

# The Dirty Truth

**Contamination & Non-Homogeneity: the hidden barrier to PFAS-free durable water repellency (DWR)**

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## Executive summary

PFAS-free durable water repellents (DWRs) are no longer optional for much of the textile market. Yet one of the most underestimated barriers is not the chemistry — it is the substrate.

Modern textiles are chemically and physically heterogeneous by design. Oils, sizes, surfactants, softeners, salts, particulates, and mixed-lot variability enter the fabric at many points across a fragmented, multi-tier supply chain. If even a small fraction remains at the surface, a PFAS-free finish can fail through poor wetting, weak anchoring, uneven film formation, or accelerated loss of repellency during care cycles.

Historically, fluorinated DWRs were 'forgiving' because extremely low surface energy can mask some variability. Many PFAS-free systems are less forgiving: they can match water repellency in ideal conditions, but their performance boundary is narrower — especially when contamination or drift is present.

The practical path forward is to treat contamination and non-homogeneity as first-class test vectors. A rigorous, stage-gated testing approach (incoming fabric characterization > controlled application > performance verification > contamination challenge > durability/process window > field validation) reduces false wins, accelerates discovery, and cuts pollution by preventing rework and failure in the field.

## 13 Checklist

## 15 References

### Where contamination enters: a multi-tier pathway

Every handoff is a potential surface-chemistry reset.

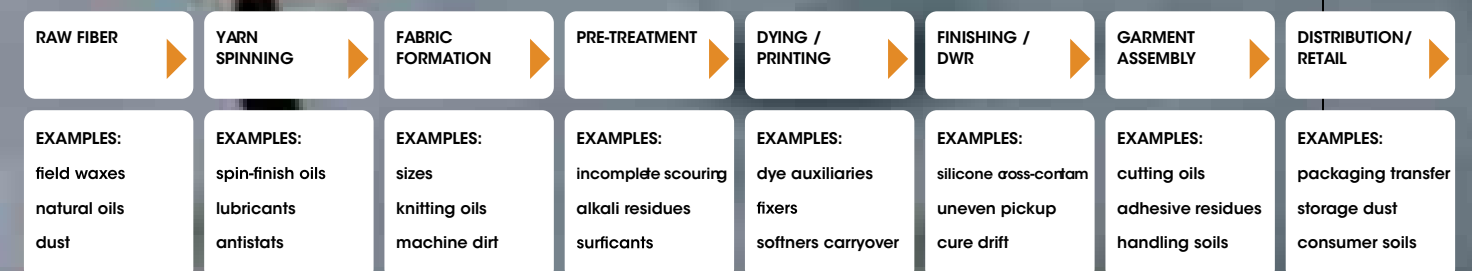


Figure 1. Where contamination enters: a multitier textile pathway



↓ 1.

### The substrate is the product: why “clean fabric” is not a given

Textile finishing is often discussed as if the fabric is an inert canvas. It is not. Most fabrics arrive with a chemical history: natural waxes and oils, spinning finishes, knitting lubricants, sizes, antistats, dyeing auxiliaries, softeners, and residues from incomplete rinsing. CottonWorks, for example, notes that manufacturing can add impurities such as fiber finishes, sizes, knitting lubricants, and oils — and that successful dyeing/finishing depends on proper preparation and removal of these materials.

A multi-tier supply chain amplifies variability. Raw materials can be blended and mixed at different stages (fiber, yarn, fabric), while processes and quality controls vary by facility and geography. Even when each partner meets its local specification, the combined system can deliver a surface that is non-homogeneous at the scale that matters to coatings: microns to millimeters.

A nuance worth stating: inconsistency is not always ‘corner cutting’. Some residues are deliberately used to run high-speed machinery; some variability comes from fiber morphology, recycled content, or process constraints. The outcome is the same: PFAS-free DWR must be engineered and validated against the reality of the substrate — not against idealized lab cloth.

↓ 2.

### Contamination is a mechanism, not a mystery

Peer-reviewed studies show that the best non-fluorinated DWRs can achieve water repellency comparable to fluorinated side-chain polymers for consumer outdoor clothing, but repellency to low-surface-tension liquids and stains is clearly reduced. In other words, PFAS-free can be ‘good enough’ for many end uses — but only if the performance target is defined correctly and the substrate is controlled.

In practice, this means PFAS-free DWR often has a narrower process window: small changes in fabric cleanliness, pickup, drying/curing, or care history can move performance from ‘pass’ to ‘fail’. ZDHC’s DWR research report notes that many non-fluorinated finishes (waxes, oils, silicones) can be penetrated by oils (including lotions and skin oils), reinforcing that real-use contamination matters.

A useful analogy comes from surface functionalization research: Nguyen et al. showed that degraded spin-finish oils can prevent reliable surface functionalization and that oil removal can be limited after degradation. While their work is not about apparel DWR, it illustrates a general truth in polymer processing: surface oils change over time and can become harder to remove — and surface chemistry will not forgive you.

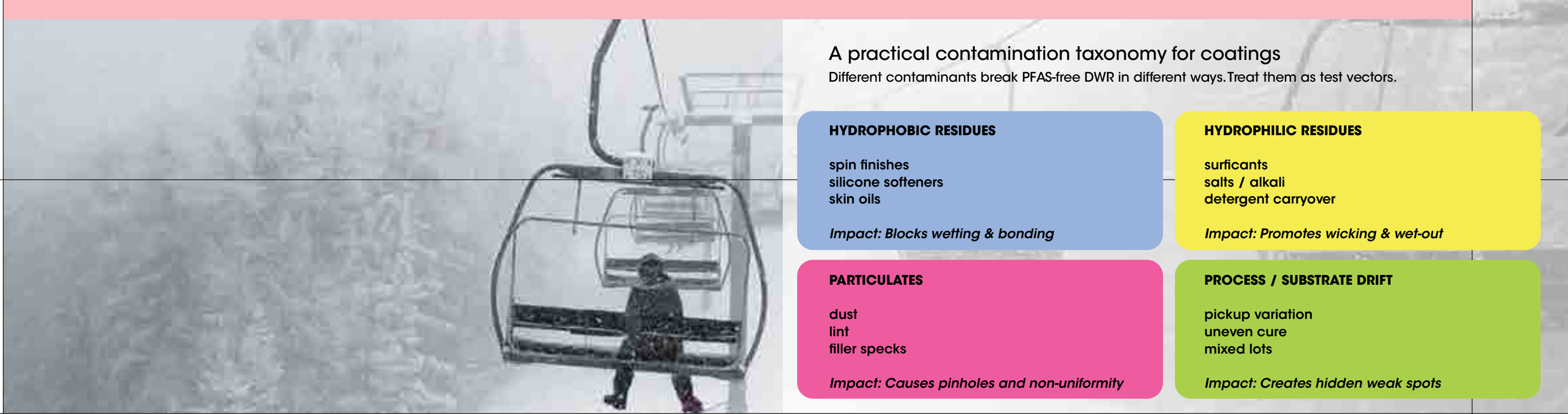


Figure 2. A practical contamination taxonomy for coatings.

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↓ 3.



### Why PFAS-free DWR feels harder: the system is less forgiving

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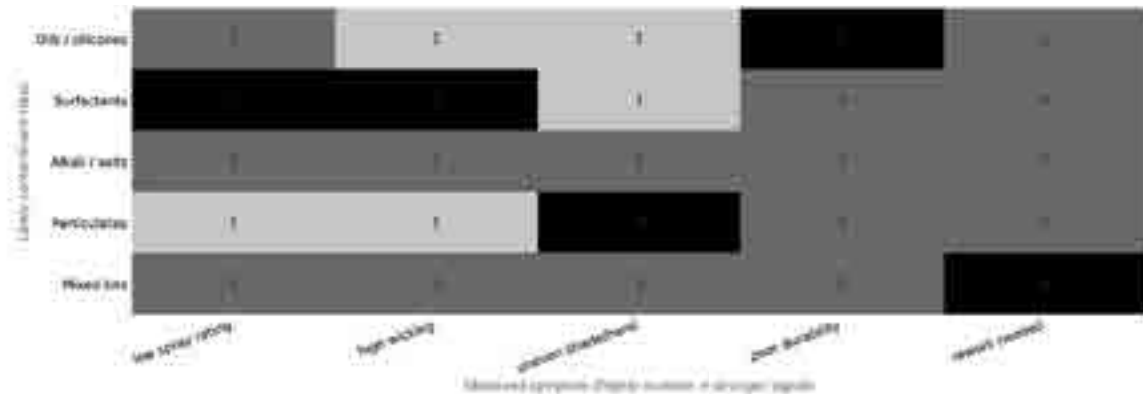
### The hidden cost of non-rigorous testing

When contamination is not built into the test plan, development teams often select a chemistry that looks excellent on a 'clean' lab fabric — and then fails during scale-up or field use. The cost is larger than a failed batch:

- Reprocessing increases water, energy, and chemical use. The World Bank/IFC PaCT program notes that poor Right-First-Time (RFT) performance in dyehouses drives reprocessing, which requires additional time, water, energy, and chemicals — and demonstrates substantial resource savings when RFT improves.
- Inconsistent field performance shortens garment life, increasing waste. UNEP reports that tens of millions of tonnes of textile waste are generated annually, while the Ellen MacArthur Foundation describes the scale of disposal as roughly a 'truckload' of textiles each second. Extending functional life is one of the fastest ways to reduce that flow.

In short: a non-rigorous test program is a pollution amplifier. It causes more wet processing (rework), more rejected lots, more returns, and ultimately more landfill.

### How contamination shows up: symptom fingerprints



↑ 4.

Figure 3. Symptom fingerprints: how contamination classes tend to show up in DWR failures.



Rigor does not mean running every test. It means running the right tests, on the right substrates, under the right stresses — and capturing the boundaries.

↓ 5.

A rigorous testing playbook for PFAS-free DWR on real textiles

This is a practical, high-leverage framework that we have seen reduce failure rates while speeding decision-making.

Suggested contamination-challenge protocol (example)

Challenge vector	Purpose	How to implement	Primary readouts
Silicone trace	Detect cross-contamination sensitivity	Dose ppm-level silicone softner surrogate on fabric line	spray rating; durability drop
Surfificant residue	Stress wicking / out	Add low g/L nonionic surficant; dry; then coat	spray rating; wicking height
Skin oil / lotion	Simulate real wear	Apply standardized oil blend; age 24h	roll-off angle; stains
Dust / particulates	Reveal pinholes & coverage issues	Apply standardized dust; lightly shake off	visual uniformity; hydrostatic
Mixed lots	Emulate supply chain reality	Blend 2-3 lots or mills in the study	variance; pass rate

- A. Characterize incoming fabrics before coating**  
Establish a 'surface readiness' gate. Typical checks include pH/extractables, absorbency/wicking, and indicators of surfactant or silicone contamination. Cotton Incorporated recommends monitoring pH/alkalinity and extractables and highlights the sensitivity of repellency to silicone and detergent residues.
- B. Separate performance from durability**  
Use a 2-axis scorecard: (1) initial repellency, and (2) durability after laundering/abrasion. The ZDHC report emphasizes that performance is a combination of attributes and depends on end use and durability requirements.
- C. Build a contamination-challenge protocol**  
Intentionally 'spike' fabrics with controlled levels of common contaminants (e.g., silicone softener trace, surfactant residue, skin oil surrogate, dust). The point is not to sabotage — it is to learn sensitivity and set substrate specifications.
- D. Map the process window**  
Run a designed experiment (DOE) over pickup, drying, curing, and add-on level. Define control limits that manufacturing can hold. This converts 'tribal knowledge' into an operating window.
- E. Validate with multi-lot, multi-mill fabrics**  
If the supply chain will deliver mixed lots, test mixed lots. A 'universal' DWR is rarely universal; a robust DWR is robust to the variation you actually buy.

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↓ 6.

### Why rigor is speed — and why it is sustainability

A rigorous program feels slower on day one because it demands better controls, better substrates, and better measurements. But it is faster over the life of development because it eliminates false positives.

- Faster PFAS replacement discovery: Contamination challenge testing quickly removes brittle formulations and reveals robust ones, reducing iteration cycles.
- Reduced pollution: Improving Right-First-Time and reducing reprocessing cuts water, chemical, and energy usage in wet processing (as demonstrated in PaCT case studies).
- Lower field failure rates: When DWR survives real-use contaminants and care cycles, garments last longer. Longer life reduces the waste stream and landfill pressure, a core objective repeatedly highlighted by circular economy efforts in fashion.



For PFAS-free DWR, the fastest path is not minimal testing; it is targeted, adversarial testing that reflects the real supply chain.

### Rigor is a development accelerator: a stage-gate testing pipeline

Build confidence by intentionally stressing the system with contamination and variability.

**Key idea:**  
the goal is not to 'pass a test' – it is to map failure boundaries before the market does.

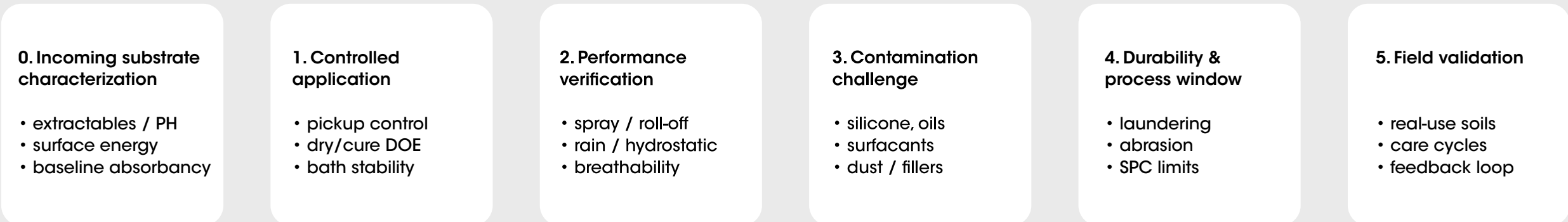


Figure 4. Stage-gate testing pipeline: using rigor to accelerate PFAS-free DWR adoption.

## Practical checklist:

*What to ask your supply chain (and your lab)*

- Do we have an incoming-fabric 'surface readiness' test (pH, extractables, wicking/absorbency)?
- Can we detect silicone contamination (especially if any line runs silicone softeners or elastomers)?
- Do we test more than one fabric lot and more than one mill?
- Do we run durability tests (laundering/abrasion) before we declare a chemistry 'ready'?
- Do we deliberately challenge with surfactants, skin oils, and dust to map sensitivity?
- Do we have a quantified process window (pickup, dry/cure) and SPC limits?
- When we see a failure, do we have a root-cause workflow (chemical residues vs. process drift vs. substrate mix)?

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EMPEL® is a clean chemistry DWR technology applied to the outer surface of textiles. Unlike traditional coatings that soak into the fabric and wash out quickly, EMPEL® is pressed into the fibers – without using water or PFAS – providing long-lasting, high-performance water repellency.

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