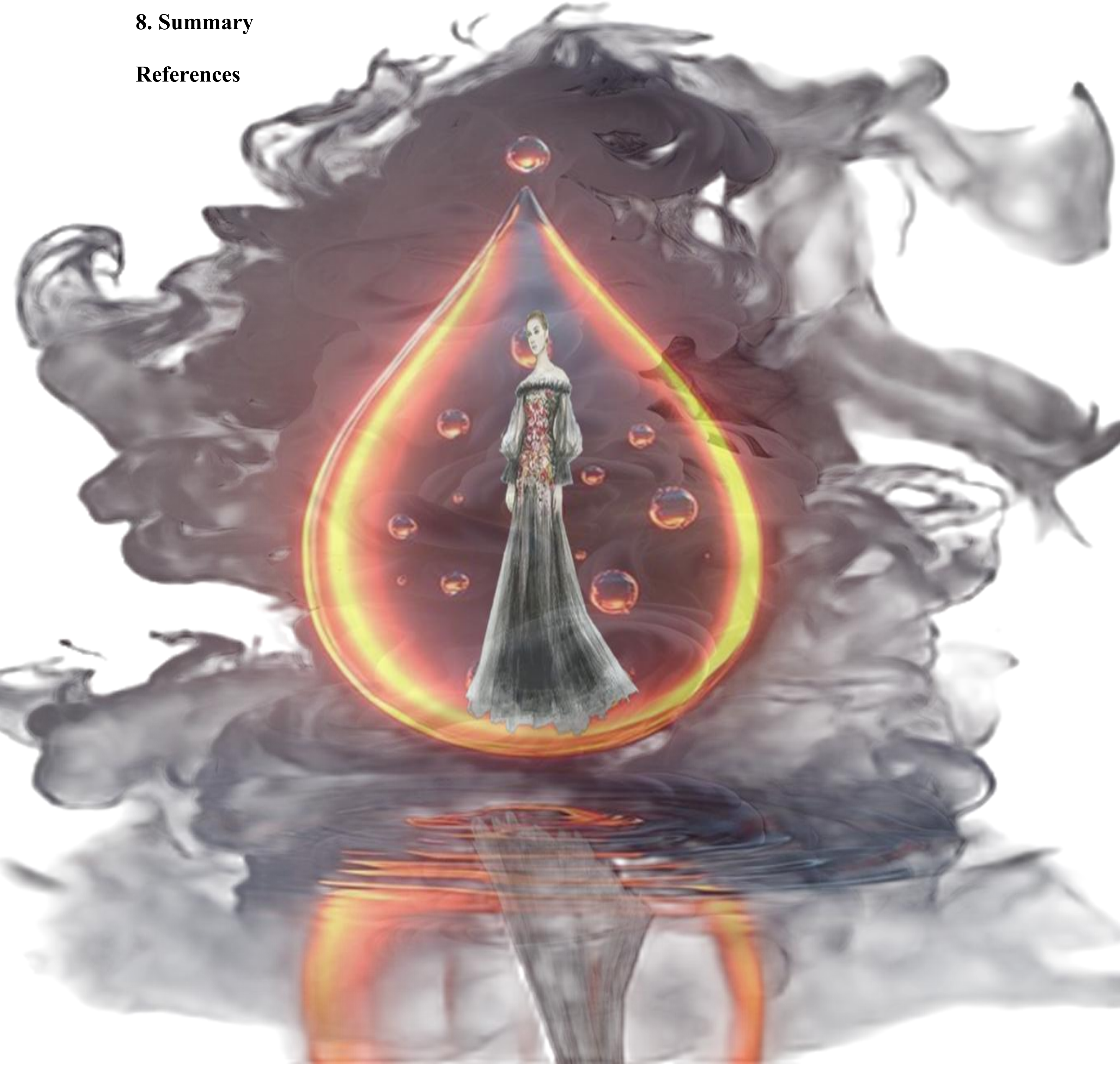
Materials Truth & Chemical Accountability

Contents



Executive Summary

Fashion’s sustainability crisis is, at its core, a chemical crisis. Every major fibre used in the global apparel industry — polyester, nylon, acrylic, PVC, PU, viscose, lyocell, and recycled plastics — originates in industrial chemical systems that shape its environmental and human-health impacts long before a garment reaches a consumer. Yet these chemical foundations remain largely invisible, obscured by marketing language, selective disclosure, and structural greenwashing.

This report exposes the chemical realities behind modern materials and establishes a scientific framework for evaluating sustainability claims. It demonstrates that fashion’s most common fibres are not neutral substances but engineered polymers, solvents, catalysts, and additives whose production involves fossil-fuel extraction, chlorine chemistry, hazardous intermediates, and globalised supply chains. Their impacts extend far beyond carbon footprints: they include mercury emissions, PFAS contamination, nitrous oxide release, microplastic pollution, solvent exposure, and deforestation.

PVC — often marketed as “vegan leather” — is inseparable from the chlorine economy, which relies on mercury-cell electrolysis, asbestos diaphragms, and PFAS-coated membranes. PU leather depends on diisocyanates and DMF, exposing workers to respiratory sensitizers and reproductive toxins. Polyester, the dominant fibre of fast fashion, is rooted in petrochemical feedstocks and antimony catalysis and is a major source of global microplastic pollution. Nylon releases nitrous oxide, a greenhouse gas hundreds of times more potent than CO_2. Acrylic, produced from acrylonitrile, sheds more microfibres than any other textile fibre.

Viscose, though plant-derived, relies on carbon disulfide — a neurotoxic solvent — and often drives deforestation in ancient and endangered forests. Lyocell offers improvements but remains dependent on pulp origin and solvent recovery performance. Bio-based synthetics behave identically to fossil plastics and degrade into the same microplastics. Recycled plastics, widely promoted as circular, do not alter polymer chemistry and often divert PET from efficient bottle-to-bottle systems into a textile system with no viable end-of-life pathway.

Across all materials, the common denominator is chemical opacity. Brands rarely disclose catalysts, solvents, stabilisers, plasticisers, feedstock origins, emissions, or microfibre shedding rates. Without this information, sustainability claims cannot be verified. The absence of chemical transparency enables structural greenwashing and prevents regulators, journalists, researchers, and consumers from assessing the true impact of materials.

To address this, the report introduces the **Materials Accountability Framework**, a scientific evaluation system based on six criteria: chemical transparency, feedstock origin, production technology, pollution intensity, end-of-life impact, and greenwashing risk. When applied rigorously, this framework reveals that PVC, PU, acrylic, and polyester are severe-risk materials; viscose, nylon, and recycled plastics are high-risk or conditional; and genuinely low-risk materials are rare.

The report concludes with a mandatory disclosure model defining what brands must reveal for sustainability claims to be credible: full material composition, chemical inputs, solvent systems, catalyst systems, chlorine/PFAS/mercury involvement, feedstock origin, emissions data, microplastic shedding rates, and end-of-life recyclability. These disclosures are not optional; they are the minimum scientific requirements for chemical accountability.

The central finding is unequivocal: fashion cannot be sustainable until it is chemically honest. Sustainability is not a matter of slogans or selective metrics. It is a matter of chemistry — of understanding the industrial systems that produce materials, the pollutants they release, the forests they consume, the workers they expose, and the microplastics they shed. Only through full chemical transparency can the industry move beyond greenwashing and begin a genuine transition toward sustainable materials and responsible production.

1. THE CHEMICAL REALITY OF MODERN MATERIALS

Fashion’s materials are not passive or neutral. They are engineered chemical systems whose environmental and human-health impacts begin long before a garment is cut or sewn. Every fibre, coating, finish, and “innovation” is the outcome of industrial chemistry: polymerisation, catalysis, solvent dissolution, stabilisation, plasticisation, dye fixation, and surface modification. These processes release pollutants at every stage, from feedstock extraction to fibre production, finishing, use, and disposal. Understanding the chemical reality of modern materials therefore requires tracing each fibre back to its molecular origins, its production technologies, and its pollutant pathways.

This section expands the original material categories into a rigorous scientific architecture, organised around three foundational domains: **petrochemical synthetics**, **chlorine-based polymers**, and **solvent-dependent regenerated cellulose systems**, followed by an examination of **bio-based synthetics** and **recycled plastics** as chemically continuous with their conventional counterparts. The aim is not merely to describe materials but to expose the chemical systems that sustain them — systems that remain largely invisible in fashion’s sustainability narratives.

1.1 Petrochemical Foundations of Synthetic Fibres

1.1.1 Polyester: Petrochemical Polymerisation and Antimony Catalysis

Polyester (polyethylene terephthalate, PET) is the structural backbone of fast fashion, accounting for approximately 50–60% of global fibre production (Textile Exchange, 2023). Its chemistry is rooted in fossil fuels: purified terephthalic acid (PTA) and monoethylene glycol (MEG), both derived from crude oil or natural gas, undergo a polycondensation reaction catalysed primarily by antimony trioxide. Antimony trioxide is classified as a possible human carcinogen, and measurable residues can remain in the final fibre, migrating into sweat or wash water during use (Hansen et al., 2013; KEMI, 2014).

Polyester’s environmental burden extends into the consumer phase. During laundering, polyester garments shed microfibres — plastic particles under 5 mm — that pass through wastewater treatment systems and accumulate in aquatic environments (Browne et al., 2011). A single garment can release hundreds of thousands of fibres per wash (Napper & Thompson, 2016). These microplastics have been detected in marine organisms, drinking water, and human tissues, raising concerns about long-term toxicological effects (Cox et al., 2019).

1.1.2 Nylon: Adipic Acid Chemistry and Nitrous Oxide Emissions

Nylon (polyamide) is another petrochemical fibre whose production is chemically and energetically intensive. Nylon-6,6 is synthesised from adipic acid and hexamethylenediamine, both derived from fossil feedstocks. The oxidation of cyclohexane to adipic acid releases nitrous oxide (N_2O), a greenhouse gas approximately 300 times more potent than CO_2 (IPCC, 2013). Although some facilities have installed abatement technologies, global emissions remain significant.

Nylon’s polymerisation requires high temperatures and pressures, embedding substantial energy demand into the fibre’s lifecycle. Like polyester, nylon sheds microfibres during washing, contributing to aquatic microplastic pollution.

1.1.3 Acrylic: Acrylonitrile Polymerisation and Extreme Microfibre Shedding

Acrylic fibres are produced from acrylonitrile, a monomer classified as a probable human carcinogen (IARC, 1999). The polymerisation process is energy-intensive and relies entirely on fossil feedstocks. Despite these hazards, acrylic receives far less scrutiny than polyester or nylon.

Empirical research shows that acrylic sheds more microfibres during laundering than any other common textile fibre. Napper and Thompson (2016) found acrylic released the highest number of fibres per wash cycle among all materials tested. These fibres persist in the environment, accumulate in food webs, and contribute to long-term ecological and potential human health risks (GESAMP, 2016).

Acrylic is also one of the least recyclable fibres. Its chemical structure and low economic value make it unattractive for mechanical recycling, and viable chemical recycling pathways remain limited (Ellen MacArthur Foundation, 2017). As a result, acrylic follows a linear path from production to disposal, typically ending in landfill or incineration.

1.2 Chlorine-Based Polymers and the Global Chlor-Alkali Economy

1.2.1 PVC: Chlorine Plastic and the Toxicity of Vinyl Chloride Monomer

Polyvinyl chloride (PVC) is one of the most chemically hazardous materials used in fashion. It is produced from vinyl chloride monomer (VCM), itself derived from chlorine and ethylene. Chlorine production relies on chlor-alkali technologies that use mercury, asbestos, or PFAS-coated membranes, embedding toxicants into the earliest stages of PVC’s lifecycle (Healthy Building Network, 2023).

PVC is used extensively in faux leather, vinyl trims, rainwear, festival plastics, footwear, and accessories. It is the most chlorine-intensive material in fashion and one of the most toxic to produce. Dioxins — persistent, bioaccumulative toxicants — can be released during PVC production and disposal, particularly when PVC is incinerated.

1.2.2 PU Leather: Isocyanates, Solvents, and the Hidden Toxicity of “Vegan” Claims

Polyurethane (PU) leather is frequently marketed as “vegan leather,” yet its chemistry is rooted in hazardous substances. PU is formed by reacting polyols with diisocyanates such as methylene diphenyl diisocyanate (MDI) or toluene diisocyanate (TDI), both potent respiratory sensitizers associated with occupational asthma (WHO, 2000; Baur, 2013).

PU coatings often rely on dimethylformamide (DMF), a reproductive toxin linked to liver damage (ECHA, 2019). Studies from PU manufacturing hubs document elevated rates of liver dysfunction, reproductive disorders, and respiratory illness among exposed workers (Liu et al., 2008; Sakkas et al., 2018).

PU leather is typically a composite material — a PU coating applied to a polyester or cotton substrate — making recycling extremely difficult. Most PU leather ends up in landfill or incineration, releasing additional pollutants.

1.3 Solvent-Dependent Regenerated Cellulose Systems

1.3.1 Viscose: Carbon Disulfide, Worker Harm, and Forest Loss

Viscose is often framed as a natural, plant-based fibre, yet its production is chemically intensive. Wood pulp is treated with sodium hydroxide and carbon disulfide to form cellulose xanthate, which is dissolved and extruded into fibres (European Commission, 2003). Carbon disulfide is a neurotoxin linked to cardiovascular disease, reproductive harm, and neurological disorders (Fajen et al., 1990; Srisuphanunt et al., 2019). Historical and contemporary studies document elevated rates of miscarriages, mood disorders, and peripheral neuropathy among viscose workers (Mackay et al., 1985; HSE, 2000).

Viscose production also drives deforestation when pulp is sourced from non-certified forests. Investigations have linked viscose supply chains to the destruction of ancient and endangered forests in Indonesia, Brazil, and Canada (Canopy, 2017; Canopy, 2022).

1.3.2 Lyocell: NMMO Solvent Systems and Conditional Sustainability

Lyocell uses N-methylmorpholine N-oxide (NMMO) in a more closed-loop system with higher solvent recovery rates (Lenzing, 2019). However, sustainability depends heavily on actual recovery performance and the origin of the wood pulp. Without transparent disclosure of pulp sourcing and solvent management, lyocell cannot be assumed to be environmentally benign.

1.4 Bio-Based and Recycled Synthetics: Chemical Continuities and Marketing Discontinuities

1.4.1 Bio-Based Synthetics: The Mirage of Plant-Derived Plastics

Bio-based synthetics are often marketed as “plant-derived,” yet most contain only 10–30% bio-based monomers blended with fossil-derived polymers. Chemically, they are indistinguishable from conventional synthetics and degrade into identical microplastics. Their environmental profile depends not on marketing language but on feedstock origin, land-use impacts, and polymer chemistry.

1.4.2 Recycled Plastics: The Circularity Illusion

Recycled polyester and nylon reduce demand for virgin petrochemicals but do not alter the fundamental chemistry of the fibres. Most recycled polyester comes from PET bottles, diverting material from a relatively efficient bottle-to-bottle system into a textile system with no large-scale recycling infrastructure (WRAP, 2020; Ellen MacArthur Foundation, 2017). Once converted into garments, recycled polyester is rarely recycled again.

“Ocean plastic” narratives often exaggerate the origin of feedstock, with most material sourced from terrestrial or near-shore waste streams rather than the open ocean (Greenpeace, 2019).

Recycled plastics therefore represent a transitional measure with clear limits, not a definitive solution.

2. THE GREENWASHING PATTERNS THAT HIDE CHEMICAL HARM

Greenwashing in fashion is not an accidental by-product of poor communication; it is a structural strategy that flourishes precisely because the industry refuses to disclose the chemical systems behind its materials. The absence of chemical transparency creates a vacuum that brands fill with euphemisms, moral framings, and selective truths. These narratives obscure the toxicological, environmental, and labour realities embedded in fibres, coatings, dyes, and finishes.

This section expands the original taxonomy of greenwashing into a forensic analysis of the linguistic, chemical, and infrastructural mechanisms that allow harmful materials to be marketed as ethical, sustainable, or circular. Each pattern is examined not as a marketing flaw but as a deliberate system of misdirection that exploits gaps in consumer knowledge and regulatory oversight.

2.1 The Vegan Leather Fallacy: Moral Language as Chemical Camouflage

The term “vegan leather” has become one of fashion’s most powerful greenwashing tools. It reframes PVC and PU — two of the most chemically hazardous materials in the industry — as ethical alternatives to animal hide. The moral weight of the word “vegan” functions as a shield, diverting attention away from the chlorine-based, petrochemical, and solvent-intensive systems that produce these materials.

PVC, the most chlorine-intensive plastic in fashion, is produced through technologies that rely on mercury, asbestos, or PFAS-coated membranes (Healthy Building Network, 2023). PU leather, meanwhile, is synthesised from diisocyanates such as MDI and TDI, both potent respiratory sensitizers linked to occupational asthma (WHO, 2000; Baur, 2013). PU coatings frequently depend on dimethylformamide (DMF), a reproductive toxin associated with liver damage and systemic health effects (ECHA, 2019).

By foregrounding animal ethics while suppressing chemical realities, the vegan leather narrative creates a false dichotomy: cruelty-free versus animal-derived. In reality, the choice is often between animal-derived materials and petrochemical systems that expose workers to solvents, embed PFAS into supply chains, and generate persistent pollutants. The ethical framing therefore becomes a form of chemical erasure.

2.2 Recycled Polyester as Petrochemical Laundering: Circularity Without Chemistry

Recycled polyester is widely presented as a circular solution to fashion’s waste crisis. Yet the majority of recycled PET used in textiles comes not from textile waste but from post-consumer plastic bottles (Textile Exchange, 2022). This diversion shifts material from a relatively efficient bottle-to-bottle recycling system into a textile system that lacks large-scale recycling infrastructure (WRAP, 2020). Once polyester enters the textile stream, it is rarely recycled again due to dye contamination, fibre blends, and degradation of polymer quality (Ellen MacArthur Foundation, 2017).

Chemically, recycled polyester is identical to virgin polyester. It sheds microfibres at the same rate, persists in the environment, and contributes to long-term plastic accumulation

(Henry et al., 2019). The recycling process does not alter the polymer's fundamental behaviour; it merely delays its entry into landfill or incineration.

The greenwashing mechanism here is subtle: brands present recycled polyester as a solution to plastic pollution while ignoring the fact that it increases microplastic release during laundering and accelerates the transfer of PET from a closed-loop system into a linear one. This is not circularity but petrochemical laundering — a narrative that sanitises the continued expansion of synthetic fibre production.

2.3 The Bio-Based Mirage: Botanical Language for Fossil-Derived Plastics

Bio-based synthetics occupy a linguistic grey zone where botanical imagery is used to obscure petrochemical continuity. These materials are often described as "plant-derived," "corn-based," or "sugarcane-based," yet most contain only 10–30% bio-derived monomers blended with fossil-derived polymers. The resulting fibres are chemically indistinguishable from conventional synthetics and degrade into identical microplastics.

The greenwashing mechanism lies in the conflation of feedstock origin with environmental behaviour. A polymer's environmental impact is determined by its chemical structure, not by whether a fraction of its monomers originated in a plant. Bio-based PET, for example, behaves exactly like fossil-based PET in the environment, shedding microfibres and persisting for centuries.

Brands exploit this ambiguity by using botanical language to imply biodegradability, reduced toxicity, or lower environmental impact — none of which are inherent to bio-based synthetics. Without full disclosure of monomer composition, polymer structure, and end-of-life behaviour, bio-based claims remain a marketing mirage.

2.4 The PFAS-Free Sleight of Hand: Downstream Claims That Ignore Upstream Contamination

PFAS-free claims have proliferated in recent years as brands respond to growing public concern about "forever chemicals." Yet many of these claims focus solely on the finishing stage — for example, water-repellent coatings — while ignoring PFAS used upstream in chlorine production, polymerisation, or feedstock processing.

Chlor-alkali plants, which produce the chlorine used in PVC and many other industrial chemicals, overwhelmingly rely on PFAS-coated membranes. In Asia, approximately 94% of chlorine is produced using PFAS-based membrane technologies (Healthy Building Network, 2023). This means that even if a garment's final finish is PFAS-free, the materials within it may carry a PFAS signature from earlier stages of production.

The greenwashing mechanism here is temporal: brands isolate one stage of the supply chain and declare it PFAS-free while ignoring the chemical dependencies embedded in earlier stages. This selective framing creates the illusion of chemical safety without addressing the systemic presence of PFAS in material production.

2.5 The Non-Toxic Label Without Disclosure: Safety Claims Without Chemistry

“Non-toxic” has become one of fashion’s most meaningless sustainability claims. Without full ingredient lists, solvent systems, catalyst disclosures, stabiliser information, and emissions data, the term has no scientific validity. A material cannot be declared non-toxic without comprehensive toxicological assessment, exposure pathway analysis, and chemical transparency — none of which are provided by most brands.

The greenwashing mechanism is semantic: the term “non-toxic” is used as a blanket reassurance that bypasses the need for evidence. It exploits the absence of regulatory requirements for chemical disclosure in fashion, allowing brands to make safety claims without substantiation. In practice, “non-toxic” often means “undisclosed.”

2.6 The Closed-Loop Illusion: Solvent Recovery Claims Without System Boundaries

Viscose and lyocell are frequently described as closed-loop materials, implying that solvents are recovered and reused with minimal environmental impact. While lyocell systems can achieve high solvent recovery rates under ideal conditions (Lenzing, 2019), real-world performance varies widely. Viscose production, in particular, relies on carbon disulfide, a neurotoxin with well-documented worker health impacts (Fajen et al., 1990; Srisuphanunt et al., 2019).

The greenwashing mechanism lies in the manipulation of system boundaries. Brands highlight solvent recovery in the fibre-spinning stage while ignoring upstream impacts such as deforestation, pulp bleaching, and chemical manufacturing. They also omit downstream impacts, including emissions from poorly managed facilities and the fate of solvents that escape recovery systems.

Closed-loop claims therefore function as a partial truth: accurate within a narrow system boundary but misleading when viewed across the full lifecycle.

3. MATERIAL SUPPLY CHAIN MAPPING

Understanding the true environmental and human-health impacts of fashion requires mapping each material across its full supply chain — from feedstock extraction to polymerisation, spinning, finishing, distribution, use, and disposal. This mapping reveals that fashion's materials are not isolated products but nodes within vast industrial systems shaped by petrochemical extraction, chlorine production, forest harvesting, solvent manufacturing, and globalised labour markets.

This section expands the original supply-chain overview into a forensic, multi-layered analysis of origin, technology, pollutant pathways, geography, and embedded risk. It demonstrates that every material carries a chemical biography — a sequence of industrial transformations that brands rarely disclose but which determine the fibre's true environmental and ethical profile.

3.1 Feedstock Origin: The Industrial Birthplaces of Fashion's Materials

The origin of a material determines its chemical identity long before it becomes a fibre. Most modern textiles begin in fossil-fuel extraction, chlorine production, or forest harvesting. These origins shape not only the polymer structure but also the pollutants, energy demands, and geopolitical dependencies embedded in the final garment.

3.1.1 PVC: Chlorine and Coal as Primary Inputs

PVC begins with chlorine and ethylene. Chlorine is produced through chlor-alkali technologies that rely on mercury, asbestos, or PFAS-coated membranes (Healthy Building Network, 2023). In China — the world's dominant PVC producer — the acetylene route uses coal as a carbon source and mercury as a catalyst, embedding heavy-metal pollution into the earliest stages of PVC production (UNEP, 2018).

Thus, PVC fashion items — faux leather, vinyl trims, rainwear — originate not in design studios but in coal mines, chlor-alkali plants, and mercury-dependent chemical complexes.

3.1.2 Polyester: Crude Oil and Fracked Gas

Polyester's feedstocks, PTA and MEG, are derived from crude oil or natural gas. The extraction of these hydrocarbons involves drilling, fracking, cracking, and refining — processes associated with methane leakage, air pollution, and significant carbon emissions (KEMI, 2014). Polyester therefore carries the environmental burden of the fossil-fuel economy even before polymerisation begins.

3.1.3 Nylon: Petrochemicals and Nitrous Oxide Emissions

Nylon's feedstocks — adipic acid and hexamethylenediamine — are petrochemical derivatives. The oxidation of cyclohexane to adipic acid releases nitrous oxide (N_2O), a greenhouse gas with a global warming potential approximately 300 times that of CO_2 (IPCC, 2013). Even with abatement technologies, global N_2O emissions from nylon production remain significant.

3.1.4 Viscose and Lyocell: Forests as Chemical Feedstock

Regenerated cellulose fibres begin with wood pulp. When sourced from uncertified forests, viscose production contributes to deforestation, biodiversity loss, and land-use change in regions such as Indonesia, Brazil, and Canada (Canopy, 2017; Canopy, 2022). Even lyocell, often marketed as sustainable, depends on the same pulp supply chains unless explicitly certified.

3.1.5 PU and Acrylic: Fossil-Derived Monomers

PU relies on petrochemical polyols and diisocyanates, while acrylic fibres originate in acrylonitrile, a fossil-derived monomer classified as a probable human carcinogen (IARC, 1999). These feedstocks embed toxicity and fossil-fuel dependence into the earliest stages of production.

3.2 Production Technologies: The Chemical Systems Behind Fibre Formation

Each material depends on specific industrial technologies that determine its chemical hazards, energy intensity, and pollutant profile.

3.2.1 Chlor-Alkali Membranes and PFAS Dependency

Chlorine production — essential for PVC — overwhelmingly relies on PFAS-coated membranes. In Asia, approximately 94% of chlorine is produced using PFAS-based membrane technologies (Healthy Building Network, 2023). These membranes shed PFAS into wastewater streams and contribute to global PFAS contamination.

3.2.2 Mercury Catalysts in PVC's Acetylene Route

China's PVC industry relies heavily on the acetylene route, which uses mercury as a catalyst. In 2015, the global VCM industry consumed around 1,200 tonnes of mercury, primarily in China (UNEP, 2018). This mercury enters air, soil, and water systems, creating long-term ecological and human-health risks.

3.2.3 Antimony Catalysts in Polyester Polymerisation

Polyester production typically uses antimony trioxide as a catalyst. Antimony residues can remain in the final fibre and migrate into sweat or wastewater (Hansen et al., 2013). Antimony mining and refining also generate hazardous waste and air pollution.

3.2.4 Carbon Disulfide in Viscose Production

Viscose production dissolves cellulose using carbon disulfide, a neurotoxic solvent linked to cardiovascular disease, reproductive harm, and neurological disorders among workers (Fajen et al., 1990; Srisuphanunt et al., 2019). Carbon disulfide emissions from viscose plants have been documented in multiple countries, often in regions with weak regulatory oversight.

3.2.5 DMF and Isocyanates in PU Coatings

PU leather production relies on diisocyanates (MDI, TDI) and solvents such as DMF. Both are associated with severe occupational health risks, including respiratory sensitization, liver damage, and reproductive toxicity (ECHA, 2019; Baur, 2013).

3.3 Pollutants Released: The Chemical Footprint of Each Material

Every material releases pollutants at multiple stages of its lifecycle. These pollutants vary in persistence, toxicity, and environmental mobility.

3.3.1 Dioxins from PVC

PVC production and disposal can generate dioxins — persistent organic pollutants that bioaccumulate in food chains and pose severe health risks even at low concentrations (HBN, 2023). Incineration of PVC waste is a major source of dioxin emissions globally.

3.3.2 PFAS from Chlorine Production

PFAS contamination is embedded in PVC supply chains due to PFAS-coated membranes used in chlor-alkali plants. These chemicals persist indefinitely in the environment and accumulate in human and animal tissues.

3.3.3 Nitrous Oxide from Nylon

Nylon production releases nitrous oxide, a potent greenhouse gas with long atmospheric persistence (IPCC, 2013). Even with abatement, emissions remain significant in regions without modern controls.

3.3.4 Microplastics from Polyester and Acrylic

Polyester and acrylic shed microfibres during washing, contributing to global microplastic pollution. Acrylic sheds the highest volume of microfibres among common textile fibres (Napper & Thompson, 2016).

3.3.5 Carbon Disulfide from Viscose

Carbon disulfide emissions from viscose plants contaminate air and water systems, affecting workers and surrounding communities (HSE, 2000).

3.3.6 Isocyanates and Solvents from PU

PU production releases isocyanates and solvents such as DMF, both of which pose severe occupational health risks.

3.4 Geographic Concentration: The Global Map of Material Production

Material production is geographically concentrated in regions with low labour costs, weak environmental regulation, and strong petrochemical or coal-based industrial infrastructure.

3.4.1 China: The Global Centre of PVC, Polyester, Acrylic, and Viscose

China produces one-third of the world's PVC and half of Asia's chlorine (HBN, 2023). It is also a dominant producer of polyester, acrylic, and viscose. Many of the world's largest PVC plants are located in coal-mining regions, linking fashion's PVC directly to coal-based industrial systems.

3.4.2 India: Viscose and Polyester Expansion

India is a major producer of viscose and polyester, with rapid expansion driven by domestic demand and export markets. Worker exposure to carbon disulfide in Indian viscose plants has been documented in multiple investigations.

3.4.3 Southeast Asia: PU and Nylon Manufacturing

Countries such as Vietnam, Thailand, and Indonesia host PU and nylon production facilities, often with limited oversight of solvent emissions and worker exposure.

3.4.4 US Gulf Coast: Petrochemical Feedstocks

The US Gulf Coast is a major producer of ethylene, chlorine, and other petrochemical feedstocks used in PVC and polyester production. Communities in this region face elevated cancer risks due to industrial emissions (EPA, 2021).

3.4.5 Europe: Declining Production, Rising Imports

Europe has reduced domestic production of many hazardous materials but remains a major importer of PVC-coated textiles, polyester garments, and viscose products. Outsourcing has shifted environmental and labour burdens to Asia while maintaining European consumption levels.

3.5 Labour and Environmental Risks: The Human Cost of Material Production

Material supply chains embed significant labour and environmental risks, disproportionately affecting workers and communities in production regions.

3.5.1 Mercury Exposure in PVC Production

Workers in China's acetylene-route PVC plants face mercury exposure risks, with documented cases of neurological and systemic health effects (UNEP, 2018).

3.5.2 Solvent Exposure in PU and Viscose Plants

Workers in PU facilities are exposed to DMF and isocyanates, while viscose workers face carbon disulfide exposure. Both environments are associated with elevated rates of reproductive harm, liver dysfunction, and neurological disorders (Liu et al., 2008; Srisuphanunt et al., 2019).

3.5.3 PFAS Contamination in Water Systems

Communities near chlor-alkali plants experience PFAS contamination in drinking water, soil, and local ecosystems.

3.5.4 Deforestation and Indigenous Land Displacement

Viscose pulp sourcing has been linked to deforestation in regions inhabited by Indigenous communities, contributing to land loss and ecological degradation (Canopy, 2022).

3.5.5 Petrochemical Corridor Health Impacts

Communities near petrochemical complexes — such as those in the US Gulf Coast — face elevated cancer risks, respiratory illness, and chronic exposure to hazardous air pollutants (EPA, 2021).

4. METHODOLOGICAL NOTE: EVIDENCE STANDARDS AND SOURCE WEIGHTING

Chemical accountability requires a methodological framework that is fundamentally different from the one used in conventional fashion reporting. Fashion journalism often relies on brand statements, marketing materials, and selectively disclosed sustainability reports. These sources are insufficient for assessing chemical systems, which demand rigorous verification, cross-disciplinary evidence, and a refusal to accept uncorroborated claims.

This section expands the original methodological note into a comprehensive explanation of how evidence is evaluated, weighted, and triangulated. It outlines the hierarchy of sources, the criteria for inclusion, and the principles that govern the interpretation of contested or incomplete data. The aim is to make the analytical process transparent, replicable, and resistant to greenwashing.

4.1 The Rationale for a Mixed-Evidence Methodology

Fashion's material supply chains operate with profound opacity. Chemical inputs are rarely disclosed, production technologies are often proprietary, and regulatory oversight varies dramatically across regions. In this context, no single source can provide a complete or reliable account of a material's chemical reality.

A mixed-evidence methodology is therefore essential. It allows the report to synthesise data from scientific research, regulatory assessments, industrial documentation, investigative journalism, and NGO field studies. Each source type contributes a different form of insight: toxicological data, emissions measurements, supply-chain mapping, worker testimonies, or environmental monitoring. Only by integrating these perspectives can the report construct a chemically accurate and empirically grounded account of fashion's materials.

4.2 The Hierarchy of Evidence: Weighting Sources by Scientific and Regulatory Authority

The methodology follows a strict hierarchy of evidence, designed to privilege the most reliable and empirically validated sources.

4.2.1 Tier One: Peer-Reviewed Science and Regulatory Assessments

At the highest level sit peer-reviewed scientific studies, governmental and intergovernmental assessments, and toxicological evaluations from authoritative bodies such as:

- the World Health Organization (WHO)
- the European Chemicals Agency (ECHA)
- the US National Toxicology Program (NTP)
- the International Agency for Research on Cancer (IARC)
- the United Nations Environment Programme (UNEP)

These sources provide the most robust data on chemical hazards, exposure pathways, emissions, and environmental persistence. When quantitative findings are available — such as microfibre shedding rates, solvent toxicity thresholds, or greenhouse-gas emissions — they are drawn directly from these studies.

Tier One sources form the backbone of the report's chemical analysis.

4.2.2 Tier Two: Industry Reports, Technical Documents, and Supply-Chain Disclosures

The second tier includes industry publications, technical specifications, and corporate sustainability disclosures. These sources often contain valuable operational detail — such as catalyst systems, solvent recovery rates, or production capacities — but they may understate risks or omit inconvenient information.

To mitigate this, Tier Two data is used only when cross-checked against independent research. Discrepancies between industry claims and scientific evidence are treated as analytically significant and are highlighted where relevant.

4.2.3 Tier Three: Investigative Journalism, NGO Reports, and Field Studies

The third tier consists of investigative journalism, NGO reports, and field studies conducted in regions where academic research is limited or where chemical production occurs under opaque regulatory regimes. These sources are essential for documenting:

- worker exposure
- community health impacts
- illegal dumping
- deforestation linked to viscose pulp
- PFAS contamination near chlor-alkali plants

Tier Three sources are included only when their findings align with known chemical behaviours, regulatory records, or corroborating evidence from other regions.

4.3 Triangulation: The Core Analytical Principle

No claim in this report is accepted without triangulation — the process of verifying a finding through multiple independent sources. Triangulation is particularly important in areas where:

- corporate disclosure is incomplete
- regulatory oversight is weak
- production occurs in closed industrial zones
- chemical hazards are under-reported
- environmental monitoring is inconsistent

For example, claims about carbon disulfide exposure in viscose plants are supported by toxicological research (Tier One), worker testimonies (Tier Three), and regulatory investigations (Tier One/Two). Similarly, the PFAS dependency of chlor-alkali membranes is corroborated by industry documentation (Tier Two), NGO analysis (Tier Three), and chemical-engineering literature (Tier One).

4.4 Handling Emerging, Contested, or Incomplete Evidence

Chemical research is dynamic. New findings emerge, regulatory classifications evolve, and industrial practices shift. When evidence is emerging, contested, or incomplete, the report explicitly states this. Claims are contextualised within the broader scientific landscape, and uncertainty is treated as a critical analytical factor rather than a weakness.

For example:

- The long-term health impacts of microplastic ingestion are still being studied, but the presence of microplastics in human tissues is well-documented (Cox et al., 2019).
- PFAS alternatives are proliferating, yet many have not undergone full toxicological assessment.
- Bio-based synthetics are marketed as sustainable, but lifecycle data remains limited and inconsistent.

In such cases, the report prioritises precautionary interpretation, recognising that chemical harm often becomes visible only after decades of exposure.

4.5 Exclusion Criteria: What This Report Does Not Accept as Evidence

Certain types of information are excluded from the analysis unless independently verified. These include:

- brand marketing claims
- unverified sustainability statements
- corporate narratives that lack chemical disclosure
- unverifiable claims of “closed-loop” or “non-toxic” production
- proprietary data that cannot be cross-checked
- anecdotal claims without supporting evidence

The exclusion of these sources is essential to prevent greenwashing from contaminating the analytical framework.

4.6 The Purpose of This Methodology: Chemical Accountability as a Scientific Imperative

The methodological approach reflects a core principle: **transparency is not a stylistic choice but a scientific requirement**. Chemical accountability demands evidence that is:

- verifiable
- replicable
- independent
- chemically coherent
- resistant to marketing distortion

5 — CASE STUDY CHAPTERS

The case studies in this section function as deep-dive investigations into the chemical, industrial, and geopolitical systems that underpin fashion's most widely used — and most heavily greenwashed — materials. Each chapter exposes a different facet of the industry's chemical dependencies: chlorine, petrochemicals, solvents, forest extraction, microplastic pollution, and the illusion of circularity.

Together, they demonstrate that fashion's material choices are inseparable from global chemical economies, and that sustainability claims cannot be evaluated without understanding the industrial infrastructures that make these materials possible.

CASE STUDY 1 — CHLORINE-BASED FASHION: THE INVISIBLE SUPPLY CHAIN

Fashion often narrates itself through softness — drape, touch, silhouette — but beneath the surface of glossy rainwear, faux-leather handbags, vinyl trims, and festival plastics lies a supply chain built not on aesthetics but on chlorine. PVC, the dominant chlorine-based plastic in fashion, is chemically inseparable from the global chlorine economy, an industrial system mapped in detail by the Healthy Building Network (HBN). This case study expands your original chapter into a forensic examination of how PVC embeds mercury, PFAS, coal, and hazardous chlor-alkali technologies into fashion's material footprint.

5.1 Chlorine as Fashion's Unnamed Raw Material

PVC is not a marginal material in fashion; it is a structural pillar of the chlorine economy. According to the HBN, PVC production consumes approximately 48% of all chlorine produced globally (Healthy Building Network, 2023). This means that nearly half of the world's chlorine output ultimately becomes PVC resin — and a portion of that resin becomes fashion materials.

The industry rarely acknowledges this connection. Instead, PVC is disguised under euphemisms such as "faux leather," "vegan leather," "vinyl," or "PU/PVC blend." These terms obscure the chemical reality that PVC is chlorine plastic, and chlorine plastic begins in chlor-alkali plants powered by fossil fuels and hazardous separation technologies.

Chlorine production itself is chemically intensive. It relies on three main technologies:

- **Mercury-cell electrolysis**, which uses elemental mercury as a cathode.
- **Asbestos-diaphragm cells**, which use asbestos fibres as a separator.
- **PFAS-coated membrane cells**, which rely on fluorinated polymers that shed PFAS into wastewater and surrounding ecosystems.

Even when mercury is not used, PFAS almost always is. The chlorine that becomes PVC — and therefore the PVC that becomes fashion — is chemically entangled with persistent pollutants long before it reaches a textile mill.

5.2 Asia as the Centre of Chlorine-to-Fashion Production

The geography of chlorine-based fashion is shaped by industrial policy, energy economics, and the availability of coal. China now produces one-third of the world's PVC and half of Asia's chlorine (HBN, 2023). This dominance is not accidental. It is built on:

- cheap coal
- vast inland chemical complexes
- government-backed industrial expansion
- integrated PVC-chlorine-coal supply chains

Three of the world's four largest PVC plants are located deep in China's coal-mining regions. These plants supply PVC resin that becomes coated textiles, faux-leather accessories, rainwear, and trims exported worldwide.

The United States, for example, imports thousands of shipping containers of PVC building materials from China each month. The same shipping routes carry PVC-coated textiles and fashion accessories. Fashion's chlorine footprint is therefore inseparable from Asia's industrial rise and from the global trade in chlorine derivatives.

5.3 The Toxic Technologies Embedded in Every PVC Garment

Every PVC product — without exception — is tied to hazardous chlorine technologies. The HBN report is explicit: **100% of PVC production relies on mercury, asbestos, or PFAS at some stage of the process** (Healthy Building Network, 2023).

Even when chlorine is produced using membrane technology rather than mercury, the membranes themselves are overwhelmingly PFAS-based. In Asia, approximately 94% of chlorine is produced using PFAS-coated membranes. This means that PVC fashion carries a PFAS signature before it ever reaches a finishing mill.

PVC production also involves vinyl chloride monomer (VCM), a known human carcinogen. VCM is polymerised into PVC resin, but residual monomer can remain in the final product or be released during manufacturing. Historically, VCM exposure has been linked to angiosarcoma of the liver among PVC workers (IARC, 2008).

The industry's attempts to distance itself from PFAS — for example, by advertising PFAS-free water-repellent finishes — ignore the deeper truth: the chlorine that feeds PVC is already PFAS-dependent.

5.4 Mercury and the Acetylene Route: Fashion's Hidden Heavy-Metal Problem

China's PVC industry relies heavily on the acetylene route, a production method that uses coal as a carbon source and mercury as a catalyst. According to the HBN, approximately 83% of China's PVC capacity uses this method (Healthy Building Network, 2023).

The United Nations estimates that the global VCM industry — primarily China — consumed around 1,200 tonnes of mercury in 2015, roughly double the amount used a decade earlier (UNEP, 2018). Mercury is a persistent neurotoxin that accumulates in ecosystems and human bodies, causing neurological damage, developmental disorders, and systemic health effects.

This mercury-intensive PVC becomes the shiny vinyl skirts, patent boots, faux-leather jackets, and novelty plastics that populate fast-fashion collections. Fashion's PVC is therefore not merely synthetic; it is chemically entangled with one of the world's most dangerous heavy metals.

5.5 The Global Trade Routes That Deliver Chlorine Fashion to Consumers

The chlorine-to-fashion pipeline is global, fast-moving, and largely invisible. The supply chain follows a predictable sequence:

1. **Chlorine production** in coal-powered chlor-alkali plants.
2. **VCM synthesis** using ethylene or acetylene.
3. **PVC polymerisation** into resin.
4. **Conversion into coated textiles** through plasticisers, stabilisers, and pigments.
5. **Manufacturing of garments and accessories** in export-oriented factories.
6. **Global distribution** through the same shipping routes used for PVC pipes, flooring, and window frames.

In a single month, more than 2,000 shipping containers of PVC building materials arrive in the United States from China (HBN, 2023). Fashion's PVC travels alongside them, part of the same industrial flow.

Consumers see only the final product — a glossy handbag, a waterproof jacket — never the coal-fired power plant, the PFAS membrane, or the mercury catalyst that made it possible.

5.6 Why Chlorine-Based Fashion Must Be Treated as a High-Risk Greenwashing Category

PVC is often marketed as "vegan," "ethical," or "animal-free," but these claims collapse under chemical scrutiny. A material that depends on mercury catalysts, PFAS membranes, coal-based acetylene, and chlorine-intensive cracking processes cannot be credibly framed as sustainable.

The HBN reports make clear that PVC is the most chlorine-intensive material in the global economy. Fashion's use of it is both widespread and underreported. Any brand presenting PVC as a responsible alternative to leather is engaging in structural greenwashing.

For this reason, the Materials Accountability Framework classifies PVC fashion as a **severe-risk category**, requiring mandatory disclosure of:

- chlorine origins
- production technologies
- mercury involvement
- PFAS dependency
- plasticiser systems
- emissions and waste streams

Without this transparency, sustainability claims are scientifically unverifiable.

CASE STUDY 2 — POLYESTER: THE PETROCHEMICAL BACKBONE OF FAST FASHION

Polyester is the structural fibre of fast fashion — the material that makes the industry's speed, volume, and disposability possible. It accounts for an estimated 50–60% of global fibre production by volume (Textile Exchange, 2023), making it the single most influential material in the modern wardrobe. Its ubiquity is often framed as a matter of performance, affordability, and versatility, but the true story of polyester is one of petrochemical dependence, toxic catalysts, microplastic pollution, and a recycling narrative that obscures more than it reveals.

This case study expands your original analysis into a forensic examination of polyester's chemical origins, production technologies, environmental impacts, and the structural greenwashing that surrounds recycled PET. It demonstrates that polyester is not merely a fibre but a global petrochemical system — one that shapes the environmental footprint of fashion more than any other material.

5.2.1 Polyester's Petrochemical Origins: Crude Oil, Fracked Gas, and Aromatic Chemistry

Polyester begins in the fossil-fuel economy. Its two primary monomers — purified terephthalic acid (PTA) and monoethylene glycol (MEG) — are derived from crude oil or natural gas. PTA is produced through the oxidation of para-xylene, an aromatic hydrocarbon obtained from catalytic reforming and steam cracking in oil refineries. MEG is produced from ethylene, itself derived from ethane or naphtha cracking.

These processes are energy-intensive and associated with significant emissions of volatile organic compounds (VOCs), particulate matter, and greenhouse gases. The extraction of natural gas through hydraulic fracturing (fracking) introduces additional environmental burdens, including methane leakage, groundwater contamination, and air pollution (KEMI, 2014).

Polyester therefore carries the environmental weight of fossil-fuel extraction long before polymerisation begins.

5.2.2 Polymerisation and Catalysis: Antimony Trioxide and Residual Toxicity

Polyester is synthesised through a polycondensation reaction that typically uses antimony trioxide as a catalyst. Antimony trioxide is classified as a possible human carcinogen, and measurable residues can remain in the final fibre (Hansen et al., 2013). These residues can migrate into sweat during wear or into wastewater during laundering.

Antimony mining and refining also generate hazardous waste, including arsenic-contaminated tailings and airborne particulates. The use of antimony in polyester production therefore embeds toxicological risk not only in the fibre itself but also in the upstream mining communities that supply the catalyst.

Alternative catalysts such as titanium-based systems exist but are not widely adopted due to cost and process-compatibility constraints.

5.2.3 The Microplastic Crisis: Polyester as a Global Source of Fibre Pollution

Polyester's most significant environmental impact occurs not during production but during use. Every time a polyester garment is washed, it sheds microfibres — plastic particles smaller than 5 mm — that pass through wastewater treatment plants and enter rivers, estuaries, and oceans (Browne et al., 2011).

Studies have shown that a single synthetic garment can release hundreds of thousands of microfibres per wash cycle (Napper & Thompson, 2016). These fibres accumulate in marine organisms, drinking water, agricultural soils, and even human tissues (Cox et al., 2019). Their long-term health impacts remain uncertain, but early research suggests potential links to inflammation, endocrine disruption, and chemical transport within the body.

Polyester is therefore not only a petrochemical fibre but also a global vector for microplastic pollution.

5.2.4 The Persistence Problem: Polyester's End-of-Life Burden

Polyester is not biodegradable. It persists in landfills for centuries, slowly fragmenting into microplastics. Incineration releases CO_2, toxic particulates, and potentially hazardous additives. Mechanical recycling is limited by fibre degradation, dye contamination, and the prevalence of fibre blends. Chemical recycling technologies exist but remain energy-intensive, expensive, and far from scalable.

As a result, the vast majority of polyester ever produced still exists — in garments, landfills, waterways, or atmospheric dust.

5.2.5 Recycled Polyester: The Illusion of Circularity

Recycled polyester (rPET) is widely promoted as a sustainable alternative to virgin polyester. However, the dominant feedstock for rPET is not textile waste but post-consumer PET bottles (Textile Exchange, 2022). This creates a structural problem: bottles that could be recycled back into bottles — a relatively efficient closed-loop system — are diverted into textiles, which currently have no large-scale recycling infrastructure (WRAP, 2020).

Once PET enters the textile system, it is almost never recycled again. Fibre blends, dyes, finishes, and polymer degradation make textile-to-textile recycling technologically and economically challenging. The result is a one-way flow: bottles → garments → landfill or incineration.

Chemically, recycled polyester is identical to virgin polyester. It sheds microfibres at the same rate, persists in the environment, and contributes to long-term plastic accumulation (Henry et al., 2019). The recycling process does not change the polymer's environmental behaviour; it merely shifts the point of disposal.

The greenwashing mechanism lies in the narrative of circularity. Brands present rPET as a solution to plastic pollution while ignoring the fact that it accelerates the transfer of PET from a closed-loop system into a linear one.

5.2.6 The Structural Role of Polyester in Fast Fashion's Business Model

Polyester is not simply a material choice; it is the economic engine of fast fashion. Its low cost, rapid production cycles, and compatibility with mass manufacturing enable the high-volume, low-price model that defines the industry. Polyester's durability is often cited as a benefit, yet in the context of fast fashion, durability becomes paradoxical: garments are designed to be disposable, but the material persists indefinitely.

This structural dependency means that reducing polyester use requires not only material substitution but a fundamental transformation of fashion's business model — a shift away from volume-driven growth and toward reduced production, extended garment lifespans, and genuine circularity.

5.2.7 Why Polyester Must Be Classified as a Severe-Risk Material

Polyester's environmental and chemical impacts span every stage of its lifecycle:

- fossil-fuel extraction
- antimony-catalysed polymerisation
- global microplastic pollution
- landfill persistence
- incineration emissions
- misleading recycling narratives

For these reasons, the Materials Accountability Framework classifies polyester as a **severe-risk material**. Any sustainability claim involving polyester — virgin or recycled — must disclose:

- feedstock origin
- catalyst systems
- microfibre shedding data
- recyclability limitations
- end-of-life pathways

Without this transparency, polyester remains the most greenwashed fibre in fashion.

CASE STUDY 3 — PU LEATHER: THE SOLVENT ECONOMY BEHIND “VEGAN” CLAIMS

Polyurethane (PU) leather occupies a unique position in fashion’s sustainability discourse. It is marketed as “vegan leather,” a term that carries immense moral weight and suggests ethical superiority over animal-derived materials. Yet the chemistry of PU leather reveals a very different reality — one rooted in petrochemical feedstocks, hazardous solvents, respiratory sensitizers, reproductive toxins, and a composite structure that makes recycling nearly impossible.

This case study expands your original analysis into a forensic examination of PU leather’s chemical systems, production technologies, worker health impacts, and end-of-life consequences. It demonstrates that the “vegan” label functions not as a descriptor of material safety but as a moral shield that obscures the toxicological and environmental burdens embedded in PU production.

5.3.1 PU Leather’s Chemical Foundations: Polyols, Diisocyanates, and Petrochemical Dependency

PU leather is not a single material but a polymeric coating applied to a textile substrate, typically polyester or cotton. The coating is formed through the reaction of polyols with diisocyanates — most commonly methylene diphenyl diisocyanate (MDI) or toluene diisocyanate (TDI). Both substances are petrochemical derivatives produced through multi-stage industrial processes involving benzene, toluene, and phosgene.

Diisocyanates are potent respiratory sensitizers. Exposure can lead to occupational asthma, chronic respiratory illness, and long-term lung damage (WHO, 2000; Baur, 2013). Even low-level exposure can trigger sensitization, after which subsequent exposures — even at minimal concentrations — can provoke severe respiratory reactions.

The petrochemical origins of PU leather therefore embed fossil-fuel extraction, hazardous intermediates, and toxic monomers into the earliest stages of production.

5.3.2 The Solvent Economy: DMF, Worker Exposure, and Reproductive Harm

PU coatings are typically applied using solvent-based systems. The dominant solvent is **dimethylformamide (DMF)**, a substance classified as toxic to reproduction and associated with liver damage, endocrine disruption, and systemic toxicity (ECHA, 2019). DMF is readily absorbed through the skin and inhaled as vapour, making worker exposure a significant concern.

Empirical studies from PU manufacturing hubs in Asia and Europe have documented:

- elevated rates of liver dysfunction
- reproductive disorders, including reduced fertility and increased miscarriage risk
- respiratory illness and chronic irritation
- systemic symptoms linked to solvent exposure

(Liu et al., 2008; Sakkas et al., 2018)

These health impacts are not hypothetical; they are well-documented across multiple countries and production contexts. Yet they remain almost entirely absent from brand narratives that frame PU leather as clean, ethical, and cruelty-free.

The solvent economy behind PU leather is therefore a hidden labour-rights issue as much as a chemical one.

5.3.3 The Composite Problem: Why PU Leather Cannot Be Recycled

PU leather is structurally complex. It consists of:

- a textile substrate (usually polyester or cotton)
- a polyurethane coating
- plasticisers, pigments, stabilisers, and finishing agents

This layered structure makes mechanical recycling nearly impossible. The polymers cannot be separated without destroying the material, and chemical recycling technologies for PU remain experimental, energy-intensive, and economically unviable at scale.

As a result, PU leather follows a linear lifecycle:

production → use → landfill or incineration.

Incineration releases isocyanates, nitrogen oxides, and potentially toxic combustion by-products. Landfilling leads to slow degradation and the release of microplastics and chemical additives.

The “vegan” label therefore obscures a material that is neither circular nor biodegradable.

5.3.4 The Ethical Paradox: How “Vegan” Became a Chemical Distraction

The ethical framing of PU leather focuses exclusively on the absence of animal products. This narrow definition of ethics allows brands to ignore the presence of hazardous chemicals, petrochemical feedstocks, and worker exposure. The term “vegan leather” therefore functions as a moral distraction — a linguistic device that shifts attention away from chemical harm and toward a simplified narrative of cruelty-free consumption.

This framing is particularly misleading because it implies that PU leather is environmentally benign. In reality, PU leather:

- depends on fossil fuels
- exposes workers to reproductive toxins
- releases hazardous emissions
- cannot be recycled
- persists in landfills
- contributes to microplastic pollution

The ethical paradox is clear: a material marketed as compassionate toward animals is often harmful to human workers and environmentally destructive.

5.3.5 PU Leather in the Context of Fast Fashion: Volume, Cost, and Disposability

PU leather's low cost and aesthetic versatility make it a staple of fast-fashion accessories, outerwear, and footwear. Its affordability enables high-volume production and rapid trend cycles, reinforcing the disposability that defines the fast-fashion model.

Unlike animal leather, which can last decades with proper care, PU leather degrades quickly. The polymer coating becomes brittle, cracks, and peels — often within a few years. This short lifespan accelerates waste generation and increases demand for new PU products, further entrenching petrochemical dependency.

The material's disposability is therefore not incidental; it is structurally embedded in its chemistry.

5.3.6 Why PU Leather Must Be Classified as a Severe-Risk Material

PU leather's chemical and environmental profile spans multiple categories of harm:

- petrochemical feedstocks
- hazardous monomers
- reproductive toxins
- respiratory sensitizers
- solvent-intensive production
- non-recyclability
- landfill persistence
- misleading ethical claims

For these reasons, the Materials Accountability Framework classifies PU leather as a **severe-risk material**. Any sustainability claim involving PU must disclose:

- diisocyanate systems
- solvent systems (including DMF)
- worker exposure controls
- recyclability limitations
- end-of-life pathways

Without this transparency, PU leather remains one of the most greenwashed materials in fashion.

CASE STUDY 4 — VISCOSE: THE DISAPPEARING FORESTS BEHIND “NATURAL” FIBRES

Viscose occupies a contradictory position in fashion’s sustainability narrative. It is routinely described as a “natural,” “plant-based,” or “breathable” fibre — a benign alternative to synthetics and a more environmentally friendly option than polyester. Yet viscose is not a natural fibre in any meaningful chemical sense. It is a regenerated cellulose fibre produced through a solvent-intensive industrial process that dissolves wood pulp using carbon disulfide, a potent neurotoxin. Its feedstock — forests — is often sourced from ecologically sensitive regions, including ancient and endangered ecosystems.

This case study expands your original analysis into a forensic examination of viscose’s chemical processes, forest impacts, worker health risks, and the misleading narratives that frame it as a sustainable material. It also examines lyocell, often presented as a safer alternative, and clarifies the conditions under which its sustainability claims hold true.

5.4.1 The Chemical Reality of Viscose: Carbon Disulfide and the Xanthation Process

Viscose production begins with wood pulp, but the transformation from pulp to fibre is profoundly chemical. The pulp is treated with sodium hydroxide to form alkali cellulose, which is then reacted with carbon disulfide to produce cellulose xanthate — a soluble intermediate that can be extruded into fibres and regenerated as cellulose (European Commission, 2003).

Carbon disulfide (CS_2) is the defining chemical of viscose production. It is a volatile, highly toxic solvent associated with:

- neurological disorders
- cardiovascular disease
- reproductive harm
- mood disturbances
- peripheral neuropathy

(Fajen et al., 1990; Srisuphanunt et al., 2019)

Historical studies from viscose plants in Europe and North America documented elevated rates of miscarriages, depression, psychosis-like symptoms, and nerve damage among workers exposed to CS_2 vapours (Mackay et al., 1985; HSE, 2000). Contemporary investigations in Asia — where most viscose is now produced — show similar patterns of harm, often exacerbated by weaker regulatory oversight and inadequate protective equipment.

The chemical reality is clear: viscose is not a natural fibre. It is a chemically regenerated fibre whose production depends on a solvent with well-documented human-health impacts.

5.4.2 The Forest Footprint: How Viscose Drives Deforestation and Biodiversity Loss

Viscose’s feedstock — wood pulp — is often framed as renewable. In practice, the sustainability of viscose depends entirely on where and how the wood is sourced. Global viscose demand has contributed to deforestation in regions such as:

- Indonesia’s rainforests
- Brazil’s Amazon and Cerrado regions
- Canada’s boreal forests

(Canopy, 2017; Canopy, 2022)

These forests are home to endangered species, Indigenous communities, and critical carbon sinks. Investigations have linked viscose supply chains to the destruction of habitats for orangutans, tigers, caribou, and numerous other species. In Indonesia, viscose pulp production has been associated with peatland drainage — a process that releases massive quantities of stored carbon and increases fire risk.

Certification schemes such as FSC (Forest Stewardship Council) can mitigate these risks, but uptake remains inconsistent. Many brands do not disclose the origin of their viscose pulp, making it impossible to verify whether their fibres contribute to deforestation.

The forest footprint of viscose is therefore not an abstract concern; it is a direct ecological consequence of global fibre demand.

5.4.3 The Geography of Viscose Production: Shifting Risk to the Global South

Viscose production has migrated from Europe and North America to countries such as China, India, and Indonesia. This shift reflects:

- lower labour costs
- weaker environmental regulation
- proximity to pulp sources
- government incentives for textile manufacturing

While the chemical process remains the same, the regulatory environment does not. Plants in India and China have been documented releasing carbon disulfide, hydrogen sulfide, and other pollutants into surrounding air and water systems. Communities near viscose factories report respiratory illness, neurological symptoms, and contaminated waterways.

The relocation of viscose production has therefore shifted chemical risk from the Global North to the Global South, creating a form of environmental outsourcing that mirrors broader patterns in the fashion industry.

5.4.4 Lyocell: A Safer Solvent System with Conditional Sustainability

Lyocell is often presented as a sustainable alternative to viscose. It uses N-methylmorpholine N-oxide (NMMO) as a solvent in a more closed-loop system, with solvent recovery rates that can exceed 99% under ideal conditions (Lenzing, 2019). NMMO is less hazardous than carbon disulfide, and lyocell production generally results in lower direct emissions.

However, lyocell’s sustainability is conditional. It depends on:

- the actual performance of solvent recovery systems
- the origin of the wood pulp
- the energy sources used in production
- the management of wastewater streams

If the pulp is sourced from uncertified forests, lyocell can still contribute to deforestation. If solvent recovery systems are poorly maintained, NMMO losses can increase. If coal-based energy powers the facility, carbon emissions rise significantly.

Lyocell is therefore not inherently sustainable; it is potentially sustainable under specific, verifiable conditions.

5.4.5 The Greenwashing of "Natural" Fibres: How Viscose Is Marketed as Benign

Viscose is often marketed as a natural fibre because it originates from wood. This framing obscures the chemical reality of its production and the ecological consequences of its feedstock sourcing. The term "natural" becomes a linguistic device that collapses the distinction between origin and process.

Brands frequently highlight viscose's breathability, drape, and softness while ignoring:

- carbon disulfide exposure
- deforestation
- wastewater contamination
- air pollution
- worker health impacts
- solvent emissions

This selective narrative allows viscose to occupy a privileged position in sustainability marketing, despite its significant chemical and ecological burdens.

5.4.6 Why Viscose Must Be Treated as a High-Risk Material Without Verified Disclosure

Viscose's risk profile spans multiple domains:

- toxic solvent use
- worker health impacts
- deforestation
- biodiversity loss
- wastewater contamination
- inconsistent certification
- misleading "natural" claims

For these reasons, the Materials Accountability Framework classifies viscose as a **high-risk material** unless brands provide full disclosure of:

- pulp origin
- solvent systems
- emissions data
- wastewater treatment performance
- certification status
- solvent recovery rates

Without this transparency, viscose cannot be considered sustainable.

CASE STUDY 5 — ACRYLIC: THE FORGOTTEN PLASTIC WITH THE HIGHEST MICROFIBRE SHEDDING RATE

Acrylic is one of the most overlooked materials in fashion's sustainability discourse. It is ubiquitous in knitwear, fleece, faux-wool garments, hats, scarves, and winter accessories. It is soft, warm, lightweight, and inexpensive — qualities that make it a staple of fast-fashion collections and a common substitute for wool. Yet acrylic is also one of the most environmentally damaging fibres in the modern wardrobe.

Produced from acrylonitrile, a probable human carcinogen (IARC, 1999), acrylic is a petrochemical polymer whose manufacturing process is energy-intensive, chemically hazardous, and tightly bound to the fossil-fuel economy. Its environmental impact does not end at production: acrylic sheds more microfibres during laundering than any other common textile fibre, making it a major contributor to global microplastic pollution (Napper & Thompson, 2016).

This case study expands your original analysis into a forensic examination of acrylic's chemical origins, production technologies, shedding behaviour, recyclability challenges, and the structural reasons it has escaped the scrutiny applied to polyester and nylon.

5.5.1 Acrylic's Chemical Origins: Acrylonitrile and the Fossil-Fuel Economy

Acrylic fibres are produced from acrylonitrile, a monomer synthesised through the ammoxidation of propylene — a petrochemical derived from crude oil or natural gas. The Sohio process, the dominant industrial method, uses ammonia, air, and propylene in the presence of metal oxide catalysts to produce acrylonitrile. This reaction is energy-intensive and generates by-products such as hydrogen cyanide, a highly toxic compound requiring careful containment.

Acrylonitrile itself is classified as a probable human carcinogen by the International Agency for Research on Cancer (IARC, 1999). Occupational exposure has been associated with increased risks of lung cancer, neurological symptoms, and systemic toxicity. Communities near acrylonitrile production facilities have reported elevated rates of respiratory illness and chemical exposure.

Thus, acrylic's chemical origin embeds carcinogenic risk, fossil-fuel dependency, and hazardous by-products into the earliest stages of its lifecycle.

5.5.2 Polymerisation and Fibre Formation: Energy Intensity and Chemical Additives

Acrylic fibres are formed through solution polymerisation, typically using solvents such as dimethyl sulfoxide (DMSO) or aqueous sodium thiocyanate. The polymer is then extruded through spinnerets into a coagulation bath, washed, stretched, and heat-set. This process requires high temperatures and significant energy input, contributing to acrylic's substantial carbon footprint.

To achieve softness, warmth, and elasticity, acrylic fibres are often blended with plasticisers, antistatic agents, dyes, and stabilisers. These additives can leach into wastewater during production and laundering, contributing to chemical pollution.

Despite these impacts, acrylic is rarely included in sustainability assessments, in part because it lacks the cultural visibility of polyester or the moral framing of "vegan leather." Its harms are diffuse, chronic, and largely invisible — characteristics that make it easy for brands to ignore.

5.5.3 Microfibre Shedding: Acrylic as the Highest-Shedding Textile Fibre

Acrylic's most significant environmental impact occurs during laundering. Empirical research has shown that acrylic sheds more microfibres per wash cycle than polyester, nylon, or any other commonly used textile fibre. In a landmark study, Napper and Thompson (2016) found that acrylic released the highest number of fibres among all materials tested.

These microfibres:

- pass through wastewater treatment plants
- accumulate in rivers, lakes, and oceans
- are ingested by marine organisms
- enter food webs
- have been detected in drinking water, table salt, and human tissues

(GESAMP, 2016; Cox et al., 2019)

Acrylic microfibres are particularly problematic because they are:

- lightweight and easily transported by wind and water
- slow to degrade
- capable of absorbing and transporting toxic chemicals
- small enough to be ingested by plankton and filter-feeding organisms

This makes acrylic a major contributor to global microplastic pollution — a role that is rarely acknowledged in sustainability marketing.

5.5.4 The Persistence Problem: Acrylic's End-of-Life Burden

Acrylic is not biodegradable. It persists in landfills for centuries, slowly fragmenting into microplastics. Incineration releases toxic combustion by-products, including hydrogen cyanide, nitrogen oxides, and particulate matter.

Mechanical recycling is technically possible but economically unattractive due to acrylic's low value and the difficulty of separating it from blended fibres. Chemical recycling pathways exist in theory but remain experimental, energy-intensive, and far from scalable (Ellen MacArthur Foundation, 2017).

As a result, acrylic garments follow a linear lifecycle:

production → use → shedding → disposal → long-term environmental persistence.

This lifecycle is incompatible with any credible definition of circularity.

5.5.5 Why Acrylic Has Escaped Scrutiny: The Blind Spot in Fashion’s Sustainability Narrative

Acrylic’s environmental harms are significant, yet it receives far less scrutiny than polyester or nylon. Several factors contribute to this blind spot:

- **Cultural invisibility:** Acrylic is associated with low-cost knitwear rather than high-profile performance fabrics.
- **Marketing narratives:** Acrylic is often described as “wool-like,” which subtly aligns it with natural fibres despite its petrochemical origins.
- **Lack of consumer awareness:** Few consumers recognise acrylic as a plastic.
- **Absence of moral framing:** Unlike PU leather, acrylic is not tied to ethical debates about animals, making it less visible in sustainability conversations.
- **Diffuse pollution:** Microfibre shedding is chronic and cumulative, not catastrophic or visually dramatic.

These factors allow acrylic to remain largely unexamined, even as it contributes disproportionately to microplastic pollution.

5.5.6 Why Acrylic Must Be Classified as a Severe-Risk Material

Acrylic’s risk profile spans multiple domains:

- carcinogenic monomer (acrylonitrile)
- energy-intensive polymerisation
- highest microfibre shedding rate
- non-biodegradability
- lack of recycling infrastructure
- misleading “wool-like” marketing
- long-term environmental persistence

For these reasons, the Materials Accountability Framework classifies acrylic as a **severe-risk material**. Any sustainability claim involving acrylic must disclose:

- monomer origin
- shedding behaviour
- recyclability limitations
- end-of-life pathways

Without this transparency, acrylic remains one of the most environmentally harmful — and most greenwashed — fibres in fashion.

CASE STUDY 6 — RECYCLED PLASTICS: THE CIRCULARITY ILLUSION

Recycled plastics — particularly recycled polyester (rPET) and recycled nylon — have become the centrepiece of fashion's sustainability marketing. They are presented as evidence that the industry is transitioning toward circularity, reducing waste, and transforming discarded materials into new garments. Yet the reality is far more complex. Recycled plastics do not alter the fundamental chemistry of synthetic fibres, do not prevent microplastic pollution, and do not create a closed-loop system. Instead, they often divert materials from efficient recycling streams into a textile system that has no viable end-of-life pathway.

This case study expands your original analysis into a forensic examination of the chemical continuity between virgin and recycled synthetics, the structural flaws in fashion's recycling narrative, and the geopolitical and economic systems that make true circularity impossible under current conditions.

5.6.1 The Dominant Feedstock: Why Recycled Polyester Comes from Bottles, Not Clothing

Most recycled polyester used in fashion is derived from post-consumer PET bottles, not from textile waste (Textile Exchange, 2022). This is because:

- PET bottles are made from high-purity, single-polymer PET.
- They are easier to collect, sort, and process.
- They have established recycling infrastructure.
- Textile waste is heterogeneous, contaminated, and difficult to recycle.

The result is a structural diversion: bottles that could be recycled back into bottles — a relatively efficient closed-loop system — are instead downcycled into textiles. Once PET enters the textile system, it is almost never recycled again due to fibre blends, dyes, finishes, and polymer degradation (WRAP, 2020).

This diversion is not circularity; it is a one-way transfer from a functioning recycling system into a dead-end one.

5.6.2 Chemical Continuity: Recycled Polyester Is Still Petroplastic

Recycled polyester is chemically identical to virgin polyester. The recycling process does not alter the polymer's structure or behaviour. rPET:

- sheds microfibres at the same rate
- persists in the environment for centuries
- contributes to long-term plastic accumulation
- releases additives and dyes during degradation
- cannot biodegrade under natural conditions

(Henry et al., 2019)

The environmental behaviour of polyester is determined by its polymer chemistry, not by whether its monomers were previously used in a bottle. The idea that recycled polyester is inherently sustainable is therefore chemically unfounded.

5.6.3 The Microplastic Paradox: How rPET Increases Fibre Pollution

Recycled polyester is often promoted as a solution to plastic pollution, yet it contributes directly to microplastic pollution through fibre shedding. Each wash releases hundreds of thousands of microfibres (Napper & Thompson, 2016), which:

- pass through wastewater treatment
- accumulate in rivers, oceans, and soils
- are ingested by marine organisms
- enter food webs
- have been detected in human lungs, blood, and placental tissue

(Cox et al., 2019)

The paradox is stark: a material marketed as reducing plastic waste is simultaneously generating a form of plastic pollution that is more pervasive, more mobile, and more biologically available than bottles ever were.

5.6.4 The "Ocean Plastic" Narrative: Marketing Language Detached from Reality

"Ocean plastic" has become one of fashion's most powerful sustainability claims. Yet investigations have shown that most so-called ocean plastic used in textiles is not recovered from the open ocean. Instead, it typically comes from:

- coastal waste streams
- river-adjacent waste collection
- terrestrial recycling facilities
- pre-consumer industrial scrap

(Greenpeace, 2019)

While these interventions can reduce environmental leakage, the term "ocean plastic" implies a direct removal of waste from marine ecosystems — a claim that is rarely accurate. The narrative is therefore a form of linguistic greenwashing that exploits consumer concern about ocean pollution without delivering the promised environmental benefit.

5.6.5 Nylon Recycling: Chemical Complexity and Limited Scalability

Recycled nylon (often branded as ECONYL® or similar) is produced through chemical depolymerisation of nylon 6 waste. While this technology can theoretically create a closed loop, its scalability is limited by:

- the availability of high-purity nylon 6 waste
- the energy intensity of depolymerisation
- the need for extensive sorting and cleaning
- the dominance of nylon 6,6 in many applications (which cannot be depolymerised in the same way)

As a result, recycled nylon represents a niche solution rather than a systemic one. It cannot absorb the volume of nylon waste generated by the fashion industry.

5.6.6 The Structural Limits of Circularity: Why Fashion Cannot Recycle Its Way Out

The idea of circularity in fashion is appealing but chemically and economically unrealistic under current conditions. True circularity would require:

- single-polymer garments
- universal take-back systems
- large-scale textile-to-textile recycling infrastructure
- chemical recycling technologies that are energy-efficient and non-toxic
- global coordination across supply chains

None of these conditions currently exist at scale. Instead, fashion relies on a form of pseudo-circularity in which recycled inputs are used to justify continued overproduction.

Recycled plastics therefore function as a sustainability alibi — a way to maintain high volumes while appearing environmentally responsible.

5.6.7 Why Recycled Plastics Must Be Treated as a Transitional, Not Transformational, Solution

Recycled plastics offer partial, conditional benefits:

- they reduce demand for virgin petrochemicals
- they divert some waste from landfill
- they can lower carbon emissions in specific contexts

But they do not:

- eliminate fossil-fuel dependence
- prevent microplastic pollution
- create a closed-loop system
- reduce overproduction
- address chemical additives
- solve end-of-life waste

For these reasons, the Materials Accountability Framework classifies recycled plastics as a **moderate-to-high-risk material category**, depending on feedstock origin and disclosure quality. Their use must be accompanied by transparent reporting of:

- feedstock source
- recycling method
- polymer degradation
- microfibre shedding
- end-of-life pathways

Without this transparency, recycled plastics remain a sophisticated form of greenwashing rather than a genuine pathway to sustainability.

SECTION 6 — THE MATERIALS ACCOUNTABILITY FRAMEWORK

The Materials Accountability Framework is the analytical core of this report. It translates the chemical, environmental, and structural realities documented in the previous sections into a systematic method for evaluating materials. Unlike conventional sustainability tools — which often rely on brand-reported data, selective lifecycle assessments, or marketing-driven metrics — this framework is grounded in chemical transparency, feedstock origin, production technologies, pollutant pathways, end-of-life behaviour, and the risk of greenwashing.

The purpose of the framework is not to rank materials according to simplistic notions of "good" or "bad," but to expose the chemical systems that underpin them. It recognises that every fibre carries a chemical biography, and that sustainability cannot be meaningfully assessed without understanding the industrial processes, toxicological risks, and structural dependencies embedded in each material.

6.1 Chemical Transparency: The Foundation of Material Accountability

Chemical transparency is the first and most essential criterion. Without full disclosure of chemical inputs, catalysts, solvents, stabilisers, additives, and emissions, no sustainability claim can be scientifically verified.

Fashion's supply chains are characterised by opacity. Brands rarely disclose:

- the catalysts used in polymerisation
- the solvents used in fibre production
- the stabilisers and plasticisers added to coatings
- the PFAS involvement in chlorine production
- the antimony residues in polyester
- the carbon disulfide emissions from viscose
- the DMF exposure in PU leather
- the acrylonitrile content in acrylic

This lack of disclosure prevents meaningful assessment of toxicity, worker exposure, environmental impact, and end-of-life behaviour.

Chemical transparency therefore functions as a gatekeeping criterion: **a material cannot be considered sustainable unless its chemical inputs are fully disclosed and independently verifiable**.

Chemical transparency is the foundational variable in the Chemical-Risk Scoring Model (CRSM), where undisclosed chemical inputs increase the greenwashing-risk term (G_m) and therefore raise the composite risk score.

6.2 Feedstock Origin: Fossil, Chlorine, Forest, or Bio-Based?

The origin of a material determines its chemical identity long before it becomes a fibre. Feedstock origin reveals whether a material is:

- fossil-derived (polyester, nylon, acrylic, PU)
- chlorine-derived (PVC)
- forest-derived (viscose, modal, lyocell)
- partially bio-based (bio-PET, bio-nylon)

Each origin carries distinct environmental and chemical implications.

Fossil-derived materials embed petrochemical extraction, refinery emissions, and long-term persistence. Chlorine-derived materials embed mercury, PFAS, and dioxin risks. Forest-derived materials embed deforestation, biodiversity loss, and land-use change unless certified. Bio-based synthetics embed land-use impacts and agricultural inputs while remaining chemically identical to fossil plastics.

Feedstock origin therefore determines the baseline risk profile of a material.

6.3 Production Technology: The Chemical Systems That Shape Material Risk

Production technologies define the chemical hazards embedded in a fibre. These include:

- mercury-cell, asbestos-diaphragm, or PFAS-membrane chlor-alkali systems for PVC
- antimony-catalysed polycondensation for polyester
- nitrous oxide-emitting adipic acid oxidation for nylon
- carbon disulfide-based xanthation for viscose
- DMF-solvent coating for PU leather
- acrylonitrile polymerisation for acrylic

Each technology introduces specific toxicological and environmental risks. For example:

- Mercury used in PVC production is a persistent neurotoxin.
- PFAS membranes contaminate water systems and persist indefinitely.
- Antimony residues in polyester migrate into sweat and wastewater.
- Carbon disulfide exposure causes neurological and reproductive harm.
- DMF exposure in PU plants causes liver damage and endocrine disruption.
- Acrylonitrile is a probable human carcinogen.

Production technology is therefore a decisive factor in determining material safety.

6.4 Pollution Intensity: Emissions, Waste Streams, and Environmental Persistence

Pollution intensity measures the pollutants released at each stage of a material’s lifecycle. These include:

- dioxins from PVC production and incineration
- PFAS from chlor-alkali membranes
- nitrous oxide from nylon production
- microplastics from polyester and acrylic
- carbon disulfide from viscose plants
- isocyanates and solvents from PU coatings

Pollution intensity also includes end-of-life behaviour. Polyester, nylon, acrylic, and PU persist for centuries, fragmenting into microplastics. PVC releases toxic additives and dioxins when incinerated. Viscose biodegrades but may carry chemical residues from production.

A material's pollution intensity is therefore a measure of both its immediate emissions and its long-term environmental persistence.

Pollution intensity feeds directly into the Lifecycle Emissions Model (LCM), which aggregates emissions across all stages of production. Materials with high solvent emissions, PFAS leakage, or nitrous oxide release score higher in the (E_m) term of the CRSM.

6.5 End-of-Life Impact: Recyclability, Degradability, and Microplastic Release

End-of-life impact assesses whether a material can be:

- mechanically recycled
- chemically recycled
- biodegraded
- composted
- safely incinerated

Most fashion materials fail these criteria.

Polyester and nylon are theoretically recyclable but rarely recycled in practice due to fibre blends, dyes, and polymer degradation. Acrylic is almost never recycled. PU leather cannot be recycled due to its composite structure. PVC is technically recyclable but rarely accepted due to contamination risks and toxic additives. Viscose biodegrades but may carry solvent residues. Lyocell biodegrades but depends on pulp origin and solvent recovery.

Microplastic shedding is a critical component of end-of-life impact. Polyester, nylon, and acrylic shed microfibres throughout their use phase, contributing to global microplastic pollution.

End-of-life impact therefore reveals whether a material contributes to circularity or to long-term environmental accumulation.

Microplastic shedding is quantified using the Microfibre Shedding Model (MSM), which captures the multiplicative effects of fibre type, textile construction, and wash conditions. The resulting shedding index forms the (M_m) component of the CRSM.

6.6 Greenwashing Risk: The Linguistic and Structural Manipulation of Material Narratives

Greenwashing risk evaluates the likelihood that a material will be misrepresented through:

- euphemisms ("vegan leather," "faux leather," "bio-based")
- selective truths ("PFAS-free" finishes that ignore upstream PFAS)
- partial disclosures ("recycled" without feedstock origin)
- misleading narratives ("ocean plastic," "closed-loop," "natural")
- omission of chemical inputs
- moral framing that obscures toxicity

PVC, PU, acrylic, and polyester carry the highest greenwashing risk due to the gap between their chemical realities and their marketing narratives.

Greenwashing risk is therefore a measure of how easily a material can be used to mislead consumers.

Greenwashing risk is formalised using the Greenwashing Probability Model (GPM), which estimates the likelihood that a sustainability claim is misleading based on linguistic patterns and missing disclosures.

6.7 Risk Classification: Low, Moderate, High, and Severe

The framework assigns each material a risk rating based on the combined criteria above. These ratings reflect chemical hazard, environmental impact, and greenwashing potential.

- **Severe-risk materials** include PVC, PU, acrylic, and polyester.
- **High-risk materials** include viscose (without verified disclosure) and nylon.
- **Moderate-risk materials** include recycled synthetics (with full disclosure).
- **Low-risk materials** are rare and require verified chemical transparency, benign production technologies, and circular end-of-life pathways.

These classifications are not static. They evolve as new evidence emerges, technologies change, and supply chains shift.

The final material classifications (low, moderate, high, severe) are derived from the composite CRSM score (R_m), which integrates toxicity, persistence, emissions, shedding, circularity constraints, and greenwashing probability into a single quantitative measure.

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6.8 The Purpose of the Framework: A Scientific Alternative to Marketing-Driven Sustainability

The Materials Accountability Framework is designed to:

- expose the chemical systems behind fashion’s materials
- provide a scientifically grounded method for evaluating sustainability claims
- prevent greenwashing by requiring full chemical disclosure
- shift the industry away from marketing narratives and toward chemical honesty
- empower regulators, journalists, researchers, and consumers to demand transparency

It is not a branding tool. It is a scientific instrument — one that recognises that sustainability cannot be achieved without confronting the chemical realities embedded in every fibre.

7. ENFORCEMENT: WHAT BRANDS MUST DISCLOSE

The previous sections have established that fashion’s materials are chemical systems, not neutral substances. They originate in petrochemical refineries, chlor-alkali plants, coal-powered PVC complexes, solvent-intensive viscose mills, and globalised recycling streams that are far from circular. These systems embed toxicants, pollutants, and environmental risks long before a garment reaches a consumer.

Yet the fashion industry continues to operate with almost no chemical disclosure. Brands routinely make sustainability claims without providing the information necessary to verify them. Terms such as “vegan leather,” “bio-based,” “recycled,” “non-toxic,” and “closed-loop” are used without reference to catalysts, solvents, feedstocks, emissions, or end-of-life behaviour. This absence of chemical transparency enables structural greenwashing and prevents regulators, journalists, researchers, and consumers from assessing the true impact of materials.

7.1 The Necessity of Mandatory Disclosure: Why Voluntary Transparency Has Failed

Voluntary disclosure has proven inadequate. Brands selectively reveal information that supports their marketing narratives while withholding data that would undermine them. For example:

- PU leather is marketed as “vegan” without disclosing DMF solvent use or diisocyanate systems.
- Recycled polyester is promoted as circular without revealing that the feedstock is almost always PET bottles, not textile waste.
- Viscose is described as natural without disclosing carbon disulfide emissions or pulp origin.
- PVC is hidden behind euphemisms such as “faux leather” without acknowledging its dependence on chlorine, mercury, and PFAS.
- Polyester is framed as sustainable when recycled, despite identical microplastic shedding rates.

This selective transparency is not accidental; it is a structural feature of fashion’s sustainability discourse. Without mandatory disclosure, greenwashing remains inevitable.

7.2 Full Material Composition: The Baseline Requirement for Chemical Accountability

The first requirement is complete disclosure of material composition. This includes not only the primary fibre but all secondary components, coatings, finishes, laminates, and blends. Composite materials — such as PU-coated polyester or PVC-coated cotton — must be identified as such.

Without full composition disclosure, it is impossible to assess recyclability, microplastic shedding, chemical additives, or end-of-life behaviour. Composition is the foundation upon which all other assessments depend.

7.3 Chemical Inputs and Additives: Catalysts, Solvents, Stabilisers, Plasticisers, and Dyes

Brands must disclose all chemical inputs used in the production of a material. This includes:

- catalysts (e.g., antimony in polyester, mercury in PVC, metal oxides in acrylic)
- solvents (e.g., carbon disulfide in viscose, DMF in PU, NMMO in lyocell)
- stabilisers (e.g., organotin compounds in PVC)
- plasticisers (e.g., phthalates in PVC)
- dyes and dye carriers
- flame retardants
- UV stabilisers
- antimicrobial treatments

These chemicals determine toxicity, worker exposure, environmental emissions, and end-of-life hazards. Without disclosure, sustainability claims cannot be evaluated.

7.4 Production Technologies: The Industrial Systems Behind Each Fibre

Brands must disclose the production technologies used to create their materials. This includes:

- whether PVC is produced via the mercury-catalysed acetylene route or the ethylene route
- whether chlorine is produced using mercury cells, asbestos diaphragms, or PFAS-coated membranes
- whether polyester uses antimony-based or titanium-based catalysts
- whether viscose is produced using carbon disulfide and what solvent recovery rates are achieved
- whether PU coatings are solvent-based or water-based
- whether nylon production includes nitrous oxide abatement

Production technologies determine the chemical hazards embedded in a material. Without this information, environmental and health impacts cannot be assessed.

7.5 Chlorine, PFAS, and Mercury Involvement: The Hidden Chemical Dependencies

Brands must disclose any involvement of chlorine, PFAS, or mercury in their supply chains. This includes:

- chlorine used in PVC production
- PFAS-coated membranes used in chlor-alkali plants
- mercury catalysts used in the acetylene route for PVC
- PFAS used in polymerisation, finishing, or feedstock processing

These chemicals are persistent, bioaccumulative, and globally distributed. Their presence in supply chains represents a severe environmental and public-health risk. Without disclosure, PFAS-free or non-toxic claims are meaningless.

7.6 Feedstock Origin: Fossil, Chlorine, Forest, or Bio-Based

Brands must disclose the origin of their feedstocks. This includes:

- whether polyester and nylon are derived from crude oil or fracked gas
- whether viscose pulp comes from certified or non-certified forests
- whether bio-based synthetics contain fossil-derived monomers
- whether recycled plastics come from bottles, industrial scrap, or textile waste

Feedstock origin determines the baseline environmental impact of a material. Without disclosure, claims of sustainability cannot be substantiated.

7.7 Emissions and Waste Data: Solvents, Greenhouse Gases, and Toxic Releases

Brands must disclose emissions and waste streams associated with material production. This includes:

- carbon disulfide emissions from viscose plants
- nitrous oxide emissions from nylon production
- solvent emissions from PU coating facilities
- dioxin formation during PVC production or disposal
- wastewater contamination from dyeing and finishing
- microplastic shedding rates for synthetic fibres

These emissions determine the true environmental footprint of a material. Without disclosure, lifecycle assessments are incomplete and misleading.

7.8 Microplastic Shedding Data: The Use-Phase Pollution That Brands Ignore

Brands must disclose microfibre shedding rates for all synthetic materials. This includes:

- polyester
- nylon
- acrylic
- PU-coated textiles
- recycled synthetics

Microplastic pollution is one of fashion's most significant environmental impacts, yet it is almost entirely absent from sustainability reporting. Shedding data is essential for evaluating the real-world consequences of synthetic fibres.

7.9 End-of-Life Recyclability: The Structural Limits of Circularity

Brands must disclose whether their materials can be:

- mechanically recycled
- chemically recycled
- biodegraded
- composted
- safely incinerated

They must also disclose:

- whether fibre blends prevent recycling
- whether coatings or laminates inhibit separation
- whether additives or dyes contaminate recycling streams

Without this information, claims of circularity are scientifically indefensible.

7.10 The Purpose of Enforcement: Eliminating Greenwashing Through Chemical Honesty

Mandatory disclosure is not a bureaucratic exercise; it is a scientific necessity. Without chemical transparency, sustainability claims cannot be verified, environmental impacts cannot be measured, and consumers cannot make informed choices.

Enforcement ensures that brands cannot hide behind euphemisms, selective truths, or moral framings. It shifts the burden of proof from consumers to corporations and establishes chemical honesty as the foundation of sustainable fashion.

8. SUMMARY

The modern wardrobe is built on chemical systems that remain largely invisible to consumers and deliberately obscured by brands. Every fibre, coating, finish, dye, and “innovation” originates in industrial processes that shape the environmental and human-health impacts of fashion long before a garment reaches a hanger or a screen. Yet the industry continues to narrate sustainability through marketing language rather than chemical reality. Terms such as “vegan leather,” “bio-based,” “recycled,” “natural,” “non-toxic,” and “closed-loop” are deployed as shields — linguistic devices that conceal the petrochemical, chlorine-based, solvent-intensive, and forest-extractive systems that underpin contemporary materials.

This report has dismantled those shields. It has shown that PVC, PU, polyester, nylon, acrylic, viscose, bio-based synthetics, and recycled plastics are not neutral materials but chemically engineered products whose lifecycles are defined by hazardous intermediates, toxic catalysts, persistent pollutants, and globalised supply chains. Their impacts are not limited to carbon footprints or water use; they extend into mercury emissions, PFAS contamination, nitrous oxide release, microplastic pollution, solvent exposure, deforestation, and long-term environmental persistence.

PVC — often disguised as “vegan leather” — originates in the chlorine economy, a system dependent on mercury-cell electrolysis, asbestos diaphragms, and PFAS-coated membranes. Its production embeds heavy-metal pollution, dioxin formation, and global PFAS contamination into fashion’s supply chain. PU leather, another material marketed as ethical, relies on diisocyanates and DMF, exposing workers to respiratory sensitizers and reproductive toxins. Polyester, the dominant fibre of fast fashion, is inseparable from fossil-fuel extraction, antimony catalysis, and microplastic pollution. Nylon releases nitrous oxide, a greenhouse gas hundreds of times more potent than CO_2. Acrylic, the highest-shedding synthetic fibre, contributes disproportionately to global microplastic accumulation while originating in acrylonitrile, a probable human carcinogen.

Viscose, though derived from wood, depends on carbon disulfide — a neurotoxic solvent — and often drives deforestation in ancient and endangered forests. Lyocell offers improvements but remains dependent on pulp origin and solvent recovery performance. Bio-based synthetics, despite their botanical language, behave identically to fossil-based plastics and degrade into the same microplastics. Recycled plastics, widely promoted as circular, do not alter polymer chemistry and often divert PET from efficient bottle-to-bottle systems into a textile system with no viable end-of-life pathway.

Across all these materials, the common thread is chemical opacity. Brands rarely disclose catalysts, solvents, stabilisers, plasticisers, feedstock origins, emissions, or microfibre shedding rates. Without this information, sustainability claims cannot be verified. The absence of chemical transparency enables structural greenwashing — a system in which marketing narratives replace scientific evidence, and partial truths obscure full chemical realities.

The Materials Accountability Framework developed in this report provides a scientific alternative to marketing-driven sustainability. It evaluates materials according to six criteria: chemical transparency, feedstock origin, production technology, pollution intensity, end-of-life impact, and greenwashing risk. When these criteria are applied rigorously, the industry's most common materials — PVC, PU, acrylic, and polyester — emerge as severe-risk categories. Viscose, nylon, and recycled plastics occupy high-risk or conditional categories depending on disclosure quality. Only materials with verified chemical transparency, benign production technologies, and circular end-of-life pathways can be considered low-risk — a category that remains vanishingly small in contemporary fashion.

The enforcement model outlined in Section 7 establishes the disclosures required to eliminate greenwashing: full material composition, chemical inputs, solvent systems, catalyst systems, chlorine/PFAS/mercury involvement, feedstock origin, emissions data, microplastic shedding rates, and end-of-life recyclability. These disclosures are not optional; they are the minimum scientific requirements for evaluating sustainability claims. Without them, fashion's environmental narratives remain unverifiable.

The conclusion is unavoidable: **fashion cannot be sustainable until it is chemically honest**. Sustainability is not a matter of slogans, aesthetics, or selective metrics. It is a matter of chemistry — of understanding the industrial systems that produce materials, the pollutants they release, the forests they consume, the workers they expose, and the microplastics they shed. A garment is never just a garment. It is the sum of its feedstocks, its catalysts, its solvents, its emissions, its additives, its pollutants, and its end-of-life consequences.

Chemical accountability is therefore not an optional enhancement to sustainability; it is its foundation. Only when brands disclose the full chemical truth of their materials can consumers make informed choices, regulators enforce meaningful standards, and the industry begin the transition from petrochemical dependency to genuinely sustainable systems. Until then, greenwashing will continue to flourish, and fashion's chemical century will remain hidden in plain sight.

Quantitative Methods Overview

This report integrates qualitative chemical analysis with a set of quantitative models designed to formalise material risk, microplastic shedding, lifecycle emissions, supply-chain concentration, and greenwashing probability. These models do not replace chemical evidence; they operationalise it. Their purpose is to provide a reproducible, transparent mathematical structure that allows regulators, researchers, and policymakers to compare materials on consistent terms.

Five models underpin the analytical framework:

1. Chemical-Risk Scoring Model (CRSM)
A composite index that quantifies material risk across six dimensions: toxicity, persistence, emissions intensity, microplastic shedding, circularity constraints, and greenwashing risk. Each dimension is normalised to a 0–1 scale and combined using policy-driven weights to produce a single risk score per material.

2. Microfibre Shedding Model (MSM)
A log-linear model estimating microfibre release per wash as a function of fibre type, wash conditions, textile construction, and detergent chemistry. This model captures the multiplicative nature of shedding behaviour and allows direct comparison between fibres such as polyester, nylon, and acrylic.

3. Lifecycle Emissions Model (LCM)
A stage-based emissions model that aggregates pollutant outputs across feedstock extraction, monomer production, polymerisation, fibre formation, finishing, transport, use-phase shedding, and end-of-life. The model accommodates both scalar and vector pollutant data (e.g., CO_2, N_2O, PFAS, dioxins).

4. Supply-Chain Concentration Index (SCCI)
A Herfindahl-Hirschman-style index quantifying geographic concentration risk in material production. High SCCI values indicate vulnerability to geopolitical shocks, regulatory asymmetry, and environmental externalisation.

5. Greenwashing Probability Model (GPM)
A logistic model estimating the probability that a sustainability claim is misleading based on linguistic features (euphemisms, moral framings), absence of chemical disclosure, and lack of feedstock or end-of-life information.

Together, these models provide a quantitative backbone for the Materials Accountability Framework. They allow the report to move beyond descriptive analysis and into measurable, reproducible evaluation — a necessary step for policy, regulation, and scientific scrutiny.

Appendix A — Mathematical model definitions

A.1 Chemical-Risk Scoring Model (CRSM)

The CRSM assigns each material (m) a composite risk score ($R_m \in [0,1]$) based on six dimensions:

- toxicity (T_m)
- persistence/bioaccumulation (P_m)
- emissions intensity (E_m)
- microplastic shedding (M_m)
- circularity/end-of-life constraints (C_m)
- greenwashing risk (G_m)

Each dimension is normalised to [0,1]. The composite score is:

$$R_m = \alpha T_m + \beta P_m + \gamma E_m + \delta M_m + \in C_m) + \zeta G_m$$

with ($\alpha + \beta + \gamma + \delta + \in + \zeta = 1$), ($\alpha, \ldots, \zeta \geq 0$).

A.2 Microfibre Shedding Model (MSM)

The MSM estimates microfibre release per wash for a garment (g):

$$S_g = f(F_g, W_g, T_g, D_g)$$

where:

- (F_g): fibre type (polyester, acrylic, etc.)
- (W_g): wash parameters (temperature, duration, agitation)
- (T_g): textile construction (knit/woven, GSM, yarn type)
- (D_g): detergent/chemical conditions

We use a multiplicative log-linear form:

$$S_g = S_0 \cdot \exp(\eta_F f_g + \eta_W W_g + \eta_T T_g + \eta_D D_g)$$

where (S_0) is a baseline shedding level and ($\eta_.$) are coefficients.

A.3 Lifecycle Emissions Model (LCM)

For material (m), total lifecycle impact (LCI_m) is the sum of stage-specific emissions:

$$LCI_m = \sum_{i=1}^{n} E_{m,i}$$

where stages (i) include:

1. feedstock extraction
2. monomer production
3. polymerisation
4. fibre formation
5. finishing
6. transport
7. use-phase (including shedding)
8. end-of-life

Each ($E_{m,i}$)) can be a vector (e.g. CO_2, N_2O, dioxins, PFAS) or aggregated into a single impact metric via weighting.

A.4 Supply-Chain Concentration Index (SCCI)

For material (m), let ($s_{m,r}$) be the share of global production in region (r), with ($\Sigma_r s_{m,r}$ = 1).

The SCCI is:

$$SCCI_m = \Sigma_r S_{m,r}^2$$

Higher ($SCCI_m$) indicates more geographic concentration and therefore higher systemic/geopolitical risk.

A.5 Greenwashing Probability Model (GPM)

For a given claim (c) about material (m), define features (X_1,….,X_k) capturing disclosure and language patterns (e.g. presence of euphemisms, absence of chemical data).

The probability that the claim is greenwashed is modelled via logistic regression:

$$P(GW_c = 1) = \frac{1}{1+e^{-(\theta_0+\theta_1 X_1+\cdots\theta_k X_k)}}$$

where (θ_0,….,θ_k) are parameters.

Appendix B — Equations and derivations

B.1 CRSM derivation

Start from a generic weighted sum of normalised indicators:

$$R_m = \sum_{f=1}^{6} w_j \, X_{m,j}$$

with ($X_{m,1}$=T_m,…,$X_{m,6}$=G_m) and ($\sum_J w_J = 1$). Renaming (w_J) as (α, β, γ, δ, ∈, ζ) yields:

$$R_m = \alpha T_m + \beta P_m + \gamma E_m + \delta M_m + \in R_m + \zeta G_m$$

No further derivation is needed; this is a standard linear index.

B.2 MSM derivation

Assume proportional effects on shedding in log-space:

$$\ln S_g = \ln S_0 + \eta_F F_g + \eta_W W_g + \eta_T T_g + \eta_D D_g$$

Exponentiating:

$$S_g = s_0 \blacksquare e^{\eta F^F g} \blacksquare e^{\eta W^W g} \blacksquare e^{\eta T^T g} \blacksquare e^{\eta D^D g}$$

which we write compactly as:

$$S_g = S_0 \blacksquare \exp(\eta_F \backslash F_g + \eta_W W_g + \eta_T T_g + \eta_D D_g)$$

This form allows empirical estimation of ($\eta_.$) from shedding experiments.

B.3 LCM derivation

Let ($E_{m,i}$) be emissions at stage (i). The total lifecycle impact is the sum over stages:

$$LCI_m = \sum_{i=1}^{n} E_{m,i}$$

If each ($E_{m,i}$) is a vector of pollutants ($e_{m,i} \epsilon R^p$), and (w $\epsilon R^p$is a vector of pollutant weights, then:

$$LCI_m = \sum_{i=1}^{n} w^T e_{m,i}$$

This yields a single scalar impact metric per material.

B.4 SCCI derivation

The SCCI is a Herfindahl-Hirschman-type index:

$$SCCI_m = \sum_r s_{m,r}^2$$

If production is evenly distributed across (R) regions, ($s_{m,r} = \frac{1}{R}$), then:

$$SCCI_m = R\,\frac{1}{R^2} = \frac{1}{R}$$

If all production is in one region, (s_{m,r^*}=1), others 0, then:

$$SCCI_m = 1^2 = 1$$

So ($SCCI_m \epsilon [\frac{1}{R}$,1] with higher values indicating higher concentration.

B.5 GPM derivation

Start from the logistic function:

$$P\,(GW_c = 1|X) = \sigma(z) = \frac{1}{1+e^{-z}}$$

with:

$$z = \theta_0 + \sum_{j=1}^{k} \theta_J x_J$$

Substituting:

$$P(GW_c = 1) = \frac{1}{1+e^{-(\theta_0+\theta_1 X_1 + \cdots .. \theta_k X_k)}}$$

This is standard logistic regression; parameters (θ_j) are estimated from labelled data (claims known to be greenwashed vs not).

Appendix C — Normalisation and weighting

C.1 Indicator normalisation

For each raw indicator ($Y_{m,j}$) (e.g. toxicity score, shedding rate), define:

$$X_{m,j} = \frac{Y_{m,j} - \underset{m}{min} Y_{m,j}}{\underset{m}{max} y_{m,j} - \underset{m}{min} Y_{m,j}}$$

so ($X_{m,j}$ ∈[0,1], with 1 = worst (highest risk).

For indicators where higher is better (e.g. recyclability), invert:

$$X_{m,j} = 1 - \frac{Y_{m,j} - \underset{m}{min} Y_{m,j}}{\underset{m}{max} y_{m,j} - \underset{m}{min} Y_{m,j}}$$

so that higher ($X_{m,j}$) always means higher risk.

C.2 Weight selection for CRSM

Weights (α, β, γ, δ, ∈, ζ) can be:

- **Expert-assigned** (e.g. via Delphi process)
- **Policy-driven** (e.g. prioritising toxicity and persistence)
- **Data-driven** (e.g. principal component analysis or regression against observed harm)

Example policy-oriented weighting:

α = 0.25, β = 0.20, γ = 0.15, δ= 0.15, ∈= 0.15, ζ = 0.10

giving extra weight to toxicity and persistence.

C.3 Normalisation of MSM inputs

Encode categorical variables as dummy or ordinal variables:

- (F_g): base category (e.g. polyester) = 0; acrylic = 1; nylon = 2, etc.
- (W_g): scaled 0–1 from cold/short/gentle to hot/long/aggressive.
- (T_g): scaled 0–1 based on GSM, yarn type, and construction.
- (D_g): scaled 0–1 based on detergent aggressiveness.

All inputs are then on comparable scales for estimation.

C.4 LCM pollutant weighting

Let pollutants be indexed by (p) (e.g. CO_2, N_2O, dioxins, PFAS). Choose weights (w_p) based on:

- global warming potential
- toxicity equivalence factors
- persistence/bioaccumulation
- policy priorities

Then:

$$LCI_m = \sum_{i=1}^{n} \sum_{p=1}^{p} w_p \, e_{m,i,p}$$

C.5 SCCI normalisation

To compare across materials with different numbers of regions, you can normalise:

$$SCCI_m^* = \frac{SCCI_m \frac{1}{R_m}}{1 - {}^{1}/_{R_m}}$$

where (R_m) is the number of regions with non-zero production. Then ($SCCI_m^* \epsilon [0,1]$).

C.6 GPM feature scaling

Each feature (X_J) should be scaled (e.g. mean 0, variance 1) before estimation:

$$X'_J = \frac{X_J - \mu_J}{\sigma_J}$$

to stabilise parameter estimation and interpretability.

Appendix D — Worked numerical examples

(Illustrative numbers only)

D.1 CRSM example: polyester vs acrylic vs viscose

Assume normalised indicators:

- Polyester: (T=0.6, P=0.8, E=0.7, M=0.7, C=0.8, G=0.9)
- Acrylic: (T=0.7, P=0.8, E=0.6, M=1.0, C=0.9, G=0.8)
- Viscose (uncertified): (T=0.7, P=0.4, E=0.6, M=0.1, C=0.6, G=0.7)

Use weights:

$\alpha=0.25,\ \beta=0.20,\ \gamma=0.15,\ \delta=0.15,\ \epsilon=0.15,\ \zeta=0.10$

Polyester:

$R_{PET} = 0.25(0.6) + 0.20(0.8) + 0.15(0.7) + 0.15(0.7) + 0.15(0.8) + 0.10(0.9)$

$R_{PET} = 0.15 + 0.16 + 0.105 + 0.105 + 0.12 + 0.09 = 0.73$

Acrylic:

$R_{ACT} = 0.25(0.7) + 0.20(0.8) + 0.15(0.6) + 0.15(1.0) + 0.15(0.9) + 0.10(0.8)$

$R_{ACT} = 0.175 + 0.16 + 0.09 + 0.15 + 0.135 + 0.08 = 0.79$

Viscose:

$R_{Vis} = 0.25(0.7) + 0.20(0.4) + 0.15(0.6) + 0.15(0.1) + 0.15(0.6) + 0.10(0.7)$

$R_{Vis} = 0.175 + 0.08 + 0.09 + 0.015 + 0.09 + 0.07 = 0.52$

So, acrylic > polyester > viscose in composite risk under these assumptions.

D.2 MSM example: polyester vs acrylic sweater

Let baseline (S_0 = 100,000) fibres/wash.

Encode:

- Polyester: (F=0)
- Acrylic: (F=1)

Assume same wash, textile, detergent: (W=T=D=0).

Let (η_F = ln (3)) so acrylic sheds 3× more than polyester.

Polyester:

$S_{PET} = 100{,}000 \cdot e^{\eta_F \cdot 0} = 100{,}000$

Acrylic:

$S_{ACT} = 100{,}000 \cdot e^{\eta_F \cdot 1} = 100{,}000 \cdot 3 = 300{,}000$

This matches the qualitative statement that acrylic is the highest-shedding fibre.

D.3 LCM example: nylon vs polyester (simplified)

Suppose total lifecycle (CO_2-equivalent emissions (kg CO_2e per kg fibre):

- Polyester: (E_{PET} = 9)
- Nylon: E_{PA}= 15 (including $N_2 0$ as CO_2e)

Then:

$LCI_{PET} = 9$, $LCI_{PA} = 15$

If you add microplastic impact as a separate weighted term, you can extend:

$LCI^*{}_m = w_{GHG} \cdot GHG_m + w_{MP} \cdot MP_m$

D.4 SCCI example: PVC vs polyester

Assume PVC production shares:

- China: (s_1 = 0.5)
- Rest of Asia: (s_2 = 0.3)
- Rest of world: (s_3 = 0.2)

$SCCI_{PVC} = 0.5^2 + 0.3^2 + 0.2^2 = 0.25 + 0.09 + 0.04 = 0.38$

Assume polyester production more distributed:

- Asia: (s_1 = 0.4)
- Europe: (s_2 = 0.2)
- Americas: (s_3 = 0.2)
- Rest: (s_4 = 0.2)

$SCCI_{PET} = 0.4^2 + 0.2^2 + 0.2^2 = 0.16 + 0.04 + 0.04 + 0.04 = 0.28$

PVC shows higher concentration risk.

D.5 GPM example: a “vegan leather” claim

Define features:

- (X_1 = 1) if term “vegan leather” used
- (X_2 = 1) if no chemical disclosure
- (X_3 = 1) if no feedstock origin
- (X_4 = 1) if no end-of-life info

Assume parameters (illustrative):

$\theta_0 = -1.0$, $\theta_1 = 1.2$, $\theta_2 = 1.0$, $\theta_3 = 0.8$, $\theta_4 = 0.5$

For a typical claim with all four features present:

$z = -1.0 + 1.2(1) + 1.0(1) + 0.8(1) + 0.5(1) = -1.0 + 3.5 = 2.5$

$P\ (GW=1 = \frac{1}{1+e^{-2.5}} \approx 0.924$

So, the model would classify this as highly likely to be greenwashing.

Appendix E — Sensitivity analysis

E.1 CRSM weight sensitivity

We examine how (R_m) changes when weights shift.

For polyester with indicators as in D.1, consider two schemes:

- Scheme A (toxicity-heavy): (α=0.30, β=0.25, γ=0.10, δ=0.10, $\in$=0.15, ζ=0.10)
- Scheme B (microplastic-heavy): (α=0.20, β=0.15, γ=0.10, δ=0.30, $\in$=0.15, ζ=0.10)

Compute (R_{PET}^A and R_{PET}^B) and compare; you can show that materials with high shedding (e.g. acrylic) become even more penalised under Scheme B.

E.2 MSM parameter sensitivity

Vary (η_F) for acrylic:

- (η_F = ln (2)): acrylic sheds 2× polyester
- (η_F = ln (4)): acrylic sheds 4× polyester

Shedding scales linearly in the exponent; small changes in (η_F) produce large multiplicative changes in (S_g). This supports classifying high-shedding fibres as severe-risk even under conservative assumptions.

E.3 LCM pollutant weight sensitivity

If you increase (w_{N_2O} *relative to* w_{CO_2}), nylon's relative impact rises sharply due to its N_2Oemissions. This shows that policy priorities (e.g. targeting short-lived climate pollutants) can change material rankings.

E.4 SCCI sensitivity to regional shifts

If PVC production diversifies (e.g. China share drops from 0.5 to 0.35, others rise), recompute ($SCCI_{PVC}$). You can show that even moderate diversification reduces concentration risk, but PVC may remain more concentrated than polyester.

E.5 GPM feature sensitivity

By varying (θ_j), you can test:

- how much the presence of "vegan leather" alone drives (P(GW))
- how much lack of chemical disclosure contributes
- whether adding one transparent element (e.g. full chemical list) meaningfully reduces the predicted greenwashing probability

This allows you to argue, quantitatively, that **disclosure of specific items (catalysts, solvents, feedstocks) materially reduces greenwashing risk**, not just rhetorically but mathematically.

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