油漆回收的**可持续**循环再利用模型

Sustainable Circular Reuse Model for Paint Recycling

涂料已成为人类文明不可或缺的一部分，已有五千多年的历史，其应用历史甚至早于巴比伦空中花园和金字塔。尽管涂料的配方、技术、成分和制造方法不断发展，但其根本目的、性能和必要性始终如一。

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涂料——意义、目的、用途、历史

涂料可增强耐久性、延长使用寿命，并提升其所应用表面的美观。因此，涂料产业透过降低更换成本、节省时间和精力，在可持续发展中发挥着十分重要的作用。这反过来又减轻了燃料、水、劳动力、自然资源和环境的压力。透过最大限度地减少资源开采、采矿、污染和碳足迹，涂料有助于实现更可持续的未来。

涂料在桥梁、船舶、飞机、电子产品、机械和住宅等各种应用中，透过延长使用寿命、增强耐用性和提高耐候性，在环境可持续性方面发挥着十分重要的作用。

Coatings — meaning, purpose, use, history

Coatings have been an integral part of human civilisation for over 5,000 years, with evidence of their use in constructions predating even the Hanging Gardens of Babylon and the Pyramids. While formulations, technology, ingredients, and manufacturing methods have continuously evolved, the fundamental purpose, performance, and necessity of coatings have remained unchanged.

Coatings enhance durability, extend lifespan, and elevate the aesthetic appeal of any surface they are applied to. As a result, the coatings industry plays a vital role in

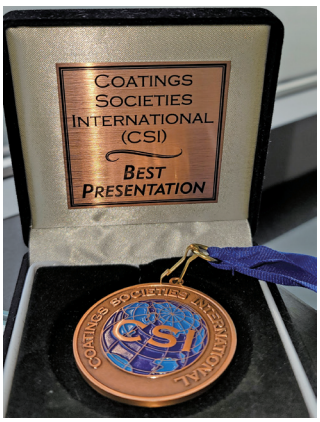

图 1（左）：我因在可持续发展、循环经济和回收利用方面的工作和演讲，而获得由国际涂料协会（CSI）授予荣誉勋章。
Figure 1 (Left): I was awarded the Medallion Honour by the Coating Society International (CSI) for my work and presentation on Sustainability, Circular Economy, and Recycling.

图 2（右）：CSI 由多个涂料协会组成，包括澳洲表面涂层协会（SCAA）、纽西兰表面涂层协会（SCANZ）、美国世界涂料协会（WCS）、斯堪的纳维亚和欧洲协会，以及成立于 107 多年前的油与色彩化学家协会（OCCA）。
Figure 2 (Right): CSI is made up of several coating associations, including SCAA (Surface Coatings Association Australia Inc.), SCANZ (Surface Coating Association New Zealand), WCS (World Coatings Society, USA), Scandinavian and European associations, and OCCA (Oil & Colour Chemists' Association), which was founded over 107 years ago.

图 3：我获得了 CSI 奖章，这是一项极高的荣誉。
Figure 3: I was awarded the CSI Medallion, a prestigious honour.

耐久性成分与制造挑战：分子组成、配方与可持续性问题

为了保持最佳功能和应用性能，涂料多年来经历了重大变革——不断发展以满足成本效益和持久耐久性的需求。随着碳氢化合物化学和分子工程的进步，超耐久涂料成为可能，有效解决了与成本和寿命相关的挑战。

然而，这项成功也带来了新的复杂性——生物降解性、温室效应以及从摇篮到坟墓的责任。对低挥发性有机化合物（VOC）排放、人体安全且环境友善的涂料的需求日益增长，重塑了行业的优先事项。虽然涂料的主要作用是保护表面免受环境破坏，但现在它们必须在不损害生态系统的情况下做到这一点。

这种矛盾带来了前所未有的挑战——整个产业努力平衡两个看似相互矛盾的目标：毫不妥协的耐久性和可持续性。

化学蕴藏着无限可能。透过选择合适的成分，我们可以取代有害成分，迈向更绿色、更健康的未来。这项转变由不断演变的涂料配方法规引导，使涂料的安全性和毒性显著降低。

然而，尽管环保涂料取得了长足进步，但实现 100% 生物降解仍然不切实际，因为这会损害其主要功能。这给我们带来了一个关键挑战——如何管理无法使用或无法销售的材料以及生产过程中产生的副产品。今天的讨论重点是如何找到对环境负责的解决方案，以确保这些材料得到可持续的处理。

sustainability by reducing replacement costs, time, and effort. This, in turn, alleviates the strain on fuel, water, labour, natural resources, and the environment. By minimising resource extraction, mining, pollution, and carbon footprint, coatings contribute to a more sustainable future.

Coatings play a crucial role in environmental sustainability by extending lifespan, enhancing durability, and improving weather resistance across various applications, from bridges and ships to aircraft, electronics, machinery, and homes.

Durability ingredients & manufacturing challenges: molecular composition, formulas, and sustainability concerns

To maintain peak performance in functionality and application, coatings have undergone significant transformations over the years — evolving to meet both cost-efficiency and long-lasting durability demands. Through advancements in hydrocarbon chemistry and molecular engineering, achieving ultra-durable coatings became possible, effectively addressing challenges related to both cost and longevity.

However, this success introduced new complexities — biodegradability, greenhouse effects, and cradle-to-grave responsibilities. The rising demand for coatings with lower VOC emissions, human-safe properties, and environmental friendliness reshaped industry priorities. While coatings primarily serve to protect surfaces from environmental degradation, they must now do so without harming the ecosystem.

This paradox presents an unprecedented challenge — an industry striving to balance two seemingly contradictory goals: uncompromising durability and sustainability.

With chemistry, possibilities are endless. By selecting the right ingredients, we can replace harmful components and transition toward a greener, healthier future. This transformation is guided by evolving regulations that govern what goes into paint formulations, making paints significantly safer and less toxic.

However, despite advancements in eco-friendly coatings, achieving 100% biodegradability remains impractical, as it would undermine their primary function. This brings us to a critical challenge — managing unusable or unsellable materials, along with byproducts generated during production. Today's discussion focuses on finding environmentally responsible solutions to ensure that these materials are handled sustainably.

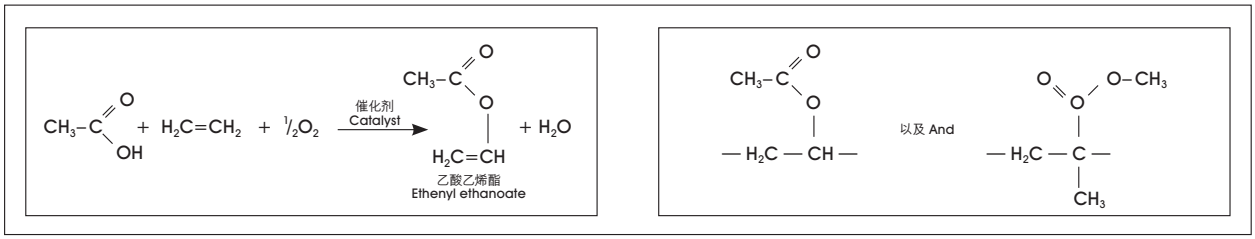

图 4：基料和树脂的分子式
Figure 4: Molecular formula of binders and resins

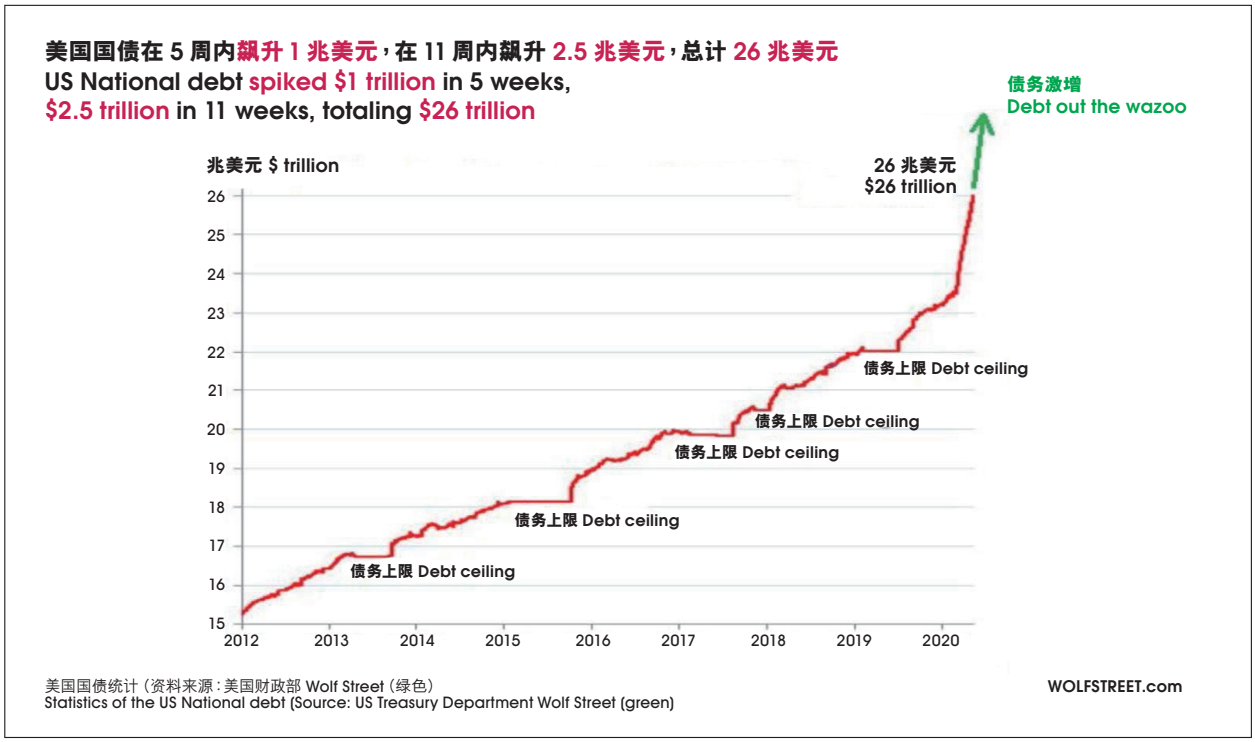

图 5：美国国债统计数据
Figure 5: Statistics of the US National debt

富足时代：经济可持续性及其连锁反应

可持续性不仅仅是一个环境问题，它还具有重大的经济影响。全球经济格局如何演变？这转变又将我们引向何方？

我们正生活在一个富足的时代，金融体系将看似无限的可能性变成现实。法定货币的主导地位使得人们可以不受限制地开采自然资源，从而推动了便利的生活方式。然而，科技与经济的紧密联系不可避免地会影响生态环境。

如果没有足够的资产或商品作为支撑，货币的创造可能会导致严重的通膨后果，破坏国家和经济的稳定。循环经济，一个革命性的框架，其设计不仅是为了对抗碳足迹，还可以作为通膨对冲工具，稳定价格，并确保有需要的社区能够公平地获得基本资源。

油漆废弃物管理的挑战与困境

目前，超过 95% 的油漆废弃物要么被填埋，要么用于燃料混合，仅有少量举措来缓解这一问题。废弃物的产生主要集中在两个领域：

家庭与零售废弃物

近期，公私合作、协会以及政府支持的计划（例如 PaintCare、PaintBack 和 ProductCare）的发展在改善油漆废弃物管理方面发挥了十分重要的作用。运输和回收公司

The era of abundance: economic sustainability and its ripple effects

Sustainability is not just an environmental concern — it carries significant economic implications. How has the global economic landscape evolved, and where has this transformation led us?

We are now living in the era of abundance, a time when financial systems make seemingly limitless possibilities a reality. The dominance of fiat currencies has enabled unrestricted extraction of natural resources, fueling convenient lifestyles. However, the intertwined relationship between technology and the economy inevitably impacts ecology.

The creation of currency, when not backed by adequate assets or goods, can lead to severe inflationary consequences, destabilising nations and economies. Enter the Circular Economy, a revolutionary framework designed not only to combat carbon footprints but also to serve as an inflation hedge, stabilise prices, and ensure equitable access to essential resources within communities in need.

Challenges and struggles in paint waste management

Currently, over 95% of paint waste is either disposed of in landfills or used in fuel blending, with only marginal initiatives in place to mitigate this issue. Waste generation occurs in two primary areas:

Household & retail waste

Recent developments in public-private partnerships,

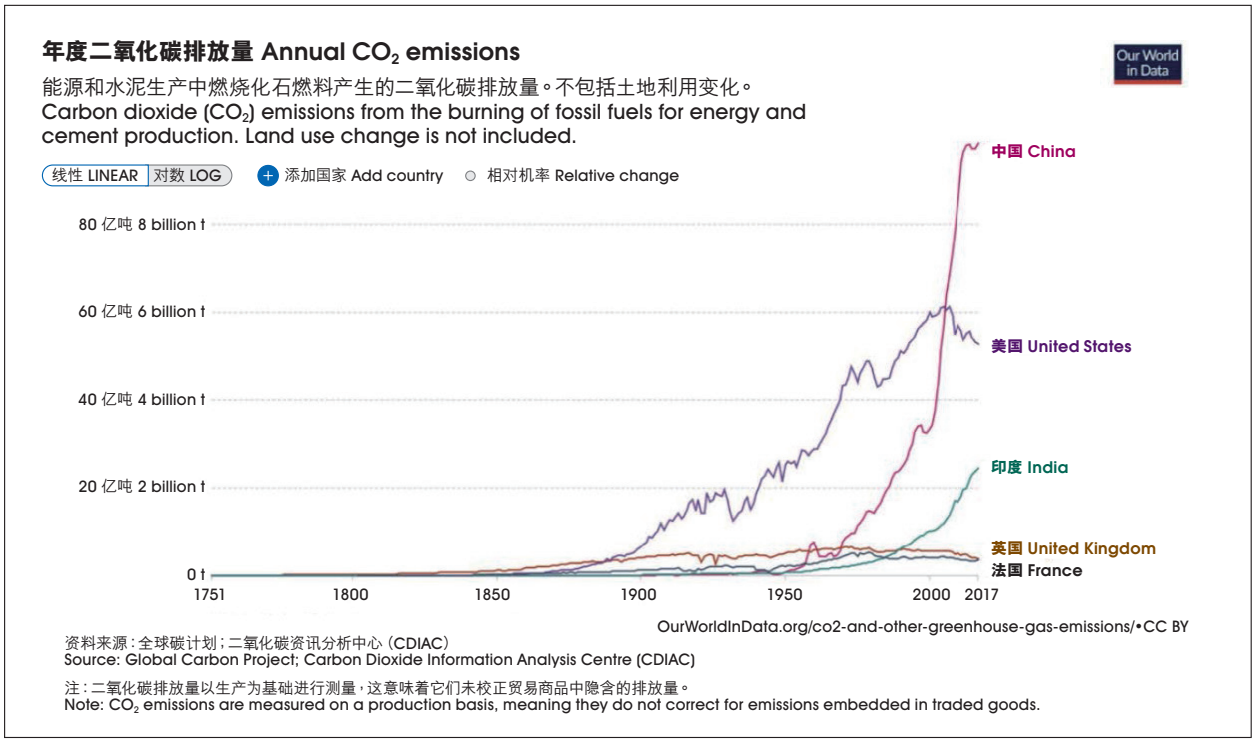

图 6：二氧化碳排放数据
Figure 6: CO_2 emissions data

与收集中心合作，回收废弃物中的材料并将其重新整合到产品管理中。

然而，尽管做出了这些努力，仍有相当一部分油漆废弃物最终被燃料燃烧和掩埋。目前，美国只有 20 至 25% 的州透过家庭危险废弃物（Household Hazardous Waste, HHW）或独立 HHW 回收计划所覆盖，这使得大多数溶剂型涂料和危险涂料容易被燃料混合。尽管法规更新、决策和专案改进有助于取得进展，但废弃物的产生率仍然远远超过控制能力。

工业涂料和原料废料

在涂料和原料产业，多种因素导致滞销或无法使用的库存积压，包括：配方变更；收购、并购和清算；破产、所有权转让和品牌重组；不断变化的法律要求；自然灾害。

此外，作为日常业务运作的一部分，涂料生产本身会产生不合格材料、过期产品和退货。虽然零售包装产品通常透过捐赠、拍卖或折扣销售的方式重新利用，但大多数工业涂料废料仍然会被填埋或用于燃料混合。

解决这个问题需要系统性的改进，包括扩大回收计划、加强监管以及创新的处置解决方案，以减少对环境的影响。

循环再利用：减少废弃物的关键策略

循环经济框架强调了涂料生命周期各个阶段产生的废弃物：提取和原料生产；工厂涂料制造；分销和零售；施工和使用。

associations, and government-backed programs — such as PaintCare, PaintBack, and ProductCare — have played a crucial role in improving paint waste management. Transport and recycling companies collaborate with collection centres to recover and reintegrate materials from the waste stream into product management.

However, despite these efforts, a significant portion of paint waste still ends up in fuel burning and landfills. Currently, only 20-25% of states have coverage through Household Hazardous Waste (HHW) or Independent HHW recycling programs, leaving the majority of solvent-based and hazardous coatings susceptible to fuel blending. While regulatory updates, decision-making, and programme enhancements contribute to progress, the rate of waste generation continues to far exceed containment capabilities.

Industrial paint & raw material waste

Within the paint and raw-material industries, several factors contribute to the accumulation of unsaleable or unusable inventory, including: Changes in formulations; Acquisitions, mergers, and liquidations; Bankruptcies, ownership transfers, and brand restructuring; Evolving legal requirements; Natural disasters.

Additionally, paint production inherently generates off-spec materials, expired products, and returned items as part of routine business operations. While retail-packaged products are often repurposed through donations, auctions, or discounted sales, a majority of industrial paint waste still finds its way into landfills or fuel blending.

Addressing this issue requires systematic improvements, including expanded recycling programmes, stronger

透过回收每个阶段的材料，这些材料可以重新融入新产品中，从而减少浪费并增强可持续性。除了循环再利用的实际益处之外，慈善计划、捐赠以及荣誉、可持续发展和企业社会责任（Corporate Social Responsibility, CSR）认证等措施在减少燃料混合和垃圾掩埋依赖方面发挥关键作用，从而推动对环境负责的解决方案。

将废弃物转化为可重复利用的资源：一种颠覆性的方法

将废弃物转化为可重复利用的材料是一个多步骤的过程，可确保产品得到有效的再利用，而不是被丢弃。此方法围绕着五个基本阶段：

- 识别——工厂内必须辨识可能重复使用的物品，并以结构化的方式指定回收点。
- 分类——收集后，这些材料必须正确分类为可用产品而非废弃物。
- 储存——为防止物品被当作废弃物处理，其储存位置必须与可销售产品并列，从而将其与废弃物流分开。
- 贴标——这些物品被分类为可重复使用，这意味着它们应贴上可重复使用产品的标签。避免使用与废弃物相关的标签，例如「废料」或「处置」，以强调其重新进入流通领域的可能性。
- 循环再利用：「按原样」——最关键的一步：以原始状态重复使用材料，不改变其成分、不焚烧、不提取或处置任何组件。当物品以其预期状态被利用时，它就成为循环经济的一部分，作为产品而非废弃物继续发展。

透过实施这一五阶段策略，我们不只是将废弃物重新用于有用的用途，还重新定义了它的身份，将废弃材料转化为有助于可持续发展的宝贵资源。

了解美国《联邦法规》第 40 条 (40 CFR) 的例外：废弃物分类与循环再利用

美国环保署（United States Environmental Protection Agency, EPA）的《联邦法规》第 40 条（40 CFR）法规在定义固体废弃物分类例外情况方面发挥着十分重要的作用，尤其是在与前述五阶段再利用模型相关的方面。

《联邦法规》第 261.2 条中的两项关键判定强调了危险二次材料（HSM）不被视为固体废弃物的情况：

- 工业制程中的使用 / 再利用：> HSM 是否直接用作工业制程中的配料，还是作为商业产品的有效替代品？> 如果是，则根据《联邦法规》第 261.2(e) 条，它不属于固体废弃物。> 如果不是，则继续进行下一步判定。
- 回收和有用产品回收：> HSM 是否经过加工以回收有用产品？它是商业化学产品、特征副产品还是特征污泥？ > 如果是，则根据《联邦法规》第 261.2(c)(3) 条，它不属于固体废弃物。

regulations, and innovative disposal solutions to reduce environmental impact.

Circular reuse: a key strategy for waste minimisation

The circular economy framework highlights how waste is generated throughout various stages of the paint lifecycle: Extraction and raw material production; Paint manufacturing in factories; Distribution and retail sales; Application and use.

By recovering materials from each phase, these items are reintegrated into new products, reducing waste and enhancing sustainability. Beyond the practical benefits of circular reuse, initiatives such as charitable projects, donations, and certifications in Honour, Sustainability, and Corporate Social Responsibility (CSR) play a pivotal role in minimising fuel blending and landfill dependency — driving environmentally responsible solutions.

Transforming waste into reusable resources: a game-changing approach

Converting waste into reusable materials is a multi-step process that ensures that products are repurposed effectively rather than discarded. This method revolves around five essential stages:

- Identification — Potentially reusable items must be recognised within the factory and designated for collection in a structured manner.
- Categorisation — Once collected, these materials must be properly categorised as usable products rather than waste.
- Storage — To prevent items from being treated as waste, their storage location must be shifted alongside sellable products — separating them from waste streams.
- Labelling — These items are classified for reuse, meaning they should be labelled as viable products. Avoid waste-related labels such as "scrap" or "disposal" to reinforce their potential for re-entry into circulation.
- Circular Reuse: "As It Is" — The most critical step: reusing materials in their original form without altering composition, burning, extracting, or disposing of any components. When an item is utilised in its intended state, it becomes part of the circular economy, moving forward as a product, not waste.

By implementing this five-stage strategy, we don't just redirect waste into useful applications — we redefine its identity, turning discarded materials into valuable resources that contribute to sustainability.

Understanding U.S. 40 CFR exceptions: waste classification & circular reuse

The EPA's 40 CFR regulations play a crucial role in defining exceptions to solid waste classifications, particularly in relation to the five-stage reuse model outlined earlier.

Two key determinations from 40 CFR 261.2 emphasise when Hazardous Secondary Materials (HSM) are not considered solid waste:

- Use/Reuse in Industrial Processes: > Is the HSM directly

可重复使用物品图表：原料、成品、洗涤溶剂、过期库存和剩余物品

透过在循环再利用模型中应用这些例外情况，业界可以优化废弃物管理，同时符合监管标准。

可重复利用材料的处理：材料接收后，进行分类、散装处理和生产整合，并经过结构化流程以优化其再利用：

- 分类——产品根据其溶剂和树脂成分、密度、相容性、颜色、光泽和粘度进行分类，以确保高效地融入生产。
- 散装处理——均质、分类好的材料被整合到 1,000 公升的 IBC 容器中，用于大规模生产批次。
- 生产利用——这些散装物料以 30% 到 80% 的比例纳入制造流程，与其它化学品混合，以生产可行的高质量产品。

所有新产品一旦完成，就会推出市场，保持竞争力并产生正面的价值。每种产品都有其明确的用途和用途，强化了高效资源管理和可持续再利用的原则。

美国环保署更倾向于回收，而非土地掩埋和燃料混合

美国环保署（EPA）积极推广回收利用，将其作为垃圾掩埋和燃料混合的更可持续替代方案。多项措施支持循环

used as an ingredient in an industrial process or as an effective substitute for a commercial product? > If YES, it is not classified as solid waste under 40 CFR 261.2(e). > If NO, proceed to the next determination.

- Reclamation & Useful Product Recovery: > Is the HSM processed to reclaim a useful product, and is it either a commercial chemical product, a characteristic byproduct, or characteristic sludge? > If YES, it is not classified as solid waste under 40 CFR 261.2(c)(3).

Chart of reusable items: raw materials, finished goods, wash solvents, expired inventories, and surpluses

By applying these exceptions within circular reuse models, industries can optimise waste management while aligning with regulatory standards.

Processing reusable materials: sorting, bulk handling, and production integration upon receipt, materials undergo a structured process to optimise their reuse:

- Sorting — Products are categorised based on their solvent and resin composition, density, compatibility, colour, sheen, and viscosity, ensuring efficient integration into production.
- Bulk Handling — Homogeneous, sorted materials are consolidated into 1,000-litre IBC totes for use in large-scale production batches.
- Utilisation in production — These bulked items are incorporated into manufacturing processes at a 30%

图 7：涂料基础循环经济图表
Figure 7: Circular economy chart of the paint foundation

图 8：涂料生产中的关键成分
Figure 8: Key ingredients in paint production

经济中的废弃物捐赠：

- 减量与再利用基础知识——美国环保署指南：https://www.epa.gov/recycle/reducing-and-reusing-basics
- 慈善捐赠指南：https://www.consumer.ftc.gov/articles/0074-giving-charity

即使捐赠材料，也属于回收；但是，如果将材料运送至土地掩埋，则仍然属于废弃物处理，只是延缓了环境影响，而不是消除了影响。

to 80% ratio, blending with other chemicals to create viable, high-quality products.

Once finalised, all newly produced items are introduced to the market, maintaining competitiveness and generating positive value. Each product serves a defined utility and purpose, reinforcing the principles of efficient resource management and sustainable reuse.

EPA's preference for recycling over land burial and fuel blending

The EPA actively promotes recycling as a more sustainable alternative to landfill disposal and fuel blending. Several initiatives support waste donation within the circular economy:

- Reducing and reusing basics – EPA guidelines: https://www.epa.gov/recycle/reducing-and-reusing-basics
- Charity guidelines for donations: https://www.consumer.ftc.gov/articles/0074-giving-charity

Recycling occurs even when materials are donated; however, if they are transported for land burial, it is still waste disposal, merely delaying environmental impact rather than eliminating it.

Waste can be recycled if solid and liquid materials are used as fuel with burning credits. However, pigments, resins, and essential solvents are not integrated into circular reuse — they remain classified as waste.

Recycling transitions into a circular economy when solvents or water are extracted through distillation. Yet, even after this process, the remaining materials still qualify as waste.

However, when materials are repurposed directly and used as-is in batches for coating production, they retain their functionality and become products rather than waste — fulfilling true circular economy principles.

In this framework, disposal transforms into donation,

如果固体和液体材料被用作具有燃烧信用额度的燃料，则可以回收废物。然而，颜料、树脂和必需溶剂并未纳入循环再利用，它们仍被归类为废弃物。

当透过蒸馏萃取溶剂或水时，回收利用就转变为循环经济。然而，即使经过这一过程，剩馀的材料仍然属于废物。

然而，当材料被直接重新利用并按原样批量用于涂料生产时，它们将保留其功能并成为产品而非废物——这真正体现了循环经济原则。

在此框架下，处置转化为捐赠，回收演变为慈善，将废弃物管理重新定义为可持续发展的机会，而不仅仅是缓解环境污染。

涂料回收的协作贡献：产业、协会和政府伙伴关系

涂料回收的成功取决于产业、协会、个人顾问和政府之间强有力的伙伴关系。

- 涂料工厂——在生产过程中创新并实施回收方法。
- 协会——作为产业领袖协作、交流想法并提出应对环境挑战解决方案的集体平台。
- 个人顾问——提供专业知识和见解，以优化回收框架。
- 政府——制定政策、法规和激励措施，以支持可持续实践。

透过产业、协会和政府的合作，建立了全面的涂料回收解决方案，有助于推动可持续发展、减少浪费并创造更环保的未来。

废弃物最小化的好处：推动涂料产业的可持续发展

减少油漆涂料产业的废弃物不仅是环保的必需，更是可持续发展和经济平衡的关键驱动力。废弃物最小化的优点包括：

- 降低碳足迹——减少与生产和处置相关的排放。
- 减轻温室效应——最大限度地减少导致气候变迁的环境污染物。
- 减少油漆生产中的废弃物——优化材料使用，防止产生过多的垃圾掩埋场。
- 减少自然资源开采——保护原料并限制资源枯竭。
- 抗通膨影响——透过优化生产成本来支持经济稳定。
- 价格实惠、触手可及的涂料——确保服务不足的社区也能获得优质涂料。
- 更绿色、更健康、更可持续的未来——支持环境责任，实现长期效益。

油漆涂料的循环再利用不仅仅是一种环保解决方案——它还在业界建立了可持续的生命周期平衡。

如果减少浪费的努力不够，那么这个过程就不是真正完成的——总是有更多的地方需要改进和完善。

and recycling evolves into charity, redefining waste management as an opportunity for sustainability rather than mere mitigation.

Collaborative contributions to paint recycling: industry, associations & government partnerships

The success of paint recycling depends on strong partnerships between industries, associations, individual consultants, and governments.

- Paint factories — innovate and implement recycling methods within production processes.
- Associations — serve as collective platforms where industry leaders collaborate, exchange ideas, and propose solutions to environmental challenges.
- Individual consultants — provide expertise and insights to optimise recycling frameworks.
- Governments — develop policies, regulations, and incentives to support sustainable practices.

Through industry-association-government collaboration, comprehensive paint recycling solutions are established — helping drive sustainability, reduce waste, and create a more environmentally responsible future.

The benefits of waste minimisation: driving sustainability in the coatings Industry

Reducing waste in the paint and coatings industry is not just an environmental necessity — it is a key driver of sustainability and economic balance. The advantages of waste minimisation include:

- Lower carbon footprint — reducing emissions associated with production and disposal.
- Mitigating greenhouse effects — minimising environmental pollutants that contribute to climate change.
- Less waste in paint manufacturing – optimising material use to prevent excess landfill contributions.
- Reduced extraction of natural resources — preserving raw materials and limiting resource depletion.
- Anti-inflationary impact — supporting economic stability by optimising production costs.
- Affordable and accessible coatings — ensuring that quality coatings remain within reach for underserved communities.
- Greener, healthier, and more sustainable future — supporting environmental responsibility for long-term benefits.

The circular reuse of paints and coatings is more than just an eco-friendly solution — it establishes a sustainability life cycle balance within the industry.

If waste minimisation efforts fall short, then the process isn't truly complete — there's always more to refine and improve.