

Review

Chewing Gum to Microplastic: Hidden Pollution and Its Scalable Circular Upcycling Pathways

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Abstract

Chewing gum is a frequently neglected polymer-containing consumer product that can be considered a source of microplastic exposure during chewing, and, upon disposal, a cause of surface contamination. This narrative review summarises the composition of the gum base, particle release during mastication, environmental fate, and the emergence of circular upcycling. Modern gum bases can be characterised by water-insoluble elastomeric and resinous phases designed for mechanical durability, as demonstrated by established evidence. Furthermore, a recent experiment has demonstrated the release of detectable microplastic-sized particles into the saliva after chewing. However, quantitative estimates, such as the apparent highest value of 637 MPs g⁻¹, and the observation that the majority of particles detected are released during the first 8 min, remain tentative, given the limited range of products offered and the lack of replication across different brands, formulations, chewing schedules, and analytical tools. Another proof point that samples of natural and synthetic gums have comparable particle discharge indicates that no amount of natural or plastic-free labelling should mean no particle exposure. The adhesive and hydrophobic nature of gum residues, along with observations of microbial colonisation and surface interaction, is also a key factor for their persistence post disposal. Since no standardised gum disintegration protocols exist, outdoor residence times are unknown. Other under-characterisations occur in nano- and ultra-small plastic fractions, as standard spectrometric analyses have size limits. Emerging materials engineering work indicates that sanitised, chewed gum can be reprocessed with conductive nanofillers to serve as flexible sensing agents. These circular paths are proof-of-concept paths at this point, as we must confirm oxidation stability, cleanliness, scalability, logistics, collection, and lifecycles. This study clearly distinguishes well-known polymer and litter issues from new exposure, degradation, and upcycling proposals.



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1. Introduction

Plastic pollution has developed into one of the most persistent 21st century environmental crises, accelerated by the global expansion of durable, hydrophobic and non-biodegradable polymers from both consumer and industrial supply chains. Although high-impact items, like packaging (42% of the total plastic waste), beverage containers,

cigarette butts and carrier bags have been studied, chewing gum has historically escaped the reach of microplastics inventory and regulatory frameworks on the basis of its confectionery nature instead of as a conventional plastic product [1,2]. However, recent evidence from analyses has also revealed the consumption of chewing gum as a direct source of MPs and as a long-term substrate, which warrants immediate scientific investigation and policy response. Chewing gum is considered one of many old habits in the world, with archaeological evidence dating it back to around 9000 years ago, when chewed tree resin was first reported on Orust Island in Sweden; it is still one of the most widespread consumer practices in the world today, especially among adolescents and adults [3,4]. Global consumption surveys indicate that around 80% of populations in Iran and Saudi Arabia consume chewing gum regularly; 60% of adolescents and adults in Europe and the United States chew 1–4 bites a day; and around 160–180 sticks a person are consumed annually in the UK and US [5,6]. According to market valuation estimates, the annual global gum trade in 2019 was over USD 30 billion, illustrating the magnitude of gum cultivation, consumption, and possible MP exposure [7]. Contemporary chewing gum formulations comprise a water-insoluble elastomeric matrix either derived from natural resins (e.g., chicle latex) or synthetic elastomers and petroleum-derived polymers (e.g., polyvinyl acetate, polyethylene, polyisobutylene, polyisoprene, butadiene–styrene rubber and petroleum waxes); however, their actual composition is frequently unknown to the polymer manufacturer, which hampers polymer monitoring and environmental degradation stock [3,8,9]. Gum is a continuous water-soluble matrix of sweeteners, flavours, humectants, organic acids, colours, and antioxidants, including BHA and BHT, that consists of a discontinuous water-insoluble gum base comprising 20–30% of the product mass, which is responsible for the elastic properties, adhesive bonding, and flavour retention, which are scientifically verified as the base of MPs secreted to the saliva, following mastication (Figure 1) [2,3]. Since the gum remains intact inside the mouth for 5–30 min, its mechanical shearing upon mastication leads to an ingestion route for MPs as saliva [2,10]. Despite labels, such as “plastic-free”, on natural gums, polymeric analyses have disproved compositional differences in MP release between natural and synthetic gum types (Figure 1), indicating universal human exposure risks ($p > 0.3$), irrespective of gum formulation type [2,3].

Natural (chicle-based) and synthetic (petrochemical-based) gums are comprised of polymeric gum bases; the mechanical disintegration of gum bases during mastication releases microplastics into saliva. That is a line of direct human exposure through ingestion. The remaining gum can stick to surfaces while going through environmental weathering due to disposal, leading to the creation of secondary microplastics. Biodegradability could play a role in longer persistence; however, the initial particle release is not eliminated, and current evidence shows that microplastic release is broadly similar in various gum forms. The figure distinguishes between direct exposure processes and post-disposal environmental fate. The fate of gum waste on the environment (Figure 2) is equally worrisome. Once cast off, gum residue sticks tightly to lyophilic surfaces (concrete, asphalt, escalator railings, clothing fibres, or rubber shoe soles). This creates long-lasting surface conditions that form urban sponges and “gum plague” areas, covering over 92% of British pavements [2,11]. London organisers removed 300,000 blobs across <2 miles of pavement during the 2012 Olympics, spending GBP 3.00 per particle, three times the retail price, highlighting municipal clean-up pressures and socio-economic costs [12,13]. Given the persistent nature of these residues, chewing gum waste is one such durable consumer polymer and a non-biodegradable MP contributor to terrestrial and aquatic systems [2,14].

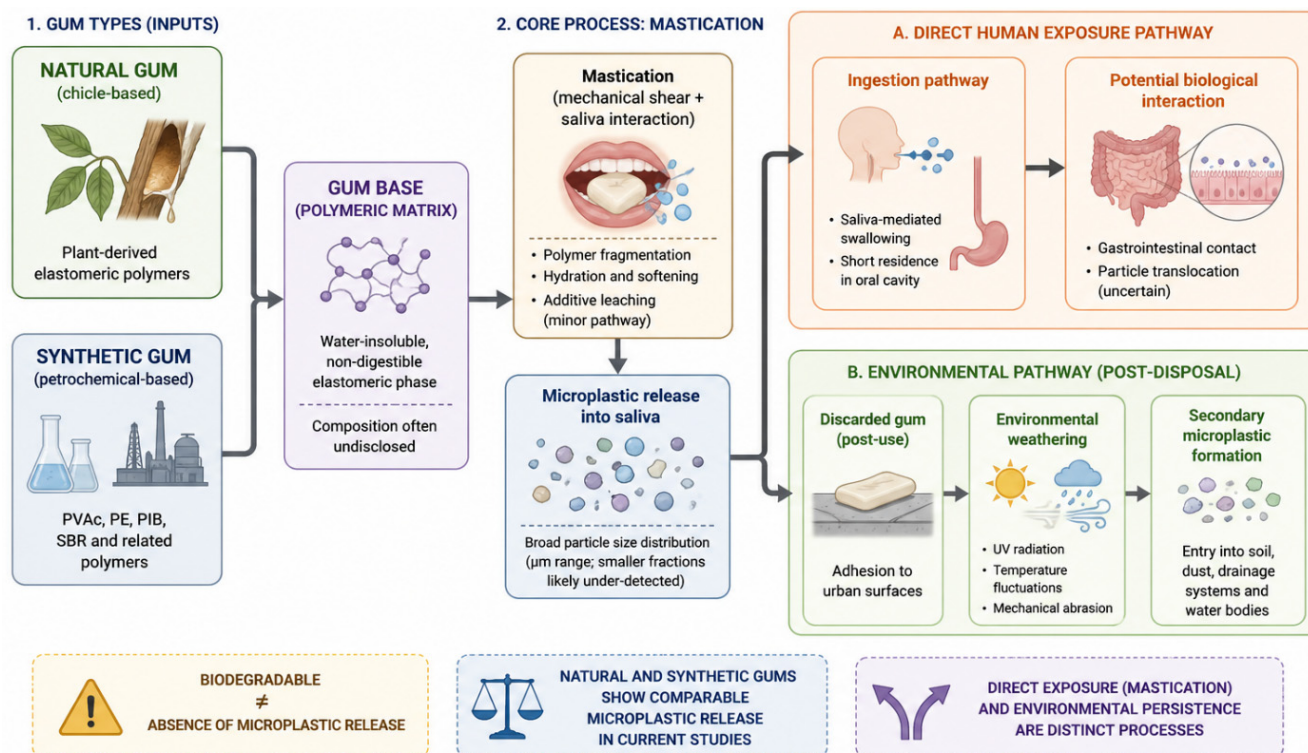


Figure 1. Conceptual pathways of chewing gum-derived microplastic generation and fate.

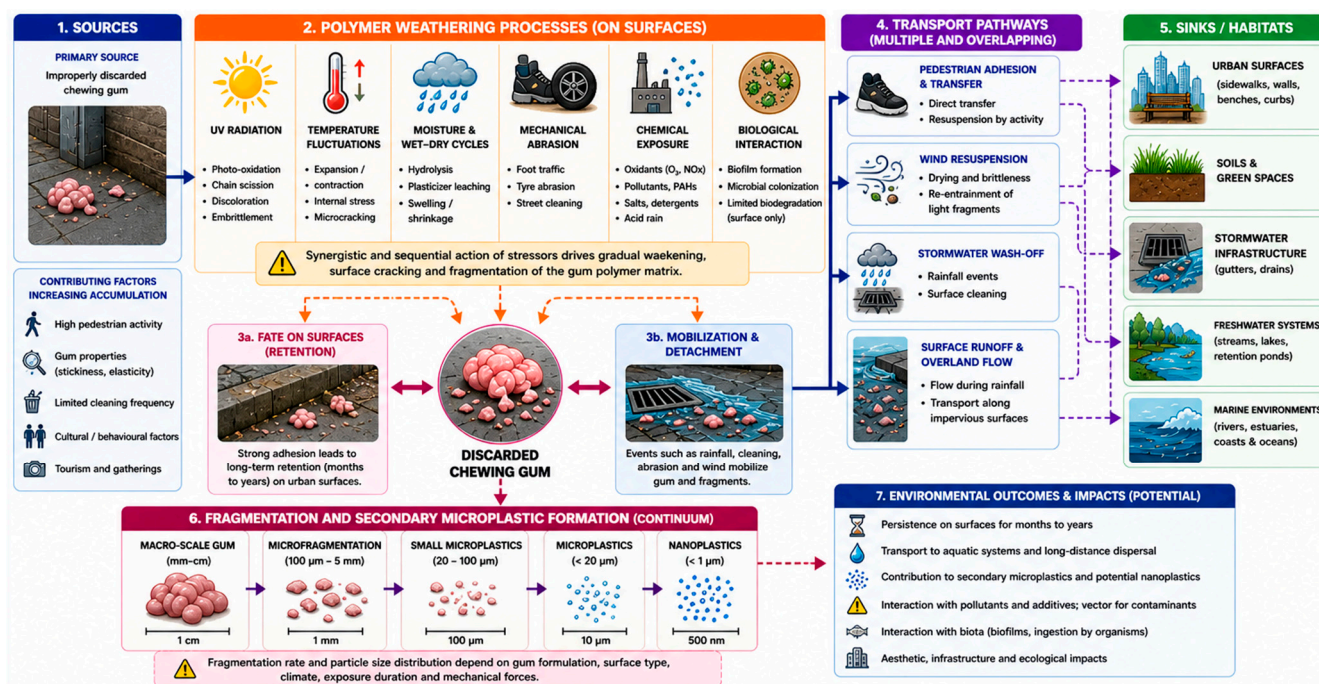


Figure 2. Environmental fate and transformation pathways of discarded chewing gum.

While gum waste has ingestion and environmental implications, it also provides the potential for circular-economy upcycling. New breakthroughs in material engineering have now suggested that recycled chewed gum, CNTs, liquid metals, borax–PVA blends, and MXene nanosheets can be fabricated as pressure-sensitive, self-healing conductive circuits that adhere to glass, metal, PI films, and skin with a high conductivity of up to 400 S m^{-1} , for sustainable bio-electronics development for motion sensing and photothermal-electricity harvesting [15,16]. Through these developments, gum waste moves away from a linear

pollution problem to a future of developing a potential circular upcycling substrate; however, oxidation stability is an issue [2,15]. This review synthesises gum polymer chemistry, mastication-driven MP genesis, environmental fate, ecological and socio-economic burdens, human exposure pathways, health implications (non-graphic, educational), sustainable material innovations, and policy opportunities for gum-derived MP mitigation.

2. Methodology

2.1. Review Approach and Evidence Selection

The current review employed a structured narrative synthesis to summarise available evidence on chewing gum as a source of microplastic exposure, its environmental fate, associated human health implications, and emerging opportunities for circular up-cycling. Although the review is not a formal systematic review or meta-analysis, a transparent and replicable literature search strategy was employed to ensure thorough coverage of the existing evidence.

The literature relevant to the topic was gathered from Scopus, Web of Science, ScienceDirect, and Google Scholar. This search covered publications from January 2000 to December 2025, encompassing the rapid development of microplastic research and the recent emergence of studies investigating chewing gum-derived microplastics. Searches were performed with multiple keywords, such as (“chewing gum” OR “gum base”) AND (“microplastic” OR “nanoplastic” OR “polymer fragmentation” OR “plastic pollution” OR “environmental fate” OR “human exposure” OR “health effects” OR “recycling” OR “circular economy”). Some relevant publications were identified via backward citation tracking of the reference lists of key articles.

Studies were selected for their relevance to polymer composition, mastication-driven microplastic release, environmental persistence, exposure pathways, human health implications, analytical methodologies, and recycling and circular economy applications. The articles provided vital background or synthesised current knowledge. Non peer-reviewed documents, including policy reports and institutional publications, were incorporated selectively to provide context on regulatory developments and socio-economic considerations. The identified literature was critically and thematically synthesised to provide insights into polymer chemistry, microplastic generation during mastication, environmental transport and persistence, human exposure pathways, potential health implications, and opportunities for sustainable circular material innovation. Such a structured narrative approach promoted up-to-date evidence on patterns and trends, methodological limitations, and key research priorities, and was flexible enough to incorporate findings from multiple disciplines such as environmental science, polymer chemistry, toxicology, and waste management.

2.2. Strength of Evidence and Uncertainty for Central Claims

The evidence supporting chewing gum-derived microplastics is nascent and conflicting. This uncertainty is expressed explicitly in Table 1, where we describe the evidence-strength framework used to interpret the key claims in this review. Here, the table ties each claim domain back to its main evidence, the extent to which any of those sources found similar findings, the major limitations of each source, and how each contributes to the current synthesis. Claims were considered robust when supported by actual measurements, repeat observations, or known polymer behaviour. Claims were considered moderate if direct evidence could be found, but were restricted, for example, by small sample sizes and only a few products available for testing, as well as method-dependent detection thresholds. A claim was considered preliminary if it was based predominantly on one experiment, an estimate of secondary value, an interpretation of a concept, or a demonstration of proof of

concept in engineering. These properties indicate that, on this basis, gum-base composition and surface adhesion appear relatively well supported, whereas chewing-induced particle release is considered experimentally supported (although it depends partly on formulation, chewing context, and analytical method). However, specific environmental residence times, nano- and ultra-small-particle loads, the magnitude of health risks, and the scalability of circular upcycling pathways are unknown.

Table 1. Primary evidence map for central claims, methods, uncertainty, and robustness assessment.

References	Claim/Domain Mapped	Sample or Evidence-Based	Analytical Method	Main Finding Used in This Review	Uncertainty/Limitations	Evidence Assessment
[3]	MP release during chewing: natural vs. synthetic comparison	10 commercial gums: 5 natural and 5 synthetic; timed chewing experiment with 5 replicates for release kinetics	Saliva collection, digestion/filtration, Nile Red screening, FTIR confirmation	Up to 637 MPs g ⁻¹ ; 94% released within first 8 min; natural vs. synthetic release not significantly different ($p > 0.8$)	Small product set; U.S. brands only; saliva/mastication variability; FTIR likely undercounts sub-20 µm particles	Moderate for MP release occurrence; preliminary for exact rate, timing, and natural-synthetic equivalence
[2]	Environmental persistence and ecological concern of discarded gum	Narrative review; no new degradation experiment	Literature synthesis and environmental commentary	Discarded gum is estimated to be persistent for 90–100 years, and as a plastic-pollution contributor	Persistence duration not derived from standardised long-term field or laboratory degradation testing	Low/preliminary for the exact persistent duration; stronger for persistent urban waste framing
[17]	Microbial colonization of wasted chewing gum	Wasted gums from five countries; outdoor exposure succession followed over three months	Bacteriome profiling, bacterial isolation, and gum-ingredient biodegradation tests	Chewed gum develops oral-to-environmental microbial succession during outdoor exposure	Three-month observation does not quantify complete polymer degradation or long-term half-life	Robust for microbial colonisation; preliminary for full polymer biodegradation implications
[18]	Metals in chewing gums, peppermints, and sweets	Selected confectionery brands in Nigeria	Metal analysis for Cd, Cr, Mn, Pb, Cu, Zn, Fe, Ni, and Co, plus dietary intake/risk assessment	Chewing gum/confectionery products can contain measurable metals	Geographically limited; not a microplastic-release study; exposure depends on product and consumption patterns	Moderate for metal occurrence in sampled products; indirect for MP-related health risk
[8]	Chicle versus petrochemical gum sustainability	Conceptual case analysis	Sustainability and strategic differentiation analysis	Chicle may offer sustainability differentiation, but cost and supply-chain constraints remain	Not an experimental biodegradation or MP-release study	Moderate for sustainability context; preliminary for superiority of all-natural/chicle gums

Table 1. *Cont.*

References	Claim/Domain Mapped	Sample or Evidence-Based	Analytical Method	Main Finding Used in This Review	Uncertainty/Limitations	Evidence Assessment
[19]	Material behaviour of chewing gum waste	Chewing gum waste processed under vulcanisation-like conditions	Infrared spectrometry and rheometry	Gum waste behaves as a processable polymeric material	Engineering process study; does not quantify MP release or field persistence	Moderate for processing potential; indirect for environmental degradation claims
[20]	Composition and testing of medicated chewing gums	Review of medicated chewing gum formulations	Composition, production, and mechanical-testing review	Gum bases are functional polymeric matrices for controlled chewing/release	Pharmaceutical focus; not designed for environmental MP release or persistence	Robust for formulation context; indirect for pollution claims
[15]	High-value reuse of chewed gum	Recycled chewed gum combined with MXene for bioelectronics/wearable sensors	Materials fabrication and device-performance testing	Chewed-gum waste can be converted into functional material platforms	Proof of concept; scalability, hygiene, logistics, and lifecycle impacts unresolved	Moderate for feasibility; preliminary for scalable circular deployment

2.3. Overview of Primary Studies

In order to complement the review methodology and improve evidential transparency, Table 2 presents the key primary studies included in this review. The table includes critical methodological and empirical information such as sample characteristics, gum types, analytical detection methodologies, particle size ranges, main findings, and study-specific limitations. In this overview, we emphasise the variety of study designs and analytical approaches used to investigate chewing gum-derived microplastics, as well as the common limitations, including small sample sizes, limited product diversity, and detection thresholds for smaller particle fractions. Through the inclusion of the original studies in a standardised format, Table 2 provides a basis for the synthesis of, and assessment of, the evidence strength and uncertainty that follows in the rest of the paper.

Table 2. Summary of primary studies on chewing gum-derived microplastics.

References	Sample/Design	Gum Type(s)	Detection Method(s)	Particle Size Range	Main Findings	Key Limitations
[3]	Multiple commercial gum brands; controlled chewing experiment	Natural and synthetic gums	Microscopy; FTIR	~20 µm and above (method-dependent)	MPs released during chewing; early-stage release dominates; comparable release between gum types	Limited number of brands; under-detection of smaller particles; controlled conditions
[21]	Single volunteer; 1-h chewing with saliva sampling	Commercial chewing gum	Automated Raman; NPoF-SERS	MPs (>1 µm); NPs (<1 µm, qualitative)	>250,000 MPs detected; nanoplastics also detected in saliva	Single-subject design; limited quantification of NPs; exploratory study

Table 2. *Cont.*

References	Sample/Design	Gum Type(s)	Detection Method(s)	Particle Size Range	Main Findings	Key Limitations
[4]	Gum formulation analysis	Mixed formulations	Polymer characterisation (review/analytical)	Not size-resolved	Identified major polymer constituents in the gum base	No direct MP measurement; composition-focused
[8]	Review of gum composition and environmental behaviour	Synthetic and natural gums	Literature synthesis	Not size-resolved	Gum base identified as a persistent polymer matrix	No primary experimental MP data
[2]	Environmental and urban waste analysis	Discarded chewing gum	Observational/review	Not size-resolved	Gum residues persist in the environment and contribute to urban pollution	Lack of standardised degradation measurements
[17]	Field samples of discarded gum across locations	Post-consumption gum	16S rRNA sequencing	Not applicable (microbial focus)	Biofilm formation on gum surfaces	Does not quantify MPs or polymer degradation
[18]	Chewing gum and confectionery samples	Mixed confectionery (including gum)	Acid digestion; AAS	Not applicable (metal focus)	Presence of toxic metals (Cd, Pb, etc.)	Not specific to MPs; regional study
[15]	Laboratory upcycling of chewed gum	Post-consumption gum	Conductivity testing; material characterisation	Not applicable	Gum can be converted into conductive composites	Laboratory scale; no environmental validation
[19]	Laboratory recycling of chewed gum	Post-consumption gum	ATR-FTIR; rheometry	Not applicable	Gum is modified into a rubber-like material	No field validation; stability not tested

3. Polymeric Composition and MP Genesis

Chewing gum is a complex engineered polymer composite designed for prolonged mastication without structural collapse. The chewing gum formulation involves two main phases, namely, a continuous water-soluble portion and a discontinuous water-insoluble elastomeric base or gum base. This biphasic structure is optimised for flavour diffusion, textural resilience, and oxidative stability, which can be simultaneously a significant source of microplastic generation (Table 3) during chewing and long-term environmental deposition after disposal [2–4].

The water-insoluble gum base forms 20–30% of the total mass of modern chewing gum. This phase contains elastomers (10–45%), plasticisers (15–35%), and emulsifiers that govern rigidity, elasticity, and ‘squishiness’ during chewing. Historically, gum bases were derived from natural latex resins, notably chicle, which is extracted from the sap of *Chicozapote* trees in the tropical forests of southeastern Mexico. Chicle consists of high molecular-weight polyterpene networks composed of thousands of isoprene subunits, providing a natural elastomer that facilitated both social livelihoods and ecological development within indigenous supply chains. However, limitations in scalability, labour availability, weather-dependent harvest yields, and supply-chain exploitation risks motivated a major industrial transition toward petrochemical-derived elastomers and thermoplastics from the 1990s onwards [2,4,8].

Table 3. Synthesised roles of chewing gum phases in microplastic generation and environmental behaviour.

Phase	Typical Composition	Functional Role	Convergence Across Studies	Key Limitation	Synthesis	Evidence Strength
Water-insoluble gum base	PVAc, PE, PIB, PIP, SBR, chicle polyterpenes, waxes	Structural integrity, elasticity, and chewiness	Consistently identified as the dominant polymer matrix and main source of MPs during mastication (Konar et al., 2016 [4]; Paul, 2023 [8]; Lowe et al., 2025 [3])	Composition is often undisclosed; persistence duration is not standardised	Primary driver of both microplastic generation and environmental persistence, irrespective of origin	Moderate–robust (mechanism established; magnitude uncertain)
Water-soluble phase	Sugars, polyols, glycerine, acids, antioxidants	Flavour release, hydration, mouthfeel	Consistently dissolves during chewing, facilitating saliva interaction (Konar et al., 2016 [4]; Roy, 2021 [2])	Indirect role in MP release not quantified; formulation-dependent	Acts as a modulator of release dynamics and exposure pathways, not a direct MP source	Moderate (indirect role)
Coating/encapsulant phase	PVA films, emulsifiers, colour coatings	Flavour protection, structural stability	Identified as an auxiliary polymer layer contributing to durability (Paul, 2023 [8]; Yin et al., 2025 [15])	Limited empirical data on independent MP contribution	Likely contributes to secondary polymer inputs and material durability, but is under-characterised	Preliminary–moderate (emerging evidence)

Contemporary synthetic gum bases are formulated from polymers, including polyvinyl acetate (PVA/PVAc), polyethylene (PE), polyisobutylene (PIB), polyisoprene (PIP), butadiene–styrene rubber (SBR), and Fischer–Tropsch paraffins and petroleum waxes. These polymers have been approved for use in food- or pharmaceutical-contact applications and are not digestible by consumers. These have been found to show high hydrophobicity and long environmental residence times [2,3], have the ability to be chemically and/or biologically persistent for decades in terrestrial systems and are especially viable for urban settings on pavements and public infrastructure. Even the so-called ‘plastic-free’ natural gums have been observed to contain measurable microplastics in some analytical surveys, largely due to manufacturer non-transparent polymer disclosures, which create an entire industry-wide analytical blind spot in microplastic budgets [3,8].

Empirical studies have shown that mastication is a mechanical polymer-fragmentation process in which MPs are directly produced in saliva, as well (see Figures 1 and 2). Infrared spectrometry and microscopy have estimated that a gram of chewing gum releases 637 microplastic particles, with 94% of these being shed in the first 8 min after chewing; the release curves plateau at 20 min. The median particle diameter is 45.4 µm; 56% of particles are <50 µm. Because of FTIR diffraction limitations, many sub-20 µm and ultra-small (sub-10 µm) MPs are assumed as underestimated, highlighting that the real MP loading is higher than the reported. Several polymer classes were measured in saliva after gum mastication, notably polyolefins (predominantly), PET (more prevalent in synthetic gums), polyacrylamides, and polystyrenes; however, overall particle counts showed statistically similar findings for natural and synthetic gums ($p > 0.8$), suggesting formulation-agnostic

ingestion of gum materials [2,3]. Gum litter also fragments under UV light, temperature variation, humidity, salivary enzymes, and mechanical wear and tear on pavements, resulting in secondary MPs that can be transported into soils, storm drains, and riverine systems. Removing gum can cost over three times the retail price, based on municipal steam-cleaning trials, and the GBP 3.00-per-particle cost for gum removal on streets during the Olympics reported by London councils, illustrating the socio-economic impact of gum polymer pollution on society [2,12]. Nevertheless, chewing gum offers the potential for upcycling when combined with conductive nanomaterials, such as CNTs and MXene nanosheets, by means of stretch–fold–knead fabrication, with conductivities of up to 400 S m^{-1} for flexible bioelectronics/self-healing sensors [15]. However, the oxidation stability of conductive gum composites in environmental weathering is not well characterised, which constitutes a significant research landscape of sustainable polymer revaluation and MP monitoring [2,15].

4. Release Kinetics, Environmental Fate, and Burdens

4.1. Microplastic Release Kinetics During Chewing

Microplastic (MP) release by chewing gum is regulated by mechanical shearing, hydration dynamics, polymer viscoelasticity, and mastication time. FTIR and microscopy data indicate the liberation of 637 MP particles per gram of gum using a human chewing saliva-collection protocol, with 94% released within the first 8 min after ingestion, and that overall release fractions converge between natural and synthetic gums, suggesting formulation-agnostic MP ingestion risk. Graphs of particle release reveal an exponential decay in MP shedding rates at 0–8 min, followed by a transition to a phase-oriented process that reaches an upper limit over 20 min after chewing [3]. It was reported by Lowe et al. [3] that all the microplastics produced when chewing gum were smaller than $100 \mu\text{m}$ in size, with a mean diameter of $82.6 \mu\text{m}$, a median diameter of $45.4 \mu\text{m}$, and 56% of the detected particles measuring less than $50 \mu\text{m}$. However, these were considered the detectable size fraction because FTIR spectroscopy was limited by a diffraction threshold of approximately $20 \mu\text{m}$. The study acknowledged that many smaller particles, most notably those $<10 \mu\text{m}$, were likely undetected. Thus, the size distribution is conservative and the true abundance of smaller microplastics released during chewing may be much larger than those presently recognised [2,3]. There is a need to conduct further studies with higher-resolution analytics to determine submicron and nanoplastic particles released during chewing. The major polymer signatures in saliva are polyolefins (dominant), polyterephthalates (PET), polyacrylamides, and polystyrenes, corresponding to base-polymer and coating-contaminated detritus. PET in synthetic gums is relatively enriched due to ethylene-derived precursors and styrene–butadiene rubber fractions [2,8]. Natural chicle gums generate significantly lower MPs per gram compared with their synthetic gum-base counterparts. However, the fate of these ingested particles in the gastrointestinal tract remains uncertain. Specifically, whether chewing gum-derived MPs undergo further fragmentation into smaller MPs or nanoplastics under highly acidic gastric conditions is currently hypothetical and lacks experimental verification [3,4]. Future investigations using simulated gastrointestinal models are needed to determine whether such fragmentation occurs and whether it contributes to human exposure and health effects. In addition, mastication further disperses MPs into the environment indirectly via saliva-to-surface transfer, spitting, misuse during chewing and remnant-to-shoe adhesion, resulting in diffuse micro-emission nodes within the urban–peri-urban polymer budgets [2,12].

4.2. Environmental Fate and Persistence

Once discarded, chewing gum residues behave as long-residence polymeric litter, forming adhesive surface deposits on pavements, kerbs, transport terminals, and built heritage. Field studies indicate that gum-derived polymers can persist in terrestrial environments, resisting hydrolysis, oxidation, and microbial decay, due to hydrophobic polymer bases, such as polyvinyl acetate (PVAc), polyethylene, SBR, PIB and PIP, which are designed for mechanical durability and non-digestibility, not environmental disintegration [2,8]. UV irradiation, seasonal temperature fluctuations, humidity, tire-wear scuffing, pedestrian abrasion, and rain-mediated runoff gradually weather these residues into secondary microplastics and nanoparticles (Table 4), which infiltrate street dust, storm drains, and soil surface horizons. In sub-aerial settings, wasted gum rapidly transitions from an oral bacteriome to a pavement biofilm bacteriome, hosting environmental genera, such as *Pseudomonas*, *Acinetobacter*, *Sphingomonas*, *Kocuria*, *Blastococcus*, and *Deinococcus*, forming protective biofilms that may enable polymer-additive sorption, but whose degradation rate of the polymer itself remains slow and incomplete [2,17]. While biofilms may colonise the gum within weeks, colonisation does not equate to biodegradation of the gum base. Instead, gum surfaces act as micro-pollutant sponges, adsorbing co-deposited airborne particulates, trace metals, and opportunistic pathogens, particularly on long-standing pavement blobs [2,18]. MPs from gum are thus part of both ingestion exposure and environmental stock pollution, a dual fate that complicates removal and quantification.

Table 4. Polymer-weathering stressors and detection limits.

Stressor/Process	Mechanism of Action on Gum Polymers	Convergence Across Studies	Key Variability	Detection Limitation	Synthesis
Mechanical stress (mastication, abrasion)	Physical fragmentation of the gum base into micro-sized particles	Consistently identified as the primary driver of MP generation during chewing (Lowe et al., 2025 [3]; Pant et al., 2025 [21])	Depends on chewing intensity, duration, and gum formulation	Smaller fragments (<20 µm) are often missed by microscopy/FTIR	Dominant mechanism of initial microplastic release, but the magnitude is likely underestimated
UV radiation (photodegradation)	Polymer chain scission, oxidation, embrittlement	Widely recognised mechanism in the polymer degradation literature (Roy, 2021 [2]; Paul, 2023 [8])	Varies with exposure duration, UV intensity, and environment	Early-stage degradation products difficult to detect	Contributes to long-term fragmentation into secondary MPs, but field quantification is limited
Thermal stress (temperature fluctuations)	Expansion–contraction cycles leading to cracking and structural weakening	Recognised but less frequently quantified in gum-specific studies	Strongly environment-dependent (urban vs. shaded areas)	Subtle structural changes not easily measurable	Acts as a secondary stressor, enhancing fragmentation over time
Chemical exposure (moisture, oxygen, pollutants)	Hydrolysis, oxidation, and additive leaching	Supported by general polymer degradation studies	Depends on humidity, pollutants, and gum composition	Additive release is poorly tracked in environmental matrices	Influences both polymer breakdown and co-contaminant release

Table 4. Cont.

Stressor/Process	Mechanism of Action on Gum Polymers	Convergence Across Studies	Key Variability	Detection Limitation	Synthesis
Biological interaction (microbial colonisation)	Biofilm formation; limited biodegradation of polymer matrix	Biofilm formation was consistently observed (Satari et al., 2020 [17])	Microbial composition varies by location	Difficult to distinguish biodegradation from surface colonisation	Gum acts as a microbial substrate rather than a biodegradable material
Secondary environmental fragmentation	Combined effect of UV, mechanical, and chemical stressors	Widely accepted across environmental plastic studies	The rate varies across environments	Lack of standardised disintegration protocols	Leads to progressive formation of smaller MPs and potential NPs
Analytical detection limits (FTIR, microscopy)	Size detection thresholds (~10–20 µm)	Consistent limitation across studies (Lowe et al., 2025 [3]; Pant et al., 2025 [21])	Instrument sensitivity varies	Nano- and ultra-small plastics not reliably detected	Current MP estimates are likely to be systematically underestimated
Advanced detection (Raman, SERS)	Improved detection of smaller particles and nanoplastics	Demonstrated in recent studies (Pant et al., 2025 [21])	Still limited in application and standardisation	Quantification of NPs remains challenging	Promising for closing detection gaps, but not yet standardised

Aside from physicochemical transformation processes, discarded chewing gum may encounter biological interactions on its surface, mainly through microbial colonisation and biofilm production [2,17]. Biofouling has been shown to modify the surface properties of the material and can alter its environmental behaviour but does not equate with polymer degradation, especially for synthetic/semi-synthetic gum bases [2,8]. Available studies report that microbial colonisation can occur on gum surfaces in various environments [17]; however, this remains limited and poorly quantified, with no clear indication of significant polymer degradation under environmental conditions [8]. Hence, biofouling should be regarded as a secondary interaction process rather than a primary mechanism of polymer transformation.

Biofouling may be viewed as a surface-driven process driven by discarded chewing gum, rather than as proof of rapid biodegradation of gum-base polymers. Gum residues are then subjected to moisture, dust, saliva-derived organic matter, additives, and environmental microorganisms, which promote microbial adhesion and biofilm formation on the polymer surface [2,17]. Gums, after disposal, may carry different microbial communities; however, colonisation does not necessarily mean polymer mineralisation or complete degradation, especially on synthetic or semi-synthetic gum bases [8]. Biofilms do not; instead, they modify surface properties, such as roughness, wettability, charge, adhesion, and pollutant-retaining capacity, which influence environmental interactions, particle transport behaviour, and surface structure. These surface modifications might interact with physicochemical factors, such as UV radiation, moisture cycling, temperature drift and mechanical abrasion, and affect the dynamics of fragmentation. The degree to which biofouling promotes microplastic development, however, is not known; biofilm coatings are further known to introduce complicating effects in the analysis of the detection of underlying polymer particles [8].

4.3. Ecological and Socio-Economic Burdens

Chewing gum residue is now recognised as a dual-fate polymer pollutant, where, through chewing, direct human exposure to human microplastics (MP) occurs; after littering, long-term environmental pollution stocks are formed. Gum MPs enter city systems as a result of street dust deposition, surface scuffing, rainwater wash-off and storm drain overflow and can finally flow into soils, rivers, and coastal sinks. Although gum surfaces are colonised by environmental biofilms at a fast pace, colonisation is not identical to polymer decay -pre-colonisation; however, gum residues instead accumulate in protective sub-aerial biofilms that facilitate particle sorption, microbial persistence, and co-pollutant aggregation without polymer disintegration [2,3]. On British streets, gum blobs have been embedded into paving stones for 90–100 years, fouling more than 92% of items inspected, diminishing surface ability, impairing drainage porosity, and fostering littering behaviour [2,8,22], especially amongst youth demographics, which are the largest consumption and disposal nodes.

The socioeconomic burden is significant. Mechanical removal is the only common remediation option; however, it is financially inefficient and linear. At London councils, GBP 3.00 per blob was spent removing 300,000 blobs over <2 miles of streets during the Olympics in 3 months—three times the retail purchase price and equivalent to millions per year for municipalities. The previous UK clean-up budgeted estimate was GBP 70 million annually, while the cost of gum selling for retail was only a fraction of this [11–13]. Unlike carrier bags and beverage containers, gum is not accurately recorded in national plastic inventories, as a result of confectionery classification gaps, wrapper-less sales, and manufacturer secrecy about the type and proportion of polymer, which obstruct MP budgets, polymer tracking, and environmental-degradation accounting [2,3,8].

Human-mediated adhesion to shoes and clothing fibres carries polymer fragments farther and farther between households and across borders as an untracked dispersal vector, bypassing waste bins altogether [2]. As with other materials, with the potential for biodegradable reformulation, deposit–return incentive pilots and community collection campaigns being studied, the scale of disintegration curves observed, the limitations of oxidation and stability, and commercial budgets [3,14,15,23] are still not certain. This highlights the importance of a formal embedding of gum into national MP stocks, long-term polymer-weathering surveillance, behavioural change interventions, and fiscal–ecological trade-off analyses to achieve a substantial burden reduction and the revaluation of circular materials.

4.4. Burden-Reduction and Knowledge Frontiers

Chewing gum MPs and pavement residues have large ecological and economic burdens; however, evidence suggests that this burden can be relieved through formulation science, waste system design, behaviour change interventions, and fiscal instruments. Polymer reformulation toward biodegradable elastomeric blends (e.g., polyisoprene/polyethylene-oxide matrices, borax–PVA crosslink intermediates, and anti-adhesion additives) provides the potential for increased hydrolysis and limited street adhesion; however, full-scale commercial environmental decomposition has not yet been proven. Collaborations with municipalities through systems, such as adhesive-resistant gum collection bins, gamification for youth, and QR code-based deposit–return incentives, can help to increase the recovery rate for chewed gum while minimising pavement scuffing and drainage transfer. Clean-up economics highlight the importance of material circularity rather than the linear mechanical scrubbing currently prevalent for cleanup.

In theory, there is the idea of taxing chewing gum to recoup the costs associated with supply-chain clean-up, similar to the successful single-use carrier bag tax; however, uptake is still inconsistent. Gum MPs are not permanent pollutants; they quickly settle into saliva

and street dust during early chews, meaning that saliva- and surface-mediated transmission are sensitive to chewing period, saliva content, and disposal behaviour. Key domains of investigation include: (i) large-scale analytical detection on nano-plastics <20 µm not covered by ATR-FTIR diffraction limits; (ii) the long-term polymer-weathering curve under UV, moisture/dry seasonality oscillation and abrasion; (iii) limits to the stable oxidation of up-cycled conductive gum electronics; and (iv) commercial-scale disintegration validation of biodegradable bases.

The future should focus on moving gum into national MP inventories, piloting deposit-return policies, standardising polymer transparency, and achieving environmental weather detection in a more efficient manner, demonstrating, at scale, disintegration and transitioning gum waste from an uncontrolled linear pollutant to a quantified, circularly recoverable polymer stock for sustainable burden reduction.

5. Human Exposure and Health Implications

Microplastic exposure from chewing gum is a new, potentially preventable, public health problem associated with polymer fragmentation during mastication and environmental transfer during disposal. The chewing matrix releases particles into saliva and provides a direct route of oral exposure after swallowing. According to [3], it was reported that chewing gum can release microplastic-sized particles into saliva, with most detected particles below 100 µm and a median size of approximately 45 µm. The same study found no statistically significant difference in particle release between sampled natural and synthetic formulations, suggesting that ingestion risk may not be limited to one gum type or formulation category, although broader cross-brand validation is still required [2,3].

After being swallowed, gum-derived particles will traverse the gastrointestinal tract and encounter saliva proteins, gastric acidity, digestive enzymes, bile salts, mucus, epithelial surfaces, and gut microbiota. Most ingested particles are expected to be excreted; however, smaller particles may find more opportunity to make contact with intestinal mucus and epithelial surfaces, owing to their greater surface-area-to-volume ratio. Furthermore, the digestive environment influences particle surfaces, aggregation or partial weathering, and additive release, although direct evidence for the progressive size reduction in gum-derived particles in digestion is sparse [3,24,25]. Thus, chewing gum-derived microplastics should be regarded as biologically plausible exposure agents; however, retention time, uptake efficiency, and health relevance cannot be established.

Some human biomonitoring studies observed microplastics in blood, lungs, placenta, and carotid arterial plaque from human biological matrices (for some exposure conditions) with particle-associated materials and/or small polymer particles have confirmed small polymer particles or particle materials outside of the gut [26–29]. Nonetheless, these results should not be read as proof for the ingestion or disease-causing role of chewing gum as a system-wide microplastic and/or disease-causing agent. Instead, they uphold the wider biological plausibility that microplastics from multiple ingestion and inhalation sources, such as tiny particles, can be introduced to human tissues. Experimental studies that reveal the effects of microplastics on digestive-tract cells and gut microbiota have been conducted; however, these were conducted on model polymers and exposure in controlled conditions and did not always constitute chewing gum-derived particles [24,25].

Potential issues for the gastrointestinal tract involve interactions with epithelial barriers, alterations in mucus interfaces, disruptions of gut microbial communities, and possible effects on nutrient absorption or inflammatory signalling. Such mechanisms are particularly pertinent for smaller particles, such as sub-20 µm and nano-sized fractions, that FTIR detection may fail to detect. Nevertheless, the evidence in question is, thus far, mechanistic and very limited. Claims that gum-derived microplastics directly impair nutrient

uptake, disrupt adolescent development, or cause irreversible health effects would be premature, in the absence of dose–response data, realistic repeated-exposure designs, and polymer-specific toxicological testing [3,24,25].

Apart from the particles themselves, chewing gum can result in chemical exposure via additives, fillers, antioxidants, colourants, flavouring agents, plasticisers, encapsulants, and trace metals. Gum-base formulations often contain elastomers, resins, waxes, emulsifiers, plasticisers, and stabilising agents that affect texture, oxidation stability, and chewing performance [2,4]. Based on metal analysis of chewing gums and related confectionery products, Cd, Cr, Mn, Pb, Cu, Zn, Fe, Ni, and Co have been reported, suggesting that gum consumption may contribute to broader oral exposure to non-polymeric constituents [18]. Long-term excessive zinc exposure has also been linked to alterations in copper balance, immune function, lipid metabolism, and oxidative stress; however, these findings do not conclude that chewing gum produces harmful zinc exposure under normal use [30,31].

Altogether, chewing gum-derived microplastics have health implications that should be framed cautiously. While there is now some evidence that one might be exposed and that further research is warranted, such evidence does not establish a direct causal link between chewing gum microplastics and adverse health outcomes. The nature of the risk seems to be dose-, behaviour-, formulation-, particle size-, and detection method-dependent, rather than fixed or inevitable. Crucially, this exposure pathway is modifiable. Mitigation approaches involve reformulating gum base formulas to reduce particle release, increasing the transparency of polymers on labels, minimising the duration of unnecessary chewing, using hygienic wrappers or disposal systems, increasing public awareness, and preventing discarded gum from entering environmental transfer pathways. The future directions of research involve standardised chewing methods, comparison of artificial and human saliva, detection of sub-20 µm and nanoparticles, digestion studies, gut-barrier systems, additive-leaching testing, and long-term exposure measurements to be used on chewing gum as means to determine its contribution towards total microplastic exposure [3,24–26].

6. Comparative Dose Load Relative to Air, Water and Food

Food pathways (e.g., seafood and salt) also lend critical context to ingestion exposure. In [32], around 39,000–52,000 particles per person^{−1} year^{−1} from food and beverages alone were reported, increasing to ~74,000–121,000 particles per person^{−1} year^{−1} when inhalation was included. The derived estimates are based on a compilation of reported concentrations and modelling by exposure factor, with particle identification mainly based on micro-FTIR and Raman spectroscopy, and detection windows of ~1–500 µm. Danopoulos et al. [33] showed that food exposure was highly diet-specific, depending on the species, trophic level, and whether organisms are consumed whole. For example, bivalves and small organisms are more directly involved in ingestion because the gastrointestinal tract is incorporated, while filleted fish might exhibit a reduced exposure. This research does underscore, however, that the dose variation is highly dependent on the specific analytical methods (e.g., digestion protocols, polymer confirmation) and particle size cut-offs, which prevents direct comparison between datasets.

Drinking water is a major chronic ingestion pathway that is known to exhibit significant methodological variation. Depending on filtration technique, contamination control, digestion methodologies, and polymer identification methods such as visual microscopy, micro-FTIR or Raman spectroscopy, varying concentrations can be reported [33]. In water studies, detection limits typically range from ~1 to 50 µm; thus, smaller fractions are usually omitted. Fresh approaches, namely dielectrophoresis-assisted Raman spectroscopy, have recently been developed and leveraged to detect sub-micrometre and nano-sized

particles [34]. Therefore, the estimated waterborne microplastic dose may underestimate the actual particle load, especially in the smaller size fractions.

Airborne microplastics are of great concern, since inhalation is continuous and cumulative. Estimates of exposure fluctuate vastly in relation to indoor versus outdoor environments, the underlying features of the building, textile sources, and analytical limits. Eberhard et al. [35] applied exposure-factor modelling and found that the inhalation dose could vary from relatively low values to thousands of particles per kg^{-1} body weight day^{-1} , especially in such indoor settings. Similarly, Zhang et al. [36] suggested that inhalation might be involved in exposure levels orders of magnitude higher than those of a subset of dietary sources, depending on assumptions and environmental factors. Many of these investigations are typically conducted by air sampling, followed by FTIR or Raman analysis, with particle sizes commonly reported in the $\sim 1\text{--}100\ \mu\text{m}$ range; however, smaller airborne fibres and fragments are now more frequently reported.

In this particular context, chewing gum serves only as a direct but episodic ingestion route. Lowe et al. [3] showed that chewing gum can release microplastic-sized particles into saliva, with an upper limit of ~ 637 particles g^{-1} , most detected particles $< 100\ \mu\text{m}$, and a median particle size of approximately $45\ \mu\text{m}$, based on microscopy and FTIR analysis, constrained by detection limits (usually $\geq 10\text{--}20\ \mu\text{m}$). Using an annual consumption estimate of $\sim 160\text{--}180$ sticks per person, the study extrapolated to a dose of $\sim 28,500\text{--}32,000$ particles per person-year $^{-1}$. This estimate, though based on small data, potentially underestimates smaller fractions of the particle and is by no means insignificant, falling within the same order of magnitude as some dietary exposure estimates, although lower than combined ingestion and inhalation estimates reported by Cox et al. [32]. Chewing gum-derived exposure is behaviour-dependent, and less continuous than air- or water-based pathways, but also provides a direct, saliva-mediated ingestion route that bypasses environmental dilution. Nonetheless, cross-source comparisons remain approximate due to differences in particle-size detection windows, sampling strategies, and analytical methodologies. Thus, chewing gum is unlikely to be a dominant exposure source relative to inhalation or combined dietary intake, but it may contribute a measurable and potentially avoidable component of total microplastic exposure, particularly among frequent users.

The quantity of microplastics (MPs) emitted by chewing gum on a single use is usually lower than that reported for some foods, including seafood; however, the comparison should be viewed with caution. Seafood and other high-MP foods are typically eaten intermittently, whereas chewing gum is commonly consumed daily, and, in some cases, multiple times per day. Accordingly, constant gum exposure may build up cumulative MP exposure, particularly among habitual users. Currently, the precise contribution of chewing gum to total human MP intake remains unclear, as exposure depends on individual chewing habits, consumption frequency, dietary patterns, and the MP content of other food and beverage sources. Future exposure measurements should, consequently, include the number of MPs emitted per chewing event and the frequency of gum consumption to obtain a better estimation of cumulative human exposure.

7. Sustainable Upcycling Innovations

Chewed gum waste, a traditional linear polymer pollutant, has recently been studied as a reclaimable elastomeric feedstock for high-value circular applications. Its inherent features—viscoelasticity, flexibility, tacky adhesion to lyophilic surfaces, stretchability, and the ability to undergo repeated deformation without structural collapse—render it particularly suitable for mechanical processing, composite coupling, and sensor interfacing [2–4]. Unlike traditional plastics that need thermally demanding melt recycling, chewing gum can be sanitised and mechanically folded, stretched, or kneaded at ambient or mildly elevated

temperatures, to facilitate sustainable recovery modes for towns, as well as for innovation systems in materials [2,37]. A major focus is the affinity of gum for conductive 2D nanomaterials (MXene nanosheets and carbon nanotubes (CNTs)) (Figure 3). Stretch–fold–knead fabrication of gum/MXene composites has yielded conductivities up to 400 S m^{-1} , excellent adhesion to glass, metal, and polyimide (PI) films, and skin, and notable self-healing behaviour, enabling wearable motion sensors, flexible bioelectronic circuits, and photothermal energy-harvesting interfaces [15]. MXene’s photothermal effect further enabled chewed gum composites to function as a thermoelectric generator, producing $\sim 135 \text{ mV}$ under 1-sun illumination, underscoring the gum’s versatility for energy-scavenging smart sensors [2,15].

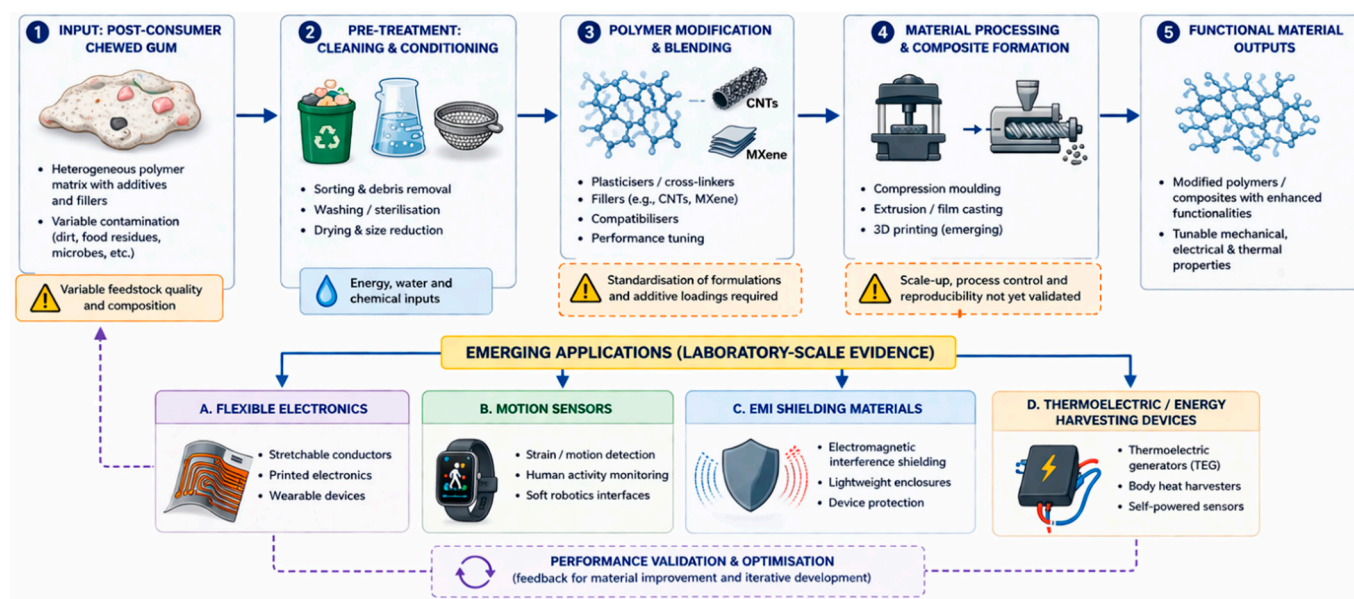


Figure 3. Emerging circular upcycling pathway for chewing gum-derived materials.

Earlier CNT-based gum sensors demonstrated strain detection up to 200–530% and applications for humidity, breathing, and real-time movement monitoring. However, leakage, oxidation susceptibility, and performance decay under wet environments limit the scalable deployment, indicating that mechanical success does not yet equate to environmental stability at the commercial scale (Table 5) [2,15]. MXenes face similar oxidation barriers: terminal groups ($-\text{OH}$, $-\text{O}$, $-\text{F}$) degrade by oxidation within weeks in aqueous or humid systems, requiring antioxidant coupling strategies, such as silane agents, sodium ascorbate, gallic acid, and catechol-functionalised PVA intermediates, although scaled stability validation remains incomplete [2,15].

The insoluble base of gum, especially PVAc and polyisobutylene fractions, offers a stable scaffold for the incorporation of conductive fillers in the gum without dissolution during chewing, leading to viable schemes for sustainable smart circuits and flexible sensor skins to substitute for virgin plastics in wearable bioelectronics [4,8]. Community-driven recovery campaigns, gamified youth engagement, and deposit–return incentives (Gumdrop Ltd.’s model) also point to scaled stock generation to facilitate a reliable deposit pool of polymer for high-value re-engineering [2,15]. Notwithstanding this progress, specific knowledge gaps still exist: (i) oxidation-resilient encapsulation for conductive gum composites; (ii) scaled validation of polymer weathering and electronic stability beyond prototypes; (iii) lifecycle impact accounting for up-cycled gum composites; and (iv) formal integration of gum into national microplastic control inventories. Collectively, this evidence indicates that chewed gum can be considered not only a removable waste but also a modifiable polymer stock with measurable upcycling potential, whose circular revaluation could thus reduce pavement interaction, offset demand for virgin plastics, and

seed potentially profitable youth-inclusive sustainable sensor industries, assuming that environmental stability, oxidation limits, and scalable composite disintegration curves can be established in future work.

Table 5. Upcycling technologies and current scalability barriers.

Technology/Approach ^z	Value Addition Achieved Using Recycled Chewed Gum	Current Barriers to Scaling and Real-World Deployment	References
CNT–gum mechanical reworking	High strain-responsive sensing (detects large deformation), foldable and wearable circuits	Filler leakage, mechanical fatigue over long outdoor periods, and lack of a standard production line	[2,4,17]
MXene–gum stretch-fold integration	~400 S m ^{−1} conductivity, excellent adhesion to glass/metal/skin/PI, self-healing circuits, ~135 mV at 1-sun photothermal–thermoelectric output	Rapid oxidation of MXene terminals in humid/aqueous conditions (weeks), high cost of MXene sheets, and environmental stability unverified at the commercial scale	[2,3,15]
Borax/PVA cross-linked MCG matrices	Correlation of chewiness, firmness, and elasticity with mouthfeel; improved composite rigidity control for sensor skins	Formulation complexity, absence of official environmental disintegration test, and manufacturer compositional opacity	[4,8]
Solar/thermoelectric ^z gum composites	Light-to-heat conversion enabling energy-scavenging for movement/temperature sensors	Prototype-only validation, oxidation stability unresolved, need for encapsulation and polymer accountability	[2,15]
Municipal gum-recovery systems	Redirects long-residence pavement gum into circular polymer deposit streams for high-value re-engineering	No deposit–return policy standard, bin-adhesion design inefficiency, untracked gum-to-shoe/fabric dispersal nodes	[2,11,37]

8. Policy, Mitigation and Circular Systems

8.1. Regulatory Blind-Spots and the Case for Gum in Plastic Inventories

The regulatory position of chewing gum is not straightforward; it is considered a confectionery under the law but does indeed carry the weight of a durable hydrophobic polymeric composite containing microplastics (MPs) generated by mastication that persist for several decades on pavements. Because labels list only ‘gum base’ without distinguishing natural from petroleum-derived polymers, manufacturers have often circumvented extended producer-responsibility (EPR) tools and national MP inventories on carrier bags and beverage plastics [2,3,8]. In addition, recent data supporting the release of 637 MPs g^{−1} into saliva, mainly occurring within 8 min, confirm that gum is a direct ingestion source and not merely ‘aesthetic litter’ and, hence, should be included in the regulatory contaminant budget [2,3]. Adding gum to the national plastic inventories will better track polymers, facilitate surveillance of nano-plastics <20 µm in size, and inform regulatory weathering curves for wet/dry seasonal oscillations [2].

8.2. Polymer Reformulation, Standards and Product-Level Mitigation

Product-level mitigation focuses on redesigning gum polymers to promote environmental degradation, reduce street adhesion, and lower micro-fragment emissions. Proposed methods also encompass biodegradable elastomeric blends (e.g., polyisoprene/polyethylene oxide, poly(vinyl alcohol)–borax intermediates), wax-free bases, and

the incorporation of anti-sticking or adhesive-reducing additives that preserve mouthfeel while weakening post-disposal pavement bonding [2,4,14]. Although standard pharmacopoeias recommend only a handful of mechanical tests for chewiness, firmness, and elasticity, environmental degradation lacks harmonised standards, underscoring the need for dedicated disintegration protocols analogous to plastic bag biodegradability standards [2,4]. Polymer additives (Zn accelerator complexes (<2.5%), BHA/BHT antioxidants, PVA-based encapsulants, and PVA/PEO scaffolds) should be examined for dose-dependent chemical exposure as well as oxidative limits, but only informatively, not in graphic or unsafe detail [2,4]. Test performance analysis should examine commercial-scale disintegration curves, UV/temperature-mediated weathering, reductions in saliva contact time, and oral-cavity safety [2,3].

8.3. Municipal Waste-System Design and Behavioural Interventions

Gum waste is a municipal remediation burden, clogging drainage porosity and surface interaction paving stones, and transferring polymer ghosts across urban surfaces. It has been demonstrated that adhesive-resistant gum-recycling bins should be offered in high-traffic terminals through partnerships between municipalities and Gumdrop Ltd., together with QR-code deposit–return incentives and gamified youth campaigns to increase the amount of recovered chewed gum [2,15]. Behavioural programmes need to underscore that MP exposure is modifiable through habit change, rather than being immutable, and that youths are central actors driving efforts to change disposal culture [2,5]. Awareness campaigns, school-based clean-up drives, community deposit incentives, and social-behaviour nudges would normalise hygienic disposal, discourage pavement spitting, and reorient gum away from untracked litter toward a reliable polymer deposit stream for circular recovery.

8.4. Deposit-Return Incentives and Circular Material Revaluation

Collectively, circular systems are predicated upon stock recovery, material re-engineering, and profitable polymer revaluation. Chewed gum can be sanitised and mechanically stretched or kneaded at low energy, unlike melt-recycled plastics, allowing for ambient composite integration. New material innovations confirm gum compatibility with CNTs and MXene nanosheets, facilitating flexible motion sensors, EMI-shielding skins, and thermoelectric energy harvesting (~135 mV at 1 sun), while still failing to address the issue of scaled oxidation stability. These developments underscore the high-value utilisation potential of gum, not just as a romanticised ideal, but rather as a practical, quantifiable polymer stock for circular reprocessing [2,15]. Yet, for circular adoption, future work must validate oxidation-resilient encapsulation, scaled disintegration, long-term polymer weathering curves, mouth-feel integrity, and end-of-life MP budgets [2,14,15]. Deposit–return pilots can offset municipal clean-up expenditure, reduce pavement interaction, and seed profitable youth-inclusive sensor industries, provided that polymer stability is proven at scale.

8.5. Fiscal Instruments: Gum Levies, Taxes and Supply-Chain Cost Recovery

Fiscal mitigation tools, such as levies, are successfully applied to single-use plastic bags. The chewing gum tax was first piloted conceptually by Liverpool organisers. Local councils spend millions annually on gum removal, with London spending GBP 3.00 per blob removed during the Olympics, a cost more than three times the retail price [11,12]. Although adoption remains tentative, the economic case for gum levies is behaviourally corrective, supply-chain justified, and materially recoverable, not linked to body ideals or unsafe acquisition guidance. Levies could recover municipal expenditure, fund adhesive-resistant bins, and subsidise the redesign of biodegradable polymers [2,8]. MPs from

gum should be quantified as a policy-relevant pollutant stream, tracked under national inventories, and mitigated through polymer transparency, scaled biodegradation validation, and circular stock recovery—framing gum pollution as a manageable, preventable polymer challenge with measurable circular re-valuation potential, not an immutable consumer habit or irreversible risk.

9. Knowledge Gaps and Research Priorities

Previous studies on chewing gum-derived microplastics (MPs) have evolved from speculation to limited experimental validation; however, they remain heterogeneous, under-standardised, and under-quantified at a large scale. Many important knowledge gaps have limited environmental accounting, health interpretation, materials re-engineering and policy design. One key gap is the lack of an agreed standard for environmental degradation and chewing gum disintegration. Unlike carrier bags or even compostable packaging, in which ISO-compliant biodegradation limits, polymeric labelling requirements, and time-resolved disintegration curves are established, chewing gum is still considered a confectionery, lacking a shared environmental fate standard. This stops gum from becoming a national plastic inventory and disrupts the enforcement of Extended Producer Responsibility (EPR) [2,3,8]. A gum disintegration standard would facilitate polymer weathering monitoring at the levels of UV, wet/dry seasonal oscillations, humidity, and pedestrian abrasion, as well as establish whether colonising pavement biofilms catalyse or simply sorb and preserve MPs without polymer decay [2]. A second limitation is the under-detection of MPs <20 µm and nanoplastic fractions <10 µm. This shows the inability of ATR-FTIR, the most prevalent method for polymer fingerprinting for gum analysis, to resolve sub-20 µm fragments due to diffraction limits and suggests that current MP loads (up to 637 MPs g⁻¹) may underestimate actual exposure [2,3]. Raman-spectrum analysis, NGS–polymer–biofilm interfaces, and higher-resolution 2D imaging pipelines are proposed, with no scaled comparative validation. Saliva, street dust, soil, drains, and riverine sinks—a common detection pipeline—should also be made. A third gap is manufacturer secrecy in relation to polymer composition and proportions, which hinders polymer tracing, lifecycle MP budgets, and reproducibility. Only ‘gum base’ appears on labelling, which makes it unclear whether gum is manufactured from PVAc, SBR, PIB, PIP, petroleum waxes, or chicle polyterpenes. This analytical opacity hinders incorporation into microplastic control models and renders polymer-type attribution, fair-trade supply-chain accounting, and circular re-engineering unfeasible [3,8]. There is an urgent need for transparency standards in polymer composition, not unlike in plastics. A fourth frontier is the oxidation stability thresholds associated with upcycled conductive gum composites. Gum–CNT and gum–MXene circuits have shown good conductivity (400 S m⁻¹) and self-healing capacity for flexible sensors and thermoelectric generators (135 mV at 1-sun) [15]. Nonetheless, environmental oxidation curves and humidity-induced performance degradation, leakage potential, and long-term composite stability after laboratory testing have not yet been determined [2,15]. Scaled validation must prove stability under environmental stressors without suggesting permanent harm or unsafe behaviours.

Other gaps include: (i) poor representation of gum in MP inventories despite high global consumption; (ii) lack of chewing time-corrected MP ingestion models; (iii) insufficient tracking of gum-to-shoe and gum-to-fabric MP dispersal nodes; and (iv) missing integration of gum MPs into One Health frameworks linking ingestion, municipal costs, youth behaviour, drainage fate, and ecological trophic transfer.

Research priorities for chewing gum-derived microplastics centre on standardisation, detection fidelity, polymer transparency, scalability, and systems integration. Key actions include: (1) establishing a standardised gum disintegration protocol to characterise environmental fate; (2) deploying high-resolution MP detection pipelines capable of resolving <20 µm and nano-plastic fractions beyond ATR-FTIR limits; and (3) enforcing polymer-transparency and compliant labelling standards for manufacturers. Additional priorities involve: (4) commercial-scale validation of biodegradable elastomeric blends and anti-adhesion additives; (5) generating time-resolved polymer-weathering curves under UV and seasonal oscillations; (6) testing oxidation-stability limits for up-cycled conductive gum circuits; (7) modelling chewing time-corrected MP ingestion and saliva-mediated transfer budgets; and (8) integrating gum MPs into national and global MP inventories, municipal waste-system design, and youth-inclusive circular-recovery campaigns. Collectively, evidence confirms that gum-derived MP burdens are not immutable; however, mitigation depends on scaled validation, reproducible detection, polymer accountability, and inclusion in formal MP-control inventories for sustainable prevention [2,3,8].

10. Conclusions

Chewing gum should be regarded as a polymer-containing consumer product that has the potential to cause exposure to particles and urban contamination both directly and after disposal. The strength of the evidence varies in these areas. The strongest of these is compositional: gum bases comprise durable, water-insoluble polymeric phases that confer long-standing mastication and adhesion onto the surface. Emerging experimental evidence is beginning to suggest that chewing can release microplastic-sized particles into saliva. These data are less abundant in terms of the magnitude and time profile. Natural and synthetic product comparison is still in its infancy. Existing estimates rely on insufficient product sample data and analytical techniques, which are likely to lack nano- and ultra-small particles. Gum remains can be left on the pavement and may undergo weathering, abrasion, dust accumulation, and microbial colonisation. Despite this, biofilm formation is not the same as complete polymer degradation; the expected persistence time (90–100 years) should remain guarded even after the establishment of standard outdoor degradation methodologies. The idea of turning chewed gum into a mobile, conductive material through circular upcycling is attractive, but it is a proof-of-concept idea. Oxidation resistance, environmental durability, hygiene, infrastructure, and lifecycle performance must be verified. The inference, therefore, is not that all exposure, persistence or circular economy outcomes have been arrived at. Chewing gum should be studied systematically, as an inadequately characterised polymer source, at present. Harmonised disintegration testing, high-resolution detection of fine particles, transparent polymer labelling procedures, cross-brand replication in release studies, and careful policy considerations related to gum's inclusion in microplastics and urban litter inventories should guide priority actions.

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