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Trust, but VERIFY

A Practical Framework for Contamination Resistant, PFASFree Textile Coatings

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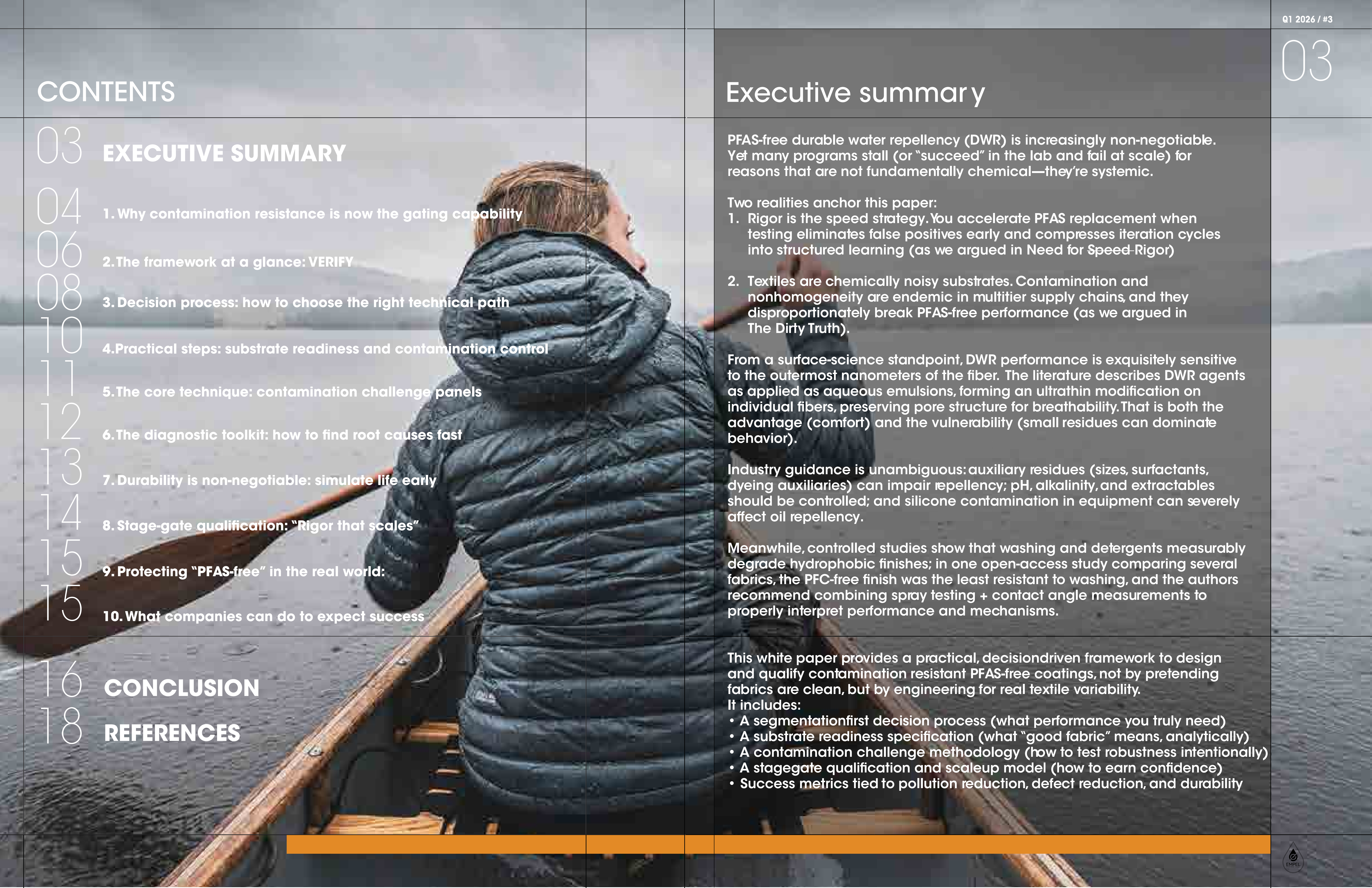

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Executive summary

PFAS-free durable water repellency (DWR) is increasingly non-negotiable. Yet many programs stall (or "succeed" in the lab and fail at scale) for reasons that are not fundamentally chemical—they're systemic.

Two realities anchor this paper:

1. Rigor is the speed strategy. You accelerate PFAS replacement when testing eliminates false positives early and compresses iteration cycles into structured learning (as we argued in Need for ~~Speed~~ Rigor)

2. Textiles are chemically noisy substrates. Contamination and nonhomogeneity are endemic in multitier supply chains, and they disproportionately break PFAS-free performance (as we argued in The Dirty Truth).

From a surface-science standpoint, DWR performance is exquisitely sensitive to the outermost nanometers of the fiber. The literature describes DWR agents as applied as aqueous emulsions, forming an ultrathin modification on individual fibers, preserving pore structure for breathability. That is both the advantage (comfort) and the vulnerability (small residues can dominate behavior).

Industry guidance is unambiguous: auxiliary residues (sizes, surfactants, dyeing auxiliaries) can impair repellency; pH, alkalinity, and extractables should be controlled; and silicone contamination in equipment can severely affect oil repellency.

Meanwhile, controlled studies show that washing and detergents measurably degrade hydrophobic finishes; in one open-access study comparing several fabrics, the PFC-free finish was the least resistant to washing, and the authors recommend combining spray testing + contact angle measurements to properly interpret performance and mechanisms.

This white paper provides a practical, decisiondriven framework to design and qualify contamination resistant PFAS-free coatings, not by pretending fabrics are clean, but by engineering for real textile variability.
It includes:
- A segmentationfirst decision process (what performance you truly need)
- A substrate readiness specification (what "good fabric" means, analytically)
- A contamination challenge methodology (how to test robustness intentionally)
- A stagegate qualification and scaleup model (how to earn confidence)
- Success metrics tied to pollution reduction, defect reduction, and durability

1.

Why contamination resistance is now the gating capability

1.1 DWR is a nanoscale interface problem
DWR is not simply "a coating on top." In practice, effective DWR modifies the external fiber surface while leaving pores open for vapor transport. Holmquist et al. describe how DWR agents are applied as aqueous emulsions, forming a thin modification on individual fibers at the nanometer scale, so garments remain breathable while resisting water droplet penetration and wetout.

That means small quantities of:
- surfactant residue
- silicone carryover
- size or wax residue
- finishing oils and lubricants

can dominate wetting behavior and destroy consistency.

1.2 PFAS used to "hide" messy substrates; PFASfree systems expose them
A large industry research report (ZDHC / outdoor sector collaboration) emphasizes that DWR performance depends on end use, durability demands, abrasion, laundering, and breathability - and that high-performing repellency historically relied on fluorinated chemistries because they repel both water and oils more effectively than wax/silicone/oil-based approaches.

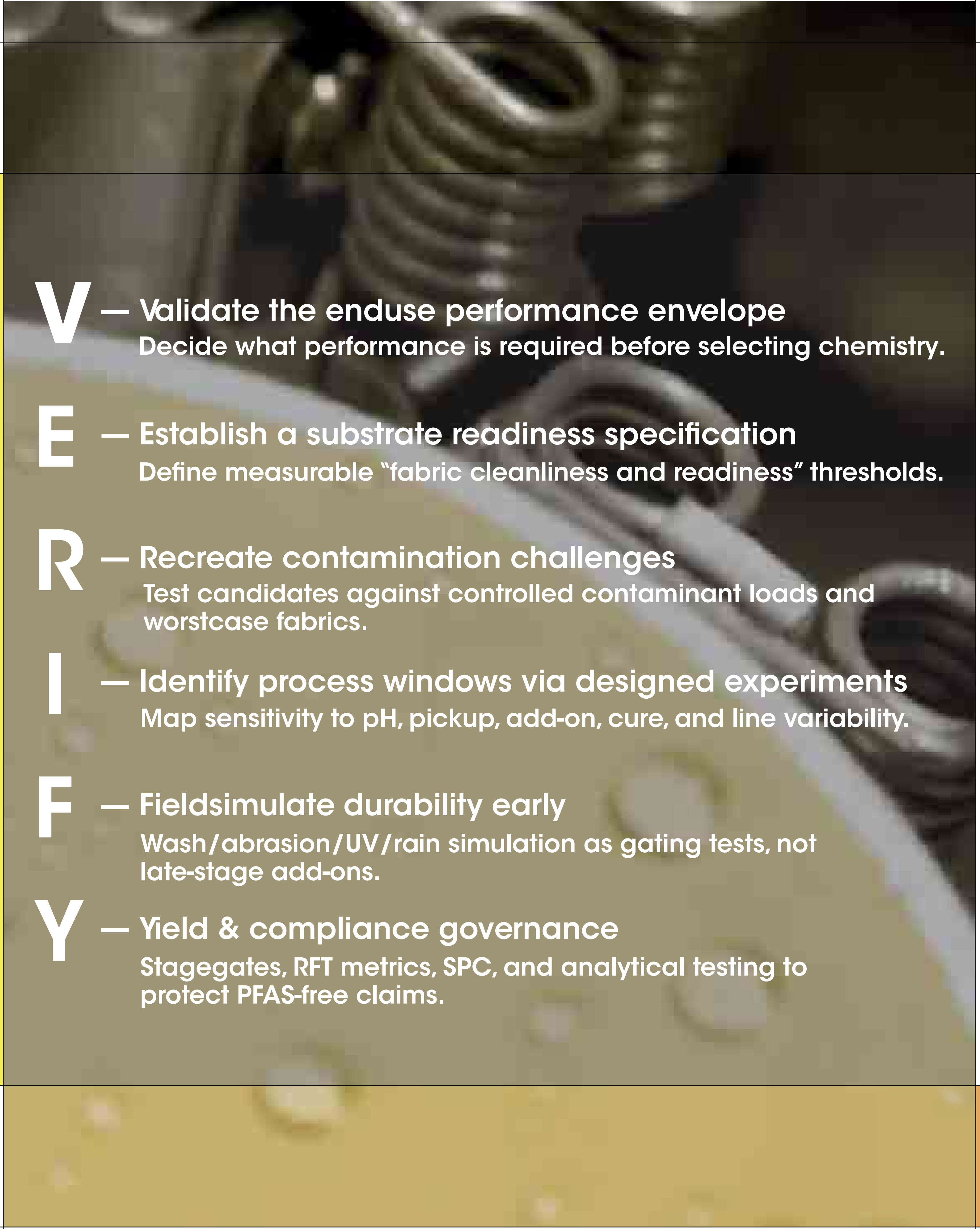
As the PFAS-free transition progresses, the substrate and process window matter more. Cotton Incorporated's technical bulletin is explicit: auxiliary residues can impair water and oil repellency, and silicone contamination in mixing/processing equipment can severely affect oil repellency.

1.3 Rigor reduces pollution by reducing rework
The "hidden sustainability tax" in poor robustness is reprocessing: extra dips, extra washes, extra drying/curing, and rejects. A World Bank cleaner production case study shows that poor RightFirstTime (RFT) performance increases water/energy/chemical use due to reprocessing; after interventions, one facility increased bulk RFT from 80% to 95.5%, eliminating reprocessing for ~15% of water baths and reducing resource use.

2.

The framework at a glance:
VERIFY for contamination resistant coatings

The framework is organized as VERIFY,a repeatable operating system
for development + qualification:



V — Validate the enduse performance envelope
Decide what performance is required before selecting chemistry.

E — Establish a substrate readiness specification
Define measurable “fabric cleanliness and readiness” thresholds.

R — Recreate contamination challenges
Test candidates against controlled contaminant loads and worstcase fabrics.

I — Identify process windows via designed experiments
Map sensitivity to pH, pickup, add-on, cure, and line variability.

F — Fieldsimulate durability early
Wash/abrasion/UV/rain simulation as gating tests, not late-stage add-ons.

Y — Yield & compliance governance
Stagegates, RFT metrics, SPC, and analytical testing to protect PFAS-free claims.

3.

Decision process: how to choose the right technical path

The biggest mistake I see is starting with "Which PFAS-free chemistry should we use?"
The correct starting question is: What problem are we solving?

Step 1 — Classify the product into a performance tier

Use an end-use segmentation aligned with test severity:

Tier A: Water repellency (surface wetting resistance)
Suitable for casual outerwear, light rain exposure
Screening tools: spray test (fast, low cost)
AATCC explicitly notes TM22 is used as a quick, low-cost screening method for water repellency.

Tier B: Rain exposure + penetration concerns
Rainwear where wet-out and penetration matter
Requires rain and/or hydrostatic testing
Note: fabric construction often dominates penetration outcomes
Cotton Incorporated notes spray testing only rates surface wetting; rain tests measure penetration, and construction heavily influences results. ISO similarly notes spray testing is not intended to predict rain penetration.

Tier C: Multi-liquid repellency (water + oils/soils)
Workwear, industrial, stain-prone environments
Requires oil repellency metrics
AATCC TM118 (technically equivalent to ISO 14419) defines oil repellency as resistance to wetting by oily liquids, graded by the highest hydrocarbon test liquid that does not wet the fabric.

Decision: If you need Tier C performance, PFAS-free options may require more tradeoffs or different system architectures (e.g., barrier concepts, hybrid designs, or acceptance of reduced oil repellency depending on use-case). ZDHC's report explicitly notes nonfluorinated alternatives often claim water repellency but generally do not provide oil repellency/stain release comparable to fluorinated systems.

Step 2 — Decide whether "contamination resistance" is a must-have (usually it is)

If any of these are true, treat contamination resistance as a primary requirement:
- multiple mills / mixed greige sources
- frequent lot changes
- recycled content
- heavy dye/print/softening history
- known silicone usage in upstream finishing
- inconsistent pre-treatment quality

Then proceed to substrate readiness specs + contamination challenge testing (Sections 4–5).

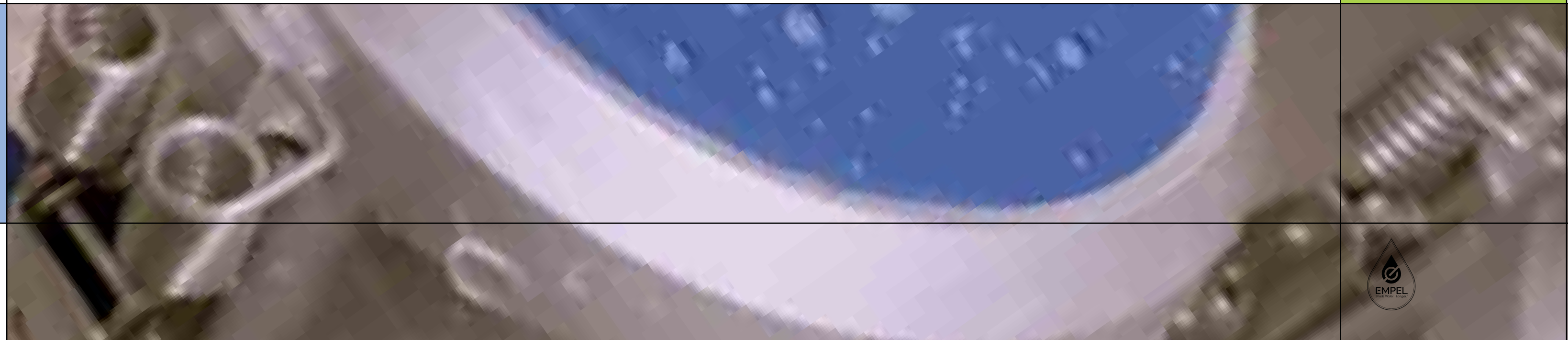
Step 3 — Select the coating route after constraints are explicit

Instead of prescribing a single "best chemistry," decide between application architectures:

- **Impregnation / finish** (fiber-level modification; preserves breathability)
- **Thin coating / hybrid** (more robust barrier, may impact hand/breathability)
- **Process innovation** (foam/spray to reduce water, improve uniformity)

Holmquist et al. discuss DWR as fiber-level modification to avoid wet-out while retaining pore structure.

ZDHC notes multiple application routes (padding primary; spraying, foams as alternatives), and foams reduce water by replacing water with air in the application step.



4.

Practical steps: substrate readiness and contamination control

4.1 Build a “fabric readiness” specification

A contamination-resistant coating strategy starts with measurable incoming controls, especially if you do not control upstream processing.

Cotton Incorporated provides a practical set of recommended checks before repellency finishing, including pH, alkalinity, water and solvent extractables, and tests for residual size and surfactants.

A practical readiness spec (adapt/validate for your materials):
- **Fabric pH:** target range (e.g., 5.5–7.5)
- **Residual alkalinity:** very low (indicative of proper neutralization)
- **Water extractables:** low (residual auxiliaries)
- **Solvent extractables:** low (oils/waxes/softeners)
- **Drop absorbency:** consistent with intended wetting behavior
- **Surfactant residue indicator:** foaming test (screen)

4.2 Enforce silicone hygiene when oil repellency matters

Cotton Incorporated explicitly warns that mixing/processing equipment must be kept free of silicone contamination, and that silicone severely affects oil repellency.

Operational translation:
- separate lines for silicone softeners vs repellent finishing (where feasible)
- validated cleaning protocols (and verification checks)
- require non-silicone defoamers when possible
- establish “silicone incident” root-cause playbooks (see Section 6.2)

4.3 Don’t ignore consumer care chemistry

Even if mill finishing is perfect, repellency can be compromised by laundering products.

Cotton Incorporated notes liquid fabric softeners and dryer sheets can interfere with water and oil repellency.

Practical action: If your brand sells high-performance repellency, provide care instructions, fand test durability under realistic consumer practices (Section 7).

5.

Practical steps: substrate readiness and contamination control

5.1 Why you need deliberate contamination challenges

If you only test on “clean lab fabric,” you’re optimizing for a condition you will not ship. The goal is not perfection—it is robustness.

5.2 How to construct contamination challenge panels

Create a standardized, repeatable “challenge set” that mimics what your supply chain actually introduces.

Contaminant classes to include (example set):
- **Surfactant residue challenge** (representative nonionic or anionic surfactant)
- **Oil/lubricant challenge** (spinning/knitting oil analog)
- **Silicone challenge** (trace silicone oil contamination, where relevant)
- **Mixed auxiliary challenge** (size + surfactant blend)

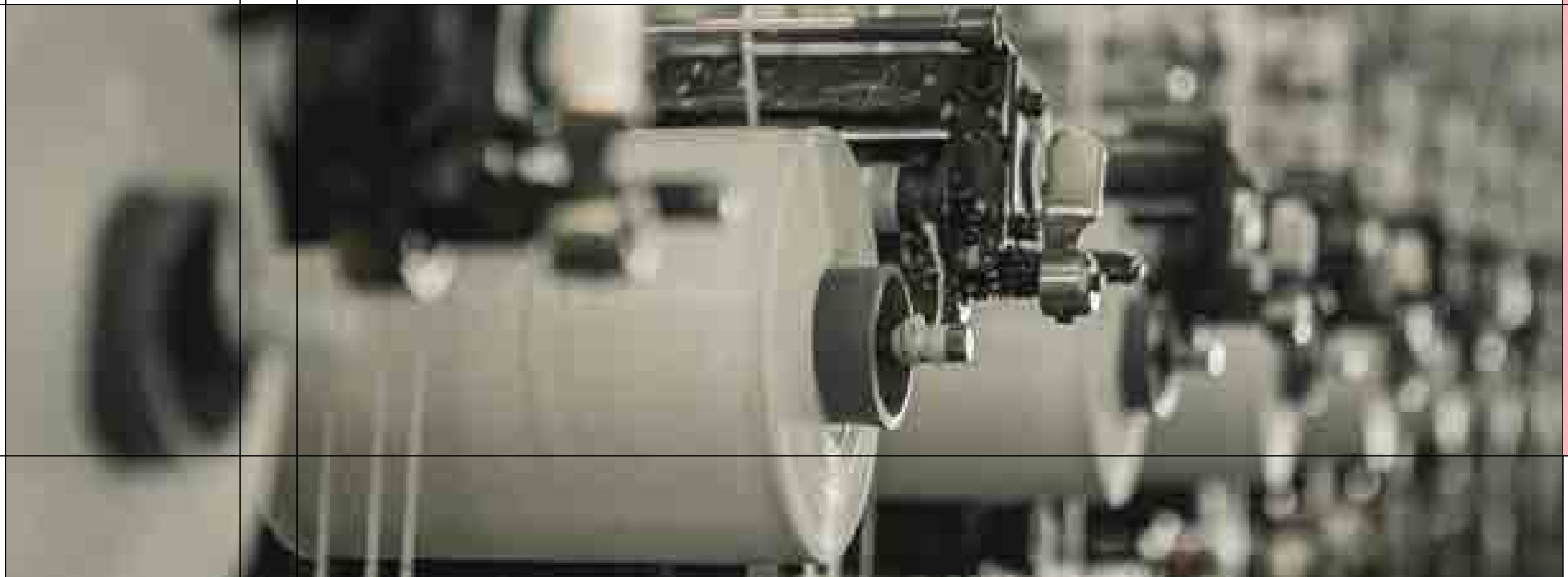
Application method:
- apply contaminants at controlled add-ons (e.g., low/med/high)
- age/condition panels (heat/humidity) to simulate storage
- then apply your PFAS-free finish under standard conditions

Outputs:
- “performance delta” between clean and challenged panels
- durability deltas after laundering/abrasion
- mechanism diagnostics (contact angle / surface energy; Section 6)

5.3 Scoring robustness

Define a Robustness Index for each candidate:
- Water repellency retention (after challenge + after durability)
- Oil repellency retention (if needed)
- Process window sensitivity (Section 6.3)
- Rework risk (variance across lots/substrates)

This becomes the decision engine for what to scale.



6.

The diagnostic toolkit: how to find root causes fast

The fastest programs I've seen treat testing as a forensic system, not a pass/fail ritual.

6.1 Pair performance tests with mechanism tests

A strong open-access study recommends using spray testing + contact angle measurements together: spray tests relate to real behavior; goniometry and surface free energy help explain changes and causes.

Practical combination:

- **Screening:** AATCC TM22 / ISO 4920 for surface wetting resistance
- **Mechanism:** static contact angle + surface free energy decomposition (where possible)
- **Penetration risk:** rain test and/or hydrostatic depending on claim level
- **Oil repellency:** AATCC TM118 / ISO 14419 (if relevant)

6.2 A symptom-to-cause "fingerprint" (practical troubleshooting)

Examples (non-exhaustive):

- **Good initial spray rating > collapses after laundering:** detergent adsorption, orientation changes, inadequate cure/crosslinking, marginal binder.
- **Good water repellency > poor oil repellency scatter:** silicone contamination, residual softener/oil,
incorrect bath pH, or insufficient low-energy surface formation.
- **Lab success > mill failures:** pickup variability, cure drift, bath instability, fabric extractables variability.

6.3 Use DOE to map process windows

PFAS-free systems often have narrower "good zones."
Don't discover that through failure—map it deliberately.

Critical factors:

- bath pH (Cotton Inc notes many finishing baths target acidic pH ranges, depending on product)
- pickup / wet add-on
- drying completeness ("bone dry" prior to cure is explicitly recommended for fluorochemical systems; analogous discipline applies broadly for crosslinking systems)
- cure temperature/time
- mechanical finishing impacts (calendering, emerizing)

DOE outputs:

- main effects and interactions
- robustness window definition
- guardbands for production control

7.

Durability is non-negotiable: simulate life early

7.1 Washing protocols

- If you sell apparel, your DWR will be laundered.
- ISO 6330 specifies domestic washing and drying procedures for textile testing and includes reference detergents/ballasts.
- For accelerated testing, AATCC TM61 is commonly used to approximate multiple home launderings in a shorter test.

7.2 What the data says about PFAS-free durability risk

- In an open-access study evaluating multiple functional clothing materials, the authors found washing caused significant changes in surface properties and explicitly state the PFC-free finish was the least resistant to washing in their set.
- This doesn't mean PFAS-free cannot work; it means durability must be engineered and validated, not assumed.

8.

Stage-gate qualification: "Rigor that scales"

A contamination-resistant PFAS-free program should run like a *gated product development system.*

Gate 0 — Define claims and constraints
- tier A/B/C classification (Section 3)
- must-have vs nice-to-have
- sustainability boundaries (e.g., limit rework; reduce water usage)

Gate 1 — Screening on clean + challenge panels
- TM22 / ISO4920 screening
- contact angle / surface energy mechanism checks
- AATCC 118 / ISO14419 if needed

Gate 2 — Robustness window DOE
- map pH, pickup, cure, add-on
- quantify variance across substrates
- define control limits

Gate 3 — Durability and field simulation
- wash protocols (ISO 6330; accelerated AATCC as appropriate)
- abrasion / flex (select based on end-use)
- rain/penetration tests if Tier B

Gate 4 — Mill pilot and RFT metrics

Tie technical success to manufacturing success:
- bulk-to-bulk RFT
- re-dip rate
- scrap/seconds
- wastewater and energy intensity per meter

World Bank's RFT case study provides a clear example of why these metrics matter: poor RFT drives reprocessing; improving RFT reduced rework and resources.

Protecting "PFAS-free" in the real world: analytical verification and supply chain controls

Contamination-resistant coatings must also be compliance-resistant, because even if your formulation is PFAS-free, upstream contamination can create exposure risk or failed audits. EN 176811:2025 represents a significant change in targeted PFAS analysis in textiles, using alkaline hydrolysis to increase detection of PFAS released from certain side-chain fluorinated polymers; industry notes this can yield much higher detected levels than prior extraction approaches.

Practical takeaways:
- align with brand RSL/MRSL test expectations early
- test representative lots, not "golden samples"
- audit and monitor chemical inputs upstream (TÜV explicitly recommends supply chain monitoring and audits alongside analytical testing)

9.

10.

What companies can do to expect success

Companies that reliably succeed in PFAS-free DWR under real supply-chain variability tend to share five behaviors:

1. They segment performance honestly (Tier A/B/C) and refuse to over-claim.
2. They specify "fabric readiness" like a material property, not a hope.
3. They stress-test contamination deliberately and score robustness, not just best-case performance.
4. They pair screening tests with mechanism diagnostics (spray + contact angle/surface energy) to accelerate root cause learning.
5. They operationalize rigor: stage gates, process windows, RFT, SPC, and compliance analytics.

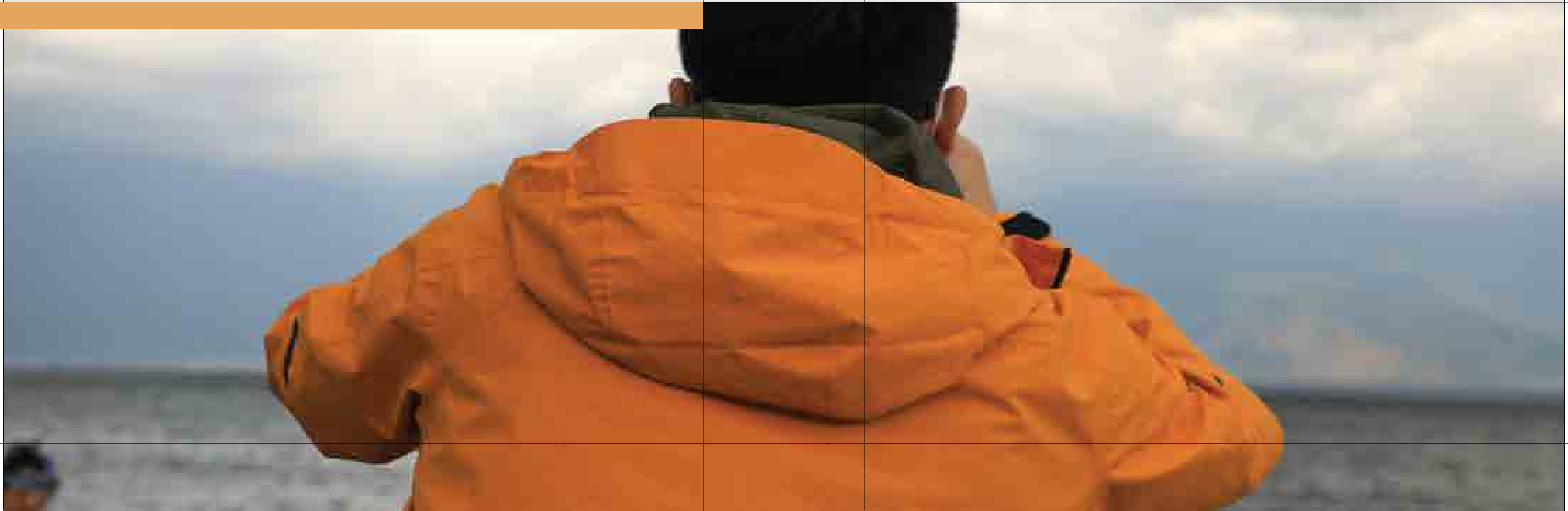
Conclusion

PFAS-free DWR at scale will not be won by the best slide deck or the most optimistic lab demo.

It will be won by organizations that accept the two realities we laid out in this series:

- Rigor is the only sustainable speed.
- Textiles are not homogeneous substrates; contamination is structural.

This paper's framework, is designed to turn those truths into a practical operating system: define the right problem, control the substrate, challenge the system, map robustness windows, simulate real life early, and govern quality and compliance like a strategic capability.



Selected references

Holmquist, H. et al. “Properties, performance and associated hazards of state-of-the-art durable water repellent (DWR) chemistry for textile finishing.” Environment International (2016).

Cotton Incorporated. “Water and stain repellent finishing of cotton fabrics (ISP 1007).”

AATCC. “The Art of Testing: Water Repellency” (TM22 overview).

ISO 4920:2012. “Textile fabrics — Determination of resistance to surface wetting (spray test).”

AATCC TM118 / ISO 14419 (Oil repellency / hydrocarbon resistance).

Kowalski, M. et al. “Quality and Quantity Assessment of the Water Repellent Properties of Functional Clothing Materials after Washing.”
(Open access, 2022).

World Bank / IFC PaCT. “Cleaner Production Case Study: Right First Time (RFT) Improvement…” (2021).

ZDHC / Outdoor sector report. “Durable Water and Soil repellent chemistry in the textile industry – a research report.”

SGS. “Updated PFAS Test Method for Textile Products”
(EN 176811:2025 summary).

Intertek. “Update on EU Standard EN 176811:2025 for Targeted PFAS Analysis in Textiles.”

TÜV Rheinland. Customer information on EN 176811:2025 method update and recommendations.

EMPEL is a PFAS-free 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.

Sheds water. Longer.

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