined that 35 related Food Contact Notifications were no longer effective because the uses had been abandoned. FDA nevertheless distinguishes those grease-proofing uses from other authorised PFAS-containing food-contact applications, for which it assesses migration and exposure separately.

That distinction is important: the US position should not be simplistically described as a universal federal ban on every PFAS in every food-contact material.

Great Britain follows its own post-Brexit packaging and food-contact architecture. UK businesses exporting packaging or packed foods into the EU must nevertheless satisfy the PPWR where the relevant packaging is placed on the Union market. Northern Ireland adds further complexity because applicable EU-derived requirements interact with the Windsor Framework arrangements.

For multinational suppliers, “PFAS-free” therefore cannot substitute for jurisdiction-specific legal analysis.

12. The Emerging Competitive Advantage: Packaging Evidence Readiness

Packaging suppliers traditionally compete on cost, appearance, machinability, barrier performance and sustainability claims. A new competitive variable is becoming visible: **evidence readiness**.

A packaging system that can be accompanied by a coherent evidence package has lower regulatory friction. That package should increasingly contain:

- material and component identity;
- supplier declarations;
- PFAS analytical evidence;
- food-contact compliance documentation;
- migration data;
- NIAS assessment where relevant;
- intended food categories;
- time-temperature conditions;
- barrier-performance data;
- recyclability evidence;
- change-control history.

For food manufacturers, this creates a procurement implication. Packaging should no longer be purchased only against physical specifications. It should be purchased against a combined physical-and-regulatory specification.

13. From “PFAS-Free” to Barrier-by-Design

The next generation of food packaging should be designed through a different sequence. Traditional development often starts with a material, measures barrier performance and later checks regulatory compliance. **Barrier-by-design** reverses the logic.

Step 1: define the food-protection problem.

Step 2: define realistic environmental and distribution conditions.

Step 3: identify the minimum barrier performance required.

Step 4: exclude restricted or strategically vulnerable chemistries.

Step 5: select candidate material architectures.

Step 6: evaluate IAS, NIAS and migration.

Step 7: evaluate conversion and sealing.

Step 8: validate real-food shelf life.

Step 9: assess recyclability and end-of-life compatibility.

Step 10: build the regulatory evidence package before scale-up.

This framework is an expert proposal, not an established regulatory doctrine. Its value is that it prevents substitution from being reduced to a negative claim: “contains no PFAS”. The product is instead defined positively by what it demonstrably does.

14. Research & Innovation Opportunity

A Food-Specific PFAS-Free Barrier Qualification Platform

Development pathway. Unresolved problem. The market lacks a broadly accepted, food-specific framework that simultaneously qualifies fluorine-free packaging for barrier performance, real-food preservation, chemical migration, NIAS, convertibility and circularity.

Why it matters. Current material-development studies often optimise laboratory barrier metrics, while regulatory compliance, real-food shelf life and end-of-life behaviour are evaluated separately or late.

What is already known. Bio-based and fluorine-free coatings can deliver substantial grease and water resistance. Analytical tools for PFAS, migration and NIAS exist. Shelf-life modelling and packaging permeability testing are mature disciplines.

What remains unknown. The field lacks an integrated decision model capable of determining which PFAS-free barrier architecture is optimal for a specific food rather than for an abstract packaging substrate.

Proposed hypothesis. A food-specific qualification platform combining barrier mapping, accelerated and real-time shelf-life testing, migration/NIAS screening, packaging conversion trials and recyclability assessment could identify lower-risk substitutions more reliably than material-only screening.

1. Select representative food matrices: high-fat dry food, moist bakery, ready meal, powdered product and chilled protein food.
2. Define critical deterioration mechanisms for each matrix.
3. Establish minimum oxygen, water-vapour, grease and seal requirements.
4. Screen fluorine-free coating families.
5. Test converted packages rather than laboratory films alone.
6. Perform targeted and non-targeted migration screening.
7. Validate food quality and shelf life.
8. Evaluate repulpability/recyclability or relevant end-of-life route.
9. Generate a regulatory evidence dossier.
10. Compare total food-system environmental performance with incumbent packaging.

Regulatory constraints. A new coating remains subject to applicable food-contact legislation independently of its PFAS status. Novel substances, multilayers and recycled substrates may require additional assessment depending on composition and jurisdiction.

Industrial relevance. Such a platform could reduce failed substitutions, shorten qualification cycles, create stronger supplier specifications and support defensible sustainability claims.

This is a proposed R&D framework, not an established legal requirement.

15. A Second Research Opportunity: Predicting NIAS Before They Appear

A particularly promising white space lies in predictive NIAS assessment.

Today, NIAS are often discovered analytically after a material or process has been developed. A more advanced approach would predict likely NIAS from formulation and process chemistry before industrial scale-up. Inputs could include monomer and oligomer structures, crosslinking chemistry, curing temperature, oxidation pathways, printing and adhesive chemistry, recycled-substrate contaminants and expected storage conditions.

Computational reaction-network prediction could then generate a candidate NIAS list for targeted high-resolution mass-spectrometry screening. This concept is technically plausible because analogous workflows already exist in metabolomics, pharmaceutical impurity prediction and reaction informatics.

It remains a research proposition for food packaging and would require careful validation. If successful, it would convert NIAS assessment from largely retrospective detection into prospective safety-by-design.

16. Practical Implications for Food and Ingredient Companies

The PPWR changes packaging governance inside food companies.

Procurement teams need regulatory competence because a supplier statement may be insufficient without analytical and technical-documentation support. Quality teams need packaging change control because a new coating, adhesive, ink or supplier can alter PFAS and migration status. R&D teams need to validate the food, not only the package.

Regulatory teams need to distinguish PPWR compliance from general food-contact compliance. Sustainability teams need to avoid burden shifting: less fluorine but more food waste, more material or poorer recyclability is not automatically a better outcome.

Commercial teams need discipline around claims. “PFAS-free”, “plastic-free”, “natural”, “bio-based”, “biodegradable” and “recyclable” describe different properties and should not be treated as interchangeable.

The strongest companies will integrate these functions rather than manage them sequentially.

17. Implications for INTABIOTECH

The most relevant opportunity for INTABIOTECH is not to enter packaging manufacturing indiscriminately.

It is to apply the company’s food-technology and regulatory capabilities to the interface between formulation, preservation and packaging. Ingredient systems and packaging are often treated as independent variables. In reality they can interact.

A product with improved oxidative stability may require less demanding oxygen-barrier packaging. A formulation with better water-activity control may alter moisture-barrier requirements. Preservation technology can influence the safety margin available during packaging transitions. Conversely, a packaging change can alter the performance required from preservation systems. This suggests a potentially valuable service and research domain: **food formulation–packaging co-design**.

The objective would be to determine the least complex packaging architecture capable of safely protecting a specific formulation, rather than specifying packaging in isolation. Any such work would need product-specific validation. It should not be used to infer that an ingredient can compensate for inadequate hygienic design, seal integrity or legally required packaging safety.

18. What Industry Should Not Do

Several shortcuts should be avoided.

Do not equate “no intentionally added PFAS” with compliance with concentration limits.

Do not use a single targeted PFAS panel as proof of every Article 5(5) threshold.

Do not assume that paper is automatically safer than plastic.

Do not assume that bio-based means non-migrating.

Do not qualify a barrier only on flat laboratory specimens if converting, creasing, sealing or heat treatment can damage it.

Do not evaluate sustainability without food waste.

Do not change coatings without packaging change control.

Do not market “PFAS-free” as if it were a complete food-contact safety claim.

And do not wait for a customer audit to discover that supplier documentation cannot support the legal status of the packaging.

19. Conclusions

The European PFAS restriction for food-contact packaging is already operational. Its immediate effect is to force companies to demonstrate that packaging placed on the EU market satisfies demanding concentration limits. Its larger effect may be to accelerate a redesign of food packaging itself.

PFAS substitution exposes a fundamental truth: packaging chemistry, food preservation, migration safety, processability and circularity cannot be optimised independently. The scientific literature shows promising fluorine-free technologies, particularly in bio-based and fibre-compatible coatings. It also shows that many proposed solutions remain insufficiently validated under industrial conversion, realistic humidity, real-food shelf life and comprehensive migration conditions.

The next innovation frontier should therefore move beyond “PFAS-free”. It should aim for **barrier-by-design**: packaging whose required performance is defined from the food backwards, whose chemistry is screened prospectively, whose migration profile is understood, whose real-food preservation is demonstrated, and whose end-of-life route is credible.

The strategic lesson is simple. Europe has restricted one problematic chemical family. Industry should use the transition not merely to substitute chemistry, but to build a better method for preventing the next regrettable substitution.

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