Chemical content validation of recycled plastics

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Executive Summary

Recent landmark reports find that plastics may contain over 13,000 chemicals including intentionally added substances (e.g. plasticisers, fillers, flame retardants) and non-intentionally added substances (NIAS), several of which may be of concern to human health or the environment. Chemicals of concern can persist and accumulate in recycled plastics, potentially leading to increased toxicity compared to virgin plastics. However, it can be difficult to determine the chemical content of recycled material to ensure chemical safety.

Standards, certifications, and quality control measures for recycled plastics exist at multiple levels:

- **Product-focused schemes** (e.g. EN 15343, APR PCR) ensure traceability, recycled content documentation, and compliance with some regulatory limits but generally do not set chemical substance thresholds.
- **Process-focused certifications** (e.g. ISO 15270, ASTM D5577-19, RecyClass) promote quality control, contamination minimisation, and analytical testing practices.
- **System-level traceability and ecolabels** (e.g. RecyClass Traceability, Blue Angel, ISCC) track recycled content and sustainability claims but do not mandate comprehensive chemical analyses.

Analytical techniques for chemical detection include chromatography, mass spectrometry, infrared and Raman spectroscopy, ICP-MS, XRF, and thermal analyses, often combined to achieve complementary coverage. Targeted analyses can be used to detect known substances, while non-targeted analyses examine a wide range of compounds without predefined targets.

Because no single analytical technique can detect all possible substances, recyclers combine complementary methods, balancing broad non-targeted screening with more selective targeted analyses. The extent of testing and industry practices varies widely since bulk recyclers often perform limited target testing, while specialised recyclers for high-end or customer-specific applications (e.g. food or medical use) require extensive combined analyses guided by regulatory or customer requirements.

Challenges and limitations are substantial:

- **Economic:** Establishing and operating laboratories capable of comprehensive chemical analysis requires high upfront investment and ongoing costs for highly skilled personnel while automation options are limited.
- **Technical:** No single technique can detect all substances present in recycled plastics. The heterogeneity of samples, limitations of detection and quantification, and the presence of complex chemistries, such as enantiomers (optical isomers, mirror opposite chemical structures), further complicate reliable chemical analyses.
- **Practical:** Comprehensive chemical testing is time-consuming and cannot be easily scaled to continuous industrial processes. Impurities and contaminants in recycled plastics may interfere with detection methods and, in some cases, even damage analytical equipment.
- **Regulatory:** There are no internationally harmonised standards that establish comprehensive chemical analysis requirements for recycled plastics. Enforcement is inconsistent, and traceability

of imported plastic waste streams remains limited, which increases the risk of chemicals of concern entering the recycled material supply chain.

Main obstacles to understanding chemical safety include limited transparency and traceability along value chains of virgin and recycled plastic for both intentional inputs and process chemicals, the diversity and potentially harmful properties of non-intentionally added substances, inadequate elimination of chemicals of concern during recycling, and insufficient material testing capabilities.

Overall, ensuring chemical safety in recycled plastics requires an integrated approach combining harmonised international standards, robust analytical techniques, chemical traceability systems, economic incentives, and research collaboration, enabling safe circularity while maximising recycling rates.

Potential policy options that could be further analysed to address these challenges include:

- Upstream and design measures including investigating reduction of chemical composition complexity per application type, restricting problematic chemicals and designing with both recycling and chemical selection consequences in mind.
- Improving transparency of chemical content of plastic products (e.g. disclosure requirements, harmonised reporting formats, product passports).
- Strengthening downstream measures such as expansion of source-separation collection, supporting pursuit of closed-loop recycling systems and further developing and scaling-up advanced recycling technologies.
- Developing internationally recognised standards with chemical content analysis requirements and test protocols.
- Supporting chemical identification and analysis of recycled plastics through collection of targeted levies, collaborative material screening chemical databases and research partnerships.

It is acknowledged that current knowledge of the potential human health and environmental risks from chemicals of concern in recycled plastics has limitations and uncertainties. Therefore, future policy decisions should be informed by careful cost–benefit and socio-economic analyses that integrate scientific evidence on potential health and environmental impacts in order to assess the overall appropriateness of proposed measures.

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Terminology

Term	Definition
Additives	Chemicals intentionally incorporated into plastics to impart specific properties (e.g. stabilisers, plasticisers, colourants), but which may become contaminants in recycled plastics after the first life cycle
Analysis	Systematic examination of plastic to determine chemical composition, structure, or properties, using scientific techniques
Analyte	Substance whose chemical constituents are being measured in an analytical procedure
Characterisation	Detailed analysis and description of the identity and structural properties of a substance in a plastic sample
Chemical content validation	The process of confirming that the chemical composition of recycled plastics meets regulatory, safety, or specification requirements
Chemicals	General term for substances or compounds with defined molecular or elemental structure, encompassing everything from impurities to monomers, polymers and additives
Compounds	A subset of substances, referring to pure chemical entities of two or more bonded elements
Contaminants	Unwanted substances present in recycled plastics including breakdown products, pollutants, and chemicals that were originally used or present in a plastic product that was recycled, that may compromise safety or regulatory compliance
Detection	Establishing the presence or absence of a substance within a plastic sample
Downcycling	Downcycling entails a transformation process of waste into secondary raw materials where recovered materials are of an inferior quality and can only be used as an input in a limited subset of applications
Elements	Pure chemical substances consisting of a single type of atom (e.g. lead, cadmium, mercury). Often regulated in plastics as heavy metals
Identification	Assigning a chemical identity and structure to a detected substance within the sample, using analytical data and reference libraries to confirm
Intentionally added substances (IAS)	Substances that are deliberately introduced during plastic manufacturing to achieve specific technical functions, such as improving flexibility, colour, stability, or processability
Non-intentionally added substances (NIAS)	Substances that are unintentionally present in plastics, typically arising as impurities, reaction by-products, degradation products, or contaminants formed during processing, use, or recycling
Plastic wastes	Discarded plastic materials or products that are disposed of, intended to be disposed of, or required to be disposed of under national law, generally consisting of a mix of materials
Post-Industrial Recycled (PIR)/Pre-Consumer Recycled	Recycled from waste generated during the manufacturing process.
Post-Consumer Recycled (PCR)	Recycled from waste generated by commercial, industrial, or institutional facilities or waste generated by households as end-users of a product
Primary plastics	Primary (or virgin) plastics are manufactured from fossil-based (e.g. crude oil) or biobased (e.g. corn, sugarcane, wheat) feedstock that has never been used or processed before.
Quantification	Measurement of the exact amount or concentration of a chemical substance

	in a plastic sample
Recyclate	Another term for recycled plastics used in industry and standards
Secondary (recycled) plastic	Plastic polymers made from recycled material
Substances	Broad regulatory term for a chemical element or its compounds

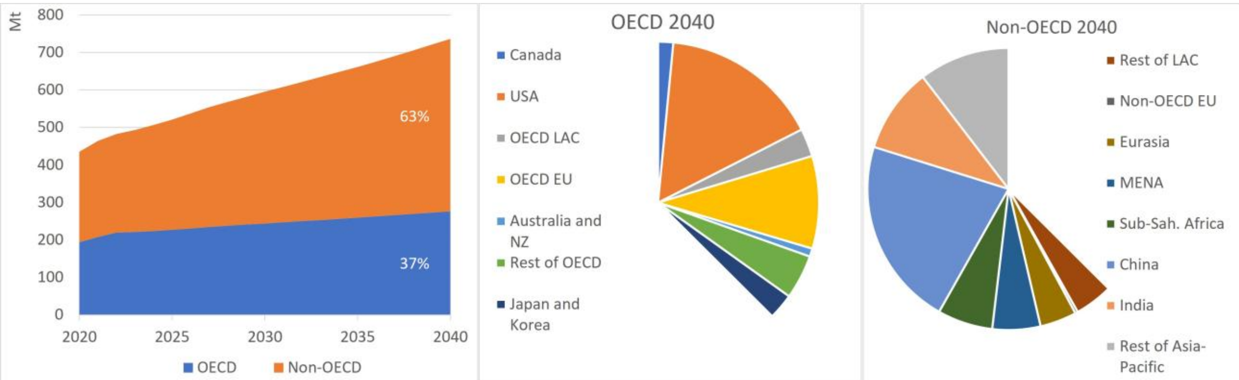
1 Background

Global production and demand for plastics reached 435 million tonnes (Mt) in 2020 (OECD, 2022a). Projections based on current trends of population growth and higher incomes lead to a 70% increase in annual plastics production and use in 2040, from 435 Mt in 2020 to 736 Mt in 2040. Plastics use is projected to increase in all regions and is expected to grow fastest in India and Sub-Saharan Africa, while China is expected to remain the region with the highest share of global plastics use (22%). Although the share of global plastics use in OECD countries is expected to decline, plastics use is still projected to grow in OECD countries, as well as in non-OECD Latin American and Eurasian countries (Figure 1) (OECD, 2024).

Plastics are versatile materials that are used across multiple applications and sectors, including, in order of volume, packaging, transportation, other, building and construction, textiles, consumer and institution products, electrical/electronic and industrial/machinery (OECD, 2024). While plastics deliver many benefits to society, the chemical components of plastics can have negative impacts on human health and the environment and thus need to be appropriately risk managed.

Figure 1. Plastics use is projected to grow by more than two-thirds worldwide

Global plastics use in million tonnes (Mt) (left-hand panel), and by regions (right-hand panels)



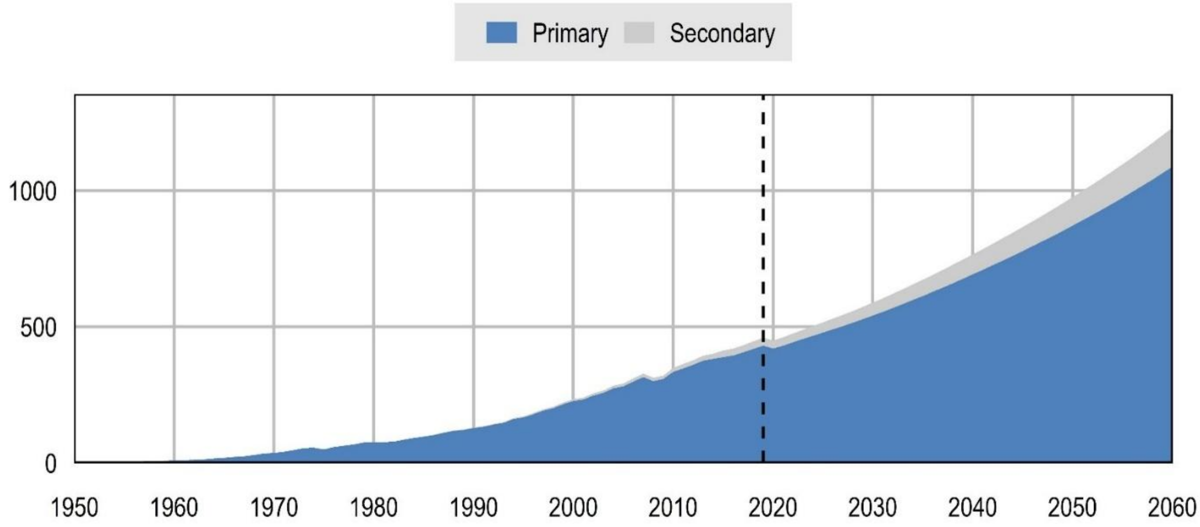
Notes:
1. In the left-hand panels, regional shares in total in 2040 are indicated in data labels.
2. The rapid growth in 2021 and (to a lesser extent) 2022 reflects the recovery from the COVID-19 crisis.
Source: OECD (2024), *Policy Scenarios for Eliminating Plastic Pollution by 2040*, OECD Publishing, Paris, https://doi.org/10.1787/76400890-en.

The background information presented here is to provide context for the topic of chemical content validation of recycled plastics, the specific scope of this report. The reader is directed to more detailed analysis of plastic and plastic recycling related topics in OECD reports such as the Global Plastic Outlook (OECD, 2022a,b), Policy Scenarios for Eliminating Plastic Pollution by 2040 (OECD, 2024) and Plastics recycled content requirements (Brown and Börkey, 2024), amongst others. Also, it is noted that scope of this report does not include comparison of similar issues for other material types (glass, paper, wood etc.).

Plastic waste recycling is a key strategy for achieving a circular economy, but its effectiveness depends not only on the type and design of plastic products, such as whether they are rigid or flexible, mono-material or multi-material, but also on the social systems for collecting and processing plastic waste, which are not yet fully developed in many regions (Nordahl and Scown, 2024). Flexible packaging and multi-layered plastics are especially difficult to sort and carry a high risk of contamination, which lowers recyclate quality and reduces yields (Darko et al., 2023). As a result, global recycling rates remain low: in 2023, Plastics Europe estimated that only 8.7% of the 413.8 Mt of plastic produced worldwide came from post-consumer mechanically recycled sources, while chemically recycled plastics accounted for just 0.1% (Plastic Europe, 2024). Although secondary plastics are expected to grow at a faster rate in the coming decades, they are still projected to represent only 12% of total plastics use by 2060 (Figure 2), up from 6% in 2019 (Nordahl and Scown, 2024).

Figure 2. Primary and secondary plastics production in million tonnes (Mt)

Baseline scenario projection (no new policy interventions), 1950-2060



Note: Primary plastics include both fossil-based plastics and biobased plastics. Secondary plastics are made from recycled materials
Source: OECD, 2022b

Mechanical recycling remains the primary approach for plastic waste management, particularly for thermoplastics, due to its lower environmental impact and established infrastructure. Its efficiency, however, depends heavily on a high-purity input, which limits its applicability to mixed, degraded, or contaminated waste streams. Chemical recycling technologies can depolymerise polymers into reusable monomers, including food-grade outputs. While potentially promising, chemical recycling technologies are still under development and currently have higher economic operating costs and environmental impacts than mechanical routes since current systems require higher energy input and more complex processing steps (Plastic Europe, 2025), (Jeswani et al., 2021).

Solvent-based purification technologies are emerging as a potential enhancement to mechanical recycling. These methods can remove dyes, additives, and other contaminants from polymers such as polypropylene (PP), expanded polystyrene (EPS) or extruded polystyrene (XPS) improving recyclate quality and removing potential substances of concern. Though still in early stages, pilot plants have shown positive results, suggesting that solvent dissolution could become economically viable with further scale-up (Plastic

Europe, 2025). The economic performance and CO2 emissions of the technologies also varies and is a consideration during uptake (Caudle, Nguyen and Kataoka, 2025).

While chemical recycling technologies are mainly being developed in high-income countries (HICs), the informal recycling sector remains central to plastic waste recovery in many low- and middle-income countries (LMICs). Informal waste pickers and small-scale recyclers recover large volumes of recyclable materials and provide essential environmental services, yet they often do so without legal recognition, social protection or safe working conditions (Velis et al., 2022). It is important that the realities and perspectives of informal workers themselves guide any transition in recycling systems and protection of livelihoods and health must be prioritised, in line with the International Labour Organization's (ILO) recommendation on the transition from the informational to the formal economy, these workers have the fundamental right to safe and healthy working environment (ILO, 2015).

An increase in the use of recycled plastics, particularly from post-consumer waste, highlights the need for effective and safe recycling technologies, as well as careful material and product design that avoids problematic chemical content. Key challenges include ensuring traceability from point of origin, addressing potential contamination, and overcoming the technical limitations of recycling processes when treating mixed, degraded, or soiled plastic waste streams (Cimpan et al., 2023). Beyond these operational issues, chemical composition itself remains a major barrier since some legacy additives, stabilisers, flame retardants and plasticisers present in plastic waste are either substances of concern or non-compatible with modern recycling processes, complicating mechanical recycling routes (Carney et al., 2025). The persistence of chemicals of concern and polymers designed without recyclability in mind limits circularity and often results in downcycling or incineration rather than reuse (GRID-Arendal and IPEN, 2025).

Phasing out problematic substances and designing substitutes that maintain functionality without compromising safety are essential steps toward sustainable recycling systems. Expanding international standards and harmonised guidance for identification, traceability, and management of substances of concern in plastic streams will be crucial for scaling safe plastic circularity (Carmona et al., 2023).

The substances that can be found in virgin and recycled plastics include both intentionally added substances (IAS) and non-intentionally added substances (NIAS) (Aurisano, Weber and Fantke, 2021), (Wiesinger, Wang and Hellweg, 2021). According to the 2024 PlastChem State of the Science on Plastic Chemicals report, at least 16,325 chemicals are potentially used in or unintentionally present in plastics as monomers, additives, and processing aids. Of these, more than 4,200 chemicals have been identified as being of chemicals of concern because they exhibit persistence, bioaccumulation, mobility, and/or toxicity (PBMT) properties. Importantly, around 3,600 of these chemicals are currently not subject to international regulation, leaving significant governance gaps (Monclús et al., 2025). Some current-day NIAS can include legacy chemicals that are now regulated under the Stockholm convention. The UN Environment Programme's Chemicals in Plastic Report highlighted that more than 13 000 chemicals have been identified as associated with plastics and plastic production (UNEP, 2023a). The European Chemicals Agency Plastics Additive Initiative (ECHA, 2018) has also collected information on over 400 additives used in plastics in the EU at high volumes (above 100 tonnes per year). Also, the International Council of Chemical Associations (ICCA) has undertaken an effort to identify plastic additives used in the last 10 years by industry, and the associated physical chemical properties, hazard classifications and regulatory activities related to these chemicals. These have been compiled in the ICCA's Plastic Additives Database (ICCA, *n.d.*) of 13,375 chemicals, including 4,549 verified plastic additives in commerce. The numbers in these sources vary due to the scope of what is being captured but all point to the wide diversity of substances within the plastics sector.

Considering the intentionally added substances, the most common functional categories include colourants, processing aids, fillers, intermediates, lubricants, plasticisers, antioxidants, and flame retardants. In addition, NIAS are present in both virgin and recycled plastics and can be introduced throughout the plastic life cycle, including during production, use, recycling, and end-of-life processes.

Despite their prevalence, NIAS remain poorly characterised and represent a major information gap, underscoring the need for greater transparency and regulation across the plastics value chain (Wagner et al., 2024), (UNEP, 2023 a).

Given the potential risks posed by some NIAS, a comprehensive understanding of global chemical flows across multiple plastic life cycles is crucial. This insight enables the identification of cross-contamination with chemical additives, which can persist as unintended residues in recycled materials. It also facilitates more precise management of additive inputs tailored to specific product applications.

This understanding ultimately highlights the trade-offs between increasing recycling rates and reducing consumer and environmental exposure to chemical risks, such as cross-contamination and migration between plastic products.

Chemical substances in recycled plastic

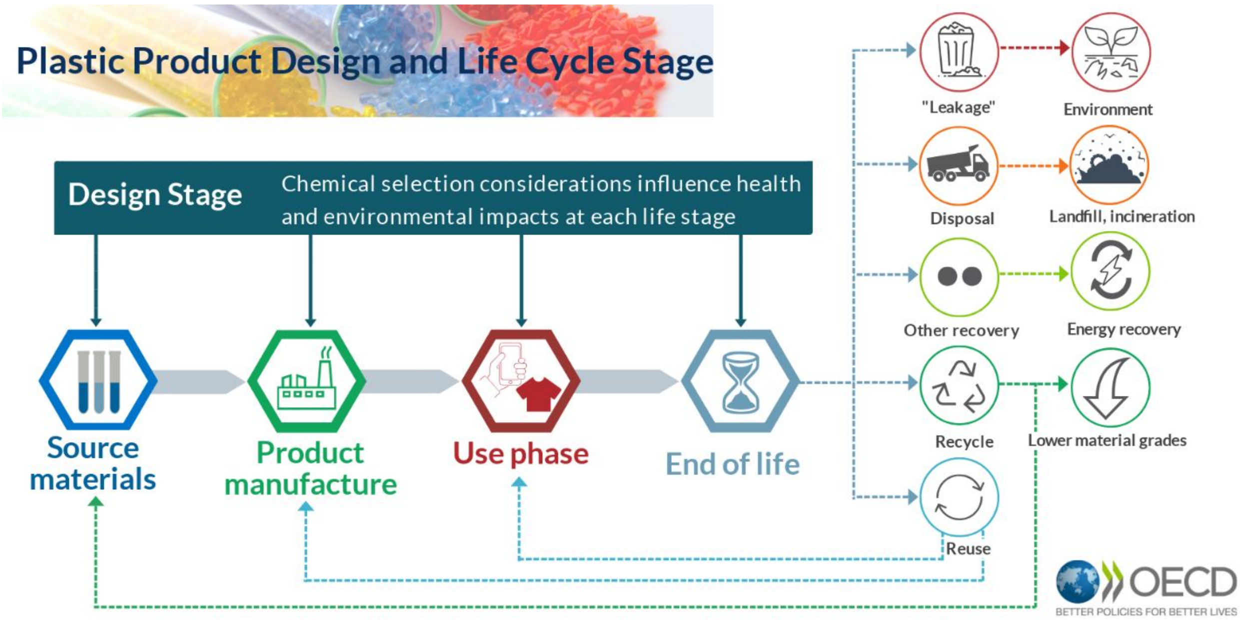
The key intended chemicals and contaminants present throughout the plastic materials lifecycle can be summarised as:

- Intentionally used polymers and monomers, including polymeric fractions and oligomers
- Additives (e.g. pigments, stabilisers, catalysts, fillers, recycling enhancers, please refer to paragraph above)
- Processing aids used during plastic conversion processes (e.g. catalysts, solvents, lubricants)
- Chemical contaminants from previous use (e.g. residues, odours, flavours)
- Contaminants introduced through mixed collection of waste polymers
- New substances formed during the recycling and degradation of polymers, including volatile organic compounds (VOCs), as well as reaction and decomposition products of additives (e.g. oxidation or other degradation products)

In the lifecycle of plastics, substances both intentionally and non-intentionally added can originate from three (potentially four) main phases: plastic production (primary and secondary) and product manufacturing processes, the previous use of plastics (and potential misuse), and waste management processes, particularly recycling processes. In addition, storage conditions during waste management, such as temperature, humidity, exposure to sunlight, and the duration of storage, can influence the presence, migration, or degradation of substances.

Figure 3 depicts at a high level that chemical selection considerations at the design stage of a plastic product can influence health and environmental impacts across the life cycle. Integrating sustainable chemistry thinking in the design process is key and is further detailed in A Chemicals Perspective on Designing with Sustainable Plastics: Goals, Considerations and Trade-offs (OECD, 2021).

Figure 3. Chemical selection considerations influence impacts across life cycle stages



Source: OECD

Substances introduced during the plastics lifecycle and present in recycled plastics

A variety of chemical substances are used in the production and processing of plastics. These include polymers, which are made from repeating monomer units; additives, which are used to maintain, enhance or impart specific properties (e.g. plasticisers to enhance flexibility, flame retardants to impart fire resistance); and processing aids used during plastic conversion processes (e.g. catalysts, solvents, lubricants). In addition to these intentionally used chemicals, many non-intentionally added substances (NIAS) can be present in plastics, including byproducts, breakdown products and contaminants. Thus, plastics contain many substances that are not chemically bound to the polymer matrix, including unreacted monomers, residual processing aids and additives.

Substances introduced during the use (and misuse) of plastics and waste management

The presence of contaminants in recycled plastics can result from the transfer of substances during the use phase of plastic products. Studies by Pivnenko et al. (2016) and Dutra et al. (2011) have highlighted phthalates as a primary class of contaminants originating from previous use and waste management. Some phthalates are chemicals of concern. These substances have been detected in water samples from polyethylene terephthalate (PET) bottles containing specific percentages of recycled content, and plastic waste samples (with a high content of PET) (Pivenko et al., 2016), (Dutra et al., 2011). The common presence of phthalates in rPET can arise from their transfer from other polymers during waste management, from intentional addition during transformation and manufacturing, and from incomplete removal during re-processing steps.

Apart from phthalates, other substances such as bisphenol A (BPA) have also been detected in recycled PET. While BPA contamination is often attributed to the mixing of various sources during recycling and waste management processes, cross-contamination can also occur during the manufacture of virgin PET. This may be due to environmental contamination within production facilities or the use of contaminated raw materials and processing equipment during PET synthesis (Geueke et al., 2023). Other esters and alcohols have also been detected in recycled high-density polyethylene (HDPE) (Dutra et al., 2011), likely due to packaging for liquids such as cleaning agents. In addition, residues from pharmaceuticals and pesticides have been identified in recycled polyethylene pellets, reflecting the diverse consumer and industrial uses of plastics prior to disposal (Carmona et al., 2023).

Misuse of plastic products by consumers can add another unpredictable range of chemical contaminants to the plastics waste stream as for example, if food-grade plastic containers are used for storage of other types of chemical products. Also, the inclusion of environmental plastic or ocean bound plastics in waste management streams creates additional uncertainty in chemical composition (FCMJEG, 2025).

Substances and contaminants formed during recycling processes

The specific process steps in mechanical recycling can vary depending on the polymer type, its previous use, and the intended application of the recycled material. Generally, the process begins with size reduction, such as cutting or shredding, followed by cleaning treatments using detergents and surfactants to remove surface contaminants. However, these pretreatment stages can also be sources of worker and environmental chemical exposures, as dusts, microplastics, volatile organic compound, and residues may be released during shredding and washing (European Environment Agency, 2023). These preparatory steps precede a controlled thermal phase, where post-consumer plastics waste is heated to a level sufficient to soften the material and facilitate filtering, while minimizing degradation, in order to facilitate further processing. As a result of these processes, residual or newly formed substances might be present in the recycled materials, and recycled polymers often have lower molecular weights and altered mechanical properties compared to primary raw materials.

There are three main types of new substances that can occur in plastics during mechanical recycling processes: by-products, reaction products and substances derived from contamination/cross-contamination.

- By-products formed during recycling and thermal degradation of polymers, such as oligomers, have been found in recycled plastics such as PET (Ares-Pernas et al., 2014). By-products also include derived substances such as acetophenone (Geueke, Groh and Muncke, 2018) or volatile NIAS (Song et al., 2019) observed in recycled plastic samples compared to virgin samples.
- Chemical reactions and transformations during plastic recycling processes can lead to the formation of new substances. These may originate from previously added components, such as plasticisers or stabilisers, or from contaminants present in the plastic waste (Dutra et al., 2014). In the case of stabilisers, reactions are intentional to protect polymer chains during recycling processes.
- Apart from undesired reactions and generation of by-products, cross-contamination can cause the transference of specific substances from recycled plastics and products. For instance, flame retardants, such as the legacy flame retardant hexabromocyclododecane (HBCD), originally used in certain applications, have been found in a variety of other items containing recycled plastics, including household products (Samsonek and Puype, 2013), food contact materials (Puype et al., 2015), and packaging waste. In addition, recycling processes can lead to the formation of brominated and chlorinated dioxins, which have been detected in consumer products and toys (Behnisch et al., 2023).
- Metal concentrations are often also found in recycled plastics are often higher than in virgin plastics, reflecting the accumulation of contaminants through multiple recycling cycles and mixed material sources (Eriksen et al., 2018).

2 Existing standards, certifications, and quality control measures for analysis of chemicals in recycled plastics

In recent years, significant efforts have been made to establish comprehensive and harmonised quality control standards for recycled plastics at the international level. Countries, industry associations, and standardisation bodies have worked to align requirements, aiming to facilitate trade, ensure consistency in recyclate quality, and build trust across markets.

The following sections outline the main harmonised standards that apply to recycled plastics, recycling processes, and traceability at system level, highlighting their scope, applicability, and key requirements.

Standards and Certifications focused on Plastic Products/Recyclates

EN 15343:2007 certification

In Europe, a European Standard (EN) is formally adopted by the national members of the European Committee for Standardization (CEN) and the European Committee for Electrotechnical Standardization (CENELEC), and it is transposed, into the national standards of 34 participating countries. These standards ensure the quality and consistency of recycled plastics and provide guidelines for the preparation of test specimens to assess their properties and suitability for various applications. This standard is focused on mechanical recycling.

The key European standard for recycled plastics is the EN 15343:2007, which focuses on recycling traceability, assessment of conformity, and recycled content. It requires strict control of incoming batches, characterisation reports before material enters the production chain, and verification of the plastic's origin.

Quality measures according to EN 15343:2007 include general tests and polymer specific tests. Some are mandatory, while others are optional, but all must comply with the specific standards for every kind of common thermoplastic that is mechanically recycled, as summarised below:

- Characterisation of Polystyrene (PS) recyclates (EN 15342:2025)
- Characterisation of Polyethylene (PE) recyclates (EN 15344:2025)
- Characterisation of Polypropylene (PP) recyclates (EN 15345:2025)
- Characterisation of Poly(vinyl chloride) (PVC) recyclates (EN 15346:2024)
- Characterisation of Poly(ethylene terephthalate) (PET) recyclates (EN 15348:2024)

Optional tests also cover substances of concern, including volatile substances, which may or may not be contaminants.

EN 15343:2007 has an associated certification scheme that verifies traceability and recycled content in mechanical recycling and recycled plastics conversion processes.

Specifically, the certification scheme requires verification of:

- Traceability of materials through recycling and transformation facilities
- Documentation of recycled input quantities, origin, additives, masterbatches, virgin material, and recirculated scrap/ regrind
- Quality controls on the recycled plastic

Third-party certifications, based on established standards, help demonstrate compliance with regulatory and market expectations, support safe use of recycled plastics, and incorporate emerging recovery processes such as chemical recycling.

EN 15343:2007 provides a structured framework that complements and supports the implementation of Commission Regulation (EU) 2022/1616, especially in areas related to traceability, safety, and recycled content verification. For organisations involved in recycling plastics for food contact applications, obtaining EN 15343 certification can be a strategic step toward full regulatory compliance.

BQA QA-CER Recycled Content Certification

The QA-CER certification scheme (Centexbel, 2025) is developed by the Belgian Quality Association (BQA) in cooperation with the accredited laboratories Centexbel and Flanders' PlasticVision (Flemish Plastics Centre).

It targets industrial companies that produce polymer recyclates and/or use them in extrusion processes, including sorting and recycling companies handling post-industrial or post-consumer plastics, textiles, or composites. It also targets processors and producers using such recyclates, and assembly companies manufacturing products with recycled plastic or textile components.

The certification is valid for one year and helps companies guarantee compliance with technical specifications regarding recycled content and final product performance. It requires at least one year of product monitoring by an externally accredited organisation, with sampling carried out by BQA, and laboratory testing performed by an ISO 17025-accredited laboratory approved by BQA. Companies with their own laboratories may conduct tests under the supervision of BQA auditors.

The certification scheme includes a system called "Management of ECO Parameters" to control substances in recycled plastics. Under this system, the audited organisation must demonstrate compliance with all relevant environmental legislation by implementing adequate control measures. For example, the organisation must ensure that no substances listed under REACH (European Chemical Agency, n.d.) or Restriction of Hazardous Substance (RoHS, which limits the use of specific hazardous materials in electrical and electronic equipment) regulations (European Union, 2011) are presented in the final product.

APR PCR Certification

The APR PCR (Post-consumer Recycled Content) Certification (Association of Plastic Recyclers, 2024) programme consists of an auditing procedure in which brand companies and converters of recycled plastic can commit to using certified post-consumer recycled plastic in their products. APR PCR certification is developed by The Association of Plastic Recyclers (APR), an international trade association focused exclusively on plastics recycling.

The certification ensures that controlled products comply with applicable regulations and legal requirements. Certificates must be renewed annually, and physical inspections of manufacturing facilities are mandatory to obtain certification. The programme currently certifies the chain of custody from source to pellet and/or flake, through to the final product containing post-consumer recycled plastic.

Although APR PCR certification assures the compliance with regulations on the manufacturing of plastic products and chain of custody, it does not set specific requirements for the chemical content of the certified products.

Standards and Certifications focused on Recycling Processes

These standards/certifications cover how recycling should be done, process quality, and technical requirements.

International standards ISO

International Organisation for Standardization (ISO) standards consist of a set of international standards that establish requirements, specifications, guidelines, or directions to ensure quality, safety, efficiency, and consistency in a wide range of products, services, and systems.

The main ISO standard that is focused on processes of recycling of plastics is **ISO 15270:2008** (ISO, 2008)**.** Plastics - Guidelines for the Recovery and Recycling of Plastics Waste.

Although the current ISO standard is still in effect, it is set to be replaced by a new series of five standards which are still under development. These upcoming standards will provide a more detailed and structured approach to different recycling methods, and include:

- ISO/CD 15270-1.3 Part 1: General principles
- ISO/WD 15270-2 Part 2: Mechanical recycling
- ISO/WD 15270-3 Part 3: Physical recycling
- ISO/DIS 15270-4 Part 4: Chemical recycling
- ISO/DIS 15270-5 Part 5: Organic/ biological recycling

ISO standards such as ISO 15270:2008 are voluntary. They serve to establish consistent benchmarks and foster trust and reliability among businesses and consumers, but they are not legally binding.

This standard provides guidelines for plastic waste management, emphasizing the importance of a preliminary analysis of available recovery options. The standard gives valuable insights into the recycling of various types of plastics, covering key aspects such as material selection and classification, and descriptions of mechanical, chemical and biological (organic) recycling methods. It also includes guidance on the use of recycled plastics in new products and discusses energy recovery from non-recyclable plastics.

One of the key components ISO 15270:2008 is its section on quality requirements, with a focus on contamination control. The standard outlines strategies to minimise contamination, including clear identification and efficient sorting, careful handling during collection and separation, effective washing processes, melt filtration where applicable, and segregation of input streams based on origin. It emphasises the importance of transparent data on additives, fillers, reinforcements, contaminants, and polymer composition, with acceptance criteria for recyclates agreed upon between supplier and end user and supported by batch-level documentation.

Unlike some other standards discussed later in this report, the ISO 15270 family does not set specific limits for individual substances found within recycled plastic waste streams.

2.2.2. American Society for Testing and Materials (ASTM) standards

Similar to ISO standards, the American Society for Testing and Materials (ASTM) develops internationally recognised technical standards that define and specify materials, products, systems, and services across a wide range of industries. These standards cover sectors such as construction, manufacturing, materials testing, textiles, including plastics. ASTM standards are voluntary, but widely used to ensure product quality, safety, and performance, and to support international trade and regulatory compliance.

Among the existent ASTM standards for plastics, ASTM D5577-19 "Standard Guide for Techniques to Separate and Identify Contaminants in Recycled Plastics" (ASTM International, 2019), is particularly relevant. It provides detailed guidance on test methods used to detect and separate contaminants, supporting improved quality control in recycled plastic materials.

This standard also outlines procedures to assess the suitability of recycled plastics against defined quality and safety criteria. By standardising identification and separation techniques, it contributes to greater consistency in testing practices and facilitates compliance with regulatory and performance requirements.

The standard includes various test methods and techniques for the separation and identification of contaminants. Depending on the type of contaminant to be detected, techniques include:

- Ash test to estimate the inorganic contaminants content of recycled plastic flake.
- Infrared analysis to identify polymeric, organic and, in some cases, inorganic components of recycled plastic materials.
- Chromatographic analysis for separation and classification of chemical contaminants or residues from original-use contents of plastic packages.
- Extrusion/Melt Flow Test: The procedure consists of an extruder equipped with a filter screen. The contaminants will be isolated on the screen and can be characterised by thermal or infrared techniques.

In addition to ASTM D5577-19 standard, several regulatory frameworks address the traceability and chemical compliance of plastics and recycled materials. A summary of the key regulations is presented in Table 2.

RecyClass Recycling Process certification

The RecyClass Recycling Process (RecyClass, 2024) is a European Certification designed for both pre- and post-consumer plastic recyclers. Its main objective is to standardise and promote environmentally responsible recycling practices. The scheme certifies the recycling of input plastic waste into recycled outputs, such as flakes or pellets, ensuring traceability throughout the mechanical recycling process.

For input waste, recyclers need to document the origin, sector, supplier, polymer type, colour, and permitted level of contamination. While the technical composition must meet agreed specifications, the certification does not require detailed chemical screening of input waste.

To ensure compliance, certified auditors conduct annual on-site audits, which include both documentation reviews and physical inspections of recycling operations. For output quality controls, companies must comply with REACH Regulation, particularly with respect to substances of very high concern (REACH SVHC substances list). According to RecyClass scheme, at least one annual test of the recycled output must confirm that SVHC content does not exceed 0.1%.

Standards and Certifications Focused on Traceability at the System Level

These standards and certifications focus on tracking recycled content through the supply chain, on sustainability claims, or on environmental labels. Tracer-based validation may also open new revenue streams by upgrading materials that would otherwise be classified as waste.

Tracer technologies are not intended to replace certification schemes such as RecyClass, Blue Angel, or International Sustainability & Carbon Certification (ISCC), but rather to complement them by providing direct, non-destructive verification of recycled content.

Most of the certification schemes described, with few exceptions, do not require comprehensive chemical analyses and assume compliance with applicable regulation.

RecyClass Recycled Plastic Traceability certification

The RecyClass Recycled Plastics Traceability (RecyClass, 2024) is a European Certification that verifies the recycled content of plastic products, with a strong focus on the traceability and conformity across the value chain. Certification can be granted to various actors involved in plastics production and transformation, including compounders, converters, blow moulders, fillers and traders.

The scheme is based on EN 15343:2007 and follows the controlled blending chain of custody model as described in ISO 22095:2020. It requires annual physical inspections by accredited auditors, which include reviews of documentation and process compliance.

To obtain certification, companies must control and record key parameters of the input material, including the share of recycled content, origin of the material, additives, masterbatches, virgin inputs, scrap or regrind recirculated during production. However, the certification does not involve quality testing of the final products, in particular, no verification of chemical substance content is required.

Blue Angel certification

Blue Angel (RAL gGmbH, 2025) is an ecolabel for products manufactured with recycled material (with at least 80% of post-consumer recycled content). It is a German Type I environmental label that establishes high standards in the design of environmentally friendly products.

The Blue Angel label for products made from recycled plastics is applicable to finished products (furniture, containers, composters, bags, etc.), although films and foils are also accepted.

To obtain certification, the following requirements must be fulfilled:

- The percentage of post-consumer recycled plastic in finished products must be at least 80%
- The requirements of the REACH Regulation on the prohibition of Cadmium compounds must be met
- They must not contain hazardous substances such as carcinogenic, mutagenic, toxic for reproduction (CMR), persistent, bio accumulative and toxic (PBT) or others labelled with H-sentences under the Global Harmonisation System for chemical hazards (H 370 – causes damage to organs; H 371- May cause damage to organs; H 372 – Causes damage to organs through prolonged or repeated exposure.; H 373 – May cause damage to organs through prolonged or repeated exposure; and H 410 – Very toxic to aquatic life with long lasting effects)
- Plastic parts must be marked according to ISO 11469 standard (for instance, polyethylene products must be marked >PE<)

This certification guarantees traceability by mandating that post-consumer recycled plastic material must come from a RecyClass certified recycler, enabling verification of their origin and composition.

Tracer technologies can further enhance the Blue Angel framework by confirming that certified recycled inputs are consistently used in finished products. In addition, tracers can help recyclers identify and separate non-compliant or contaminated streams earlier in the process, which supports both compliance and the creation of higher-value applications for recycled plastics.

CAN/BNQ 3840-100/2023 - Recycled Plastic Content Products

The Bureau de normalisation du Québec (BNQ) standard CAN/BNQ 3840-100/2023 (BNQ, 2023) provides guidance for products containing recycled plastics. It is a Canadian national standard that focuses on tracing, verifying, and classifying recycled plastic content in products.

The standard applies to finished products containing recycled plastics and defines procedures for tracing recyclate entering the supply chain. It establishes requirements for third-party verification of recycled content claims and for marking or labelling products to indicate recycled content. It also sets basic requirements for classifying recycled material based on origin (pre- or post-consumer) and treatment (mechanical or chemical).

REMADE Product Certification Scheme

REMADE is a product certification scheme based in Italy focusing on the traceability of recycled content (or by-products) in a material, semi-finished or finished product (REMADE, 2025). It requires a company to prepare a traceability plan for materials and flows including the monitoring of suppliers and classification of incoming material.

The standard is not specific to plastic and does not target specific substances but focuses on recycled content measurement and traceability. Certification is conducted by accredited certification bodies.

Plastica Seconda Vita Certification

Plastica Seconda Vita (PSV) is a certification for recycled plastic materials and products obtained from the valorisation of plastic waste, first in Italy and EU, while focusing on the quality and traceability (Plastica Seconda Vita, 2022). It requires a company to prepare information about a traceability and the content of materials and products.

It relies on the guarantees offered by the technical standards of the sector UNI UNIPLAST 10667 and EN 15343:2007. Certification is conducted by accredited certification bodies and applies the concept of “traceability” of recycled materials and determines their content according to EN ISO 14021.

PSV certification includes the use of blockchain-based technologies, which allow for the immutable information recording, guaranteeing its integrity, authenticity and data. It is also paving the way for the Digital Product Passport (DPP). Its certification program recognised by PolyCert Europe.

Both Italian Certifications described (REMADE and Plastica Seconda Vita) allow all manufacturing companies, both Italian and EU, to obtain their Certifications, and these Certifications are valid in Italy and in the countries of the European Union.

International Sustainability & Carbon Certification (ISCC) Recycling certification

ISCC is an independent multistakeholder organisation with multiple participants that provides a globally applicable certification system for the sustainability of raw materials and products, traceability throughout the supply chain, and the determination and reduction of greenhouse gas emissions.

In the ISCC EU 203 document (ISCC, 2021), the certification criteria regarding traceability and chain of custody are specified. These criteria are aligned with the Renewable Energy Directive (EU) 2018/2001, often referred to as RED II.

The following information is required for the chain of custody:

- Description of process flows: inventory of inputs and outputs, transformation processes, technologies used, etc.
- Company organisational chart.
- Documentation on organisational structure.
- Traceability protocols.
- Description of internal processes, quantities of raw materials, quantities of co-products, quantities of waste or residues, yields, and relevant conversion factors, greenhouse gas emissions from processes, as well as production dates.
- Sustainability declarations.

In relation to chemical control and the presence of substances in recycled plastics, no specific measures are currently required to obtain certification. This is primarily due to the lack of harmonisation, standardisation, and regulatory frameworks governing newly established recycling technologies, such as chemical recycling.

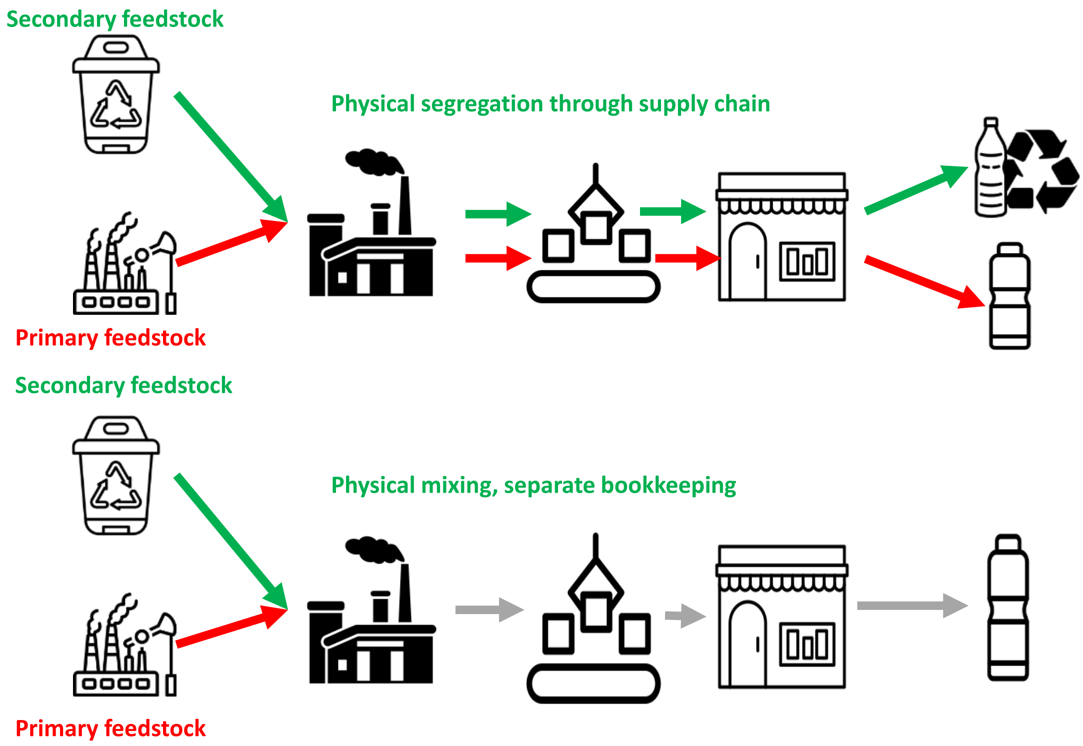
Regarding the chain of custody methodologies for defining the composition of the final product in a specific process, two methods are employed: mass balance and physical segregation (Figure 4).

The mass balance is a chain of custody model in which certified characteristics (such as the type of raw material, country of origin, greenhouse gas value) remain assigned to material batches on an accounting basis. In this model, there is a mixing of batches in the transformation process, and a certification can be attributed to a mass of the output material equivalent to the mass of the initial proportion of the certified inputs (minus process losses).

In the context of plastics recycling, the mass balance methodology is considered fundamental for the upscaling of chemical recycling technologies. Even more important is the measurement rule that is applied to the mass balance formula. While less strict rules (i.e. free allocation) can allow more recycled attributed content to be claimed in plastics, such flexible rules raise concerns about misleading recycled content claims in plastic products. Adopting more strict measurement rules (i.e. polymer-only) would limit recycled content claims to the proportion of chemicals produced that are used only in the production of plastic products.

Unlike the mass balance model, physical segregation does not allow the mixing of batches with different certified characteristics, making it a stricter chain of custody method as materials with different properties are physically kept separated throughout the supply chain. However, it is not applicable to several processes where the mixing of material qualities (virgin and recycled plastic resin) is inevitable.

Figure 4. Mass balance and segregation as chain of custody models



Source: Brown and Börkey, 2024 as adapted from ISCC, 2019

Tracer systems can strengthen both the mass balance and physical segregation models described above (Figure 4). By providing independent, real-time data on quality and % blending between virgin and recycled content, tracers give recyclers, converters, and brand owners clearer assurance than documentation alone. As demonstrated in pilot projects, tracer-based validation may also open new revenue streams by upgrading materials that would otherwise be classified as waste.

Summary

The key voluntary initiatives, standards, and certification schemes described in the section above are summarised in Table 1. An assessment to each standard was conducted to allow for comparison between the different standards regarding their geographical scope, if they are publicly available or need to be purchased, if they are voluntary or regulatory and what are the requirements and what substances do they target. Table 2 summarises regulations and compliance systems addressing chemical safety and traceability requirements for plastics and recycled plastic materials.

In summary, while certification schemes establish important frameworks for recycled content traceability, integrating tracer technologies offers a practical pathway for cost-efficient, independent validation of material composition. This approach enhances confidence in sustainability claims, supports compliance reporting, and creates additional value for recyclers and downstream users.

Table 1. Overview of key voluntary initiatives, standards, and certification schemes addressing the identification and management of substances of concern and contaminants in recycled plastics

Legislation name	Geographical scope	Brief description	Publicly available?	Are they regulatory/ voluntary?	What substances do they target?
Plastics Recyclers Europe PRE-1000 list of 240 substances to screen	Europe	Standard and tool for substance analysis, designed to enable recyclers to provide high confidence statements on the presence or absence of substances of concern	No	**Voluntary**	**All substances of concern (SoC) including:** -all SVHCs -all substances under REACH restrictions -all POP substances -all hazardous substances (RoHS)
ISO 15270:2008	Worldwide	Provides guidance for the development of standards and specifications covering plastics waste recovery, including recycling. The standard establishes the different options for the recovery of plastics waste arising from pre-consumer and post-consumer sources. It also establishes the quality requirements that should be considered in all steps of the recovery process, and provides general recommendations for inclusion in material standards, test standards and product specifications. Consequently, the process stages, requirements, recommendations and terminology presented in the standard are intended to be of general applicability.	No	**Voluntary**	Does not target specific substances
ASTM D5577-19	Worldwide	This guide is intended to provide information on available methods for the separation and classification of contaminants such as moisture, incompatible polymers, metals, adhesives, glass, paper, wood, chemicals, and original-product residues in recycled plastic flakes or pellets.	No	**Voluntary**	Targets contaminants (moisture, incompatible polymers, metals, adhesives) but no specific substance limits
EN 15343:2007	Europe	This standard is intended to describe the necessary procedures for mechanical recycling that are needed for products that have been manufactured completely or in part from recycled plastics and need proof of traceability.	No	**Voluntary**	Does not target specific substances
RecyClass certifications	Europe	Certification system assessing recyclability of plastic packaging and recycled content traceability	Yes	**Voluntary**	Must comply with REACH regulation (at least one test on the recycled output of the company per year ensuring that the total content of SVHC does not exceed 0,1%
Blue Angel eco-label	Germany (recognised EU-	Eco-label for environmentally friendly products, including recycled plastics	Yes	**Voluntary**	Recyclates cannot contain substances classified as:

	wide)				-carcinogenic -mutagenic -reprotoxic substances -persistent, bioaccumulative and toxic (PBT) substances, very persistent or accumulative (vPvB substances) included in the REACH regulation -required proven compliance with the REACH regulation
BQA QA-CER Recycled Content Certification	Belgium/ EU	Certification scheme verifying recycled content targeting companies producing polymer recyclates	Yes	**Voluntary**	Not substance-specific, focuses on chain of custody and recycled content verification
REMADE Certification Scheme	Italy/EU	Certification scheme verifying recycled content and focusing on content traceability	Yes	**Voluntary**	Not substance-specific, focuses on chain of custody and recycled content verification
Plastica Seconda Vita Certification	Italy/EU	Certification verifying recycled content and focusing on content traceability	Yes	**Voluntary**	Not substance-specific, focuses on traceability and recycled content verification
CAN/BNQ 3840-100/2023 - Recycled Plastic Content Products	Canada	Standard that focuses on tracing, verifying, and classifying recycled plastic content in products	Yes	**Voluntary**	Not substance-specific, focuses on chain of custody and recycled content verification
APR PCR Certification	United States	Certification developed by the Association of Plastic Recyclers (APR) to verify post-consumer recycled (PCR) content in plastics	Yes	**Voluntary**	Not substance-specific, focuses on recycled content measurement and traceability
ISCC Recycling Certification	Global	Independent certification scheme covering sustainability and traceability of raw materials	Yes	**Voluntary**	Not substance-specific, uses mass balance or physical segregation for traceability

Table 2. Summary of regulations and compliance systems addressing chemical safety and traceability requirements for plastics and recycled plastic materials

Legislation name	Geographical scope	Brief description	Publicly available?	Are they regulatory/ voluntary?	What substances do they target?
Restriction of Hazardous Substances (RoHS) Directive	Europe	Restricts the use of certain hazardous substances in electrical and electronic equipment (EEE), including plastics used in these products	Yes	**Regulatory** Manufacturers, importers or distributors need to declare compliance themselves, rather than submitting periodic reports Compliance is officially demonstrated via 3 mandatory elements: CE marking on EEE, a declaration of Conformity (DoC), and a technical file with detailed documentation of materials, testing, supplier declarations and design processes	Cadmium (Cd) Lead (Pb) Mercury (Hg) Hexavalent Chromium: (Cr VI) Polybrominated Biphenyls (PBB) Polybrominated Diphenyl Ethers (PBDE) Bis(2-Ethylhexyl) phthalate (DEHP) Benzyl butyl phthalate (BBP) Dibutyl phthalate (DBP) Diisobutyl phthalate (DIBP)
EU No 10/2011 on plastics and articles in contact with foods	Europe	EU regulation for plastics and articles in contact with food, specifying authorised substances and their specific migration limits (SMLs)	Yes	**Regulatory** Compliance is self-declared; no official periodic reporting is required. Manufacturers, importers, or distributors must ensure that materials comply with the regulation with a Declaration of Compliance (DoC) and technical documentation.	**Follows a positive listing approach.** Instead of listing substances which are prohibited, they specify what substances are explicitly allowed for use in plastics that contact food. Each substance comes with a specific migration limit (SML) and restrictions in some cases. All substances not in the list are by default, not authorised.
EU No 2022/1616 for recycled plastics in contact with foods	Europe	EU regulation that imposes that only plastics containing recycled plastic materials manufactured with a suitable recycling technology or notified novel technology can be placed on the market	Yes	**Regulatory** Compliance is self-declared; manufacturers must maintain a Declaration of compliance (DoC) and technical documentation demonstrating that the recycled plastic has been processed using a suitable recycling technology that effectively removes contaminants. No official periodic reporting is required.	**All substances present in recycled plastics that may migrate into food.** Focuses on ensuring that contaminants are removed or reduced to safe levels through suitable recycling processes.
Directive 2009/48/EC for toys	Europe	Directive that sets out the safety requirement for toys marketed in the EU.	Yes	**Regulatory** Compliance is self-declared; no official periodic reporting is required.	**Lists restricted/banned substances explicitly:** Heavy metals: lead, cadmium, mercury,

				Manufacturers, importers, or distributors must ensure that materials comply with the regulation with 3 elements: Declaration of Compliance (DoC), technical documentation and a CE label on the toy	chromium VI Phthalates: DEHP, DBP, BBP (some also DINP, DIDP, DNOP) Others: polycyclic aromatic hydrocarbons (PAHs), nitrosamines in rubber/plastic
Waste Framework Directive (2008/98/EC)	Europe	Established the EU's waste management policy, including the waste hierarchy (prevention, reuse, recycle, recovery, disposal), definitions of waste/ by-products/ end-of-waste, and sets the framework for extended producer responsibility and high-quality recycling. It includes end-of-waste criteria, specifying when a recycled material ceases to be waste and becomes a secondary raw material.	Yes	**Regulatory** Competent national authorities are responsible for enforcement. No official periodic reporting is required from recyclers, but operators seeking to market materials as end-of-waste must demonstrate that they meet the criteria through documentation, testing, and quality assurance systems.	**Does not list individual substances. Instead, it uses hazard-based classification (Annex III, properties H1–H15, e.g. carcinogenic, toxic, ecotoxic, flammable).** Substances of concern are controlled indirectly through their hazard properties in waste streams. For plastics, this means recycled materials can only achieve end-of-waste status if they do not contain hazardous levels of contaminants that could pose risks to human health or the environment.

3 Existing methods for the analysis of recycled plastics and the identification of chemical substances in plastic

Analytical techniques for identification of chemical substances in recycled plastics

Additives and chemicals used in plastics are often specific to the polymer type, and their potential to migrate out of the polymer matrix depends on characteristics such as polymer density, morphology, additive concentration and dispersion, diffusion coefficients and environmental conditions. Within plastic waste streams, even items made from the same polymer can differ substantially in their additive profiles depending on the final product and its intended use (e.g. polyethylene rigid closures versus polyethylene flexible films). Therefore, when developing analytical methods to detect chemical substances in recycled plastics, it is important to apply best available science and standardised analytical practices, including the use of blanks and internationally recognised methods (e.g. ASTM, ISO).

The input stream of plastic waste entering a recycling process can contain a broad variety of chemicals and contaminants originating from production, product use and waste collection. During recycling, some contaminants may be removed, while others may be introduced or formed through processing. Because no single analytical method can detect and quantify all possible substances, laboratories typically employ multiple techniques.

A common approach is to combine a chromatographic technique with a spectrometric technique. Table 3 summarises commonly used analytical techniques and the types of chemicals they can detect, as referenced across a selection of studies.

Chromatographic techniques

Chromatographic techniques are among the most widely used analytical methods today. They can be broadly categorised into gas chromatography (GC), which is suitable for volatile or semi-volatile analytes, and liquid chromatography (LC), which is used for non-volatile analytes or samples with high water content. Identification of analytes is generally based on comparing retention times with those of reference standards or library spectra. The accuracy of both identification and quantification also depends on the type of detector employed, such as thermal conductivity detectors (TCD) or flame ionisation detectors (FID). The selection of a detector is based on a trade-off between selectivity and sensitivity, whether a broad screening of potential contaminants is required or a precise analysis for targeted compounds. For more precise identification, chromatographs are often coupled with mass spectrometers, which analyse the molecular mass and fragmentation patterns of compounds.

Spectrometry techniques

Spectrometry techniques are based on the measurement of how a substance interacts with various forms of energy, such as light, electromagnetic radiation, or charged particles, to provide information about its structure, composition, or concentration.

Mass spectrometry (MS) is based on ionisation of the molecules, acceleration of the ions with electric fields, and detection of the mass to charge ratio. Based on the methods of ionisation and detection, MS can be used to identify or quantify the compounds or analyse the molecular structure. In Table 3, the terms 'time-of-flight' and 'quadrupole' refer to the type of detectors, while the terms 'Electron Ionisation' and 'Electrospray Ionisation' refer to the type of ionisation. Other considerations in the selection of the ionisation method include the type of molecule targeted, the state of the sample, the chromatographic technique with which it is combined, and the goal of the analysis (i.e. screening for known substances or identifying unknown contaminants).

Tandem mass spectrometry (MS/MS) is a technique of sequential MS steps in which a detected molecule is further fragmented to verify or more confidently identify it.

Inductively Coupled Plasma Mass Spectrometry (ICP-MS) is the primary spectrometry technique used for the detection of heavy metals from liquid samples at very low concentrations. X-ray Fluorescence (XRF) Spectroscopy is based on how atoms in a solid sample react to X-rays. It is less sensitive than ICP-MS, but it is fast and can be applied with portable handheld scanners. XRF is commonly used to screen input materials before a recycling process. It does not detect molecules so it cannot be used to screen for organic contaminants or additives, but it can be used for screening of heavy metals and elements of inorganic contaminants such as bromine and chlorine.

Validity of these techniques is determined by the sensitivity of the equipment, the sample preparation itself, as well as the concentration of substance to be detected.

Spectroscopy techniques

Spectroscopic techniques analyse the absorption, emission, or scattering of electromagnetic radiation across different spectral regions, enabling both qualitative and quantitative identification of chemical compositions. In the context of plastic recycling, these optical methods are widely employed to detect and characterise additives, degradation products, and substances such as flame retardants, plasticisers, and pigments. Their ability to provide fast, non-destructive analysis makes them valuable tools for assessing the purity and composition of recycled plastic streams (Sormunen et al., 2022), (Dzoh Fonkou et al., 2025).

Fourier-transform infrared spectroscopy (FTIR) and Raman are based on comparing the signal of a sample to a library of substances thanks to their infrared or vibrational/rotation energy absorption. These techniques can be applied to samples in any state, that means solid, liquid or gas, while for the analysis of recycled plastic they are commonly employed to solid samples (Dzoh Fonkou et al., 2025).

Differential thermal analysis (DTA) and thermal gravimetric analysis (TGA)

These techniques are used to study the thermal properties of materials. DTA measures the temperature differences between a sample and a reference material, while TGA determines the weight loss of a given material as the temperature increases. This type of analysis can be coupled with techniques such as FTIR, which allows for the identification of substances (in TGA, there is a weight loss, and with FTIR, it is associated with the specific molecule).

Detection in cases of homogenous or heterogenous samples

Regarding the application rate of substances, detection techniques can be used for homogeneous or heterogeneous samples. In case of homogeneous samples, where the batches of waste used for recycled plastic are very similar and the composition of the waste is uniform, simpler detection techniques can be implemented as it is assumed that the composition of the plastic in the whole batch will be similar. However, detection techniques can also be applied to heterogeneous samples.

In cases where heterogenous samples are analysed, proper sampling is essential to ensure that the portion tested is as representative of the whole as possible. Proper sampling includes taking sufficient samples and taking them randomly from a batch. This is critical for meaningful interpretation of the results.

Additionally, regardless of whether the analytical technique is suited for homogeneous or heterogeneous samples, it is important that the equipment used has detection limits aligned with relevant legislation. Since regulatory thresholds for chemical detection vary across jurisdictions, analytical methods should be selected to comply with the most stringent legal limits applicable to the intended market. For example, the European Union’s Commission Regulation (EU) No 10/2011 (European Commission, 2011) sets detection limits for substances such as bisphenol A in food-contact plastics, while in the United States, the Food and Drug Administration (FDA) may apply different criteria or assess substances on a case-by-case basis (U.S. Food and Drug Administration, 2021). Ensuring that the analytical methods can reliably detect substances at or below the tightest thresholds helps maintain regulatory compliance.

Therefore, detection systems can be adapted to homogeneous or heterogeneous samples and the selection of one type of technique or the other will also depend on the type of sample. In order to choose the most accurate detection technique, the specific objectives of the analysis must be addressed, considering the substance to be identified and/or quantified, detection limits, concentration range of the contaminant, and generally, the expected limit of presence of the substance (mainly according to established limits in existing legislation and regulations for every substance and/or material).

Targeted vs non-targeted analysis

Another way of classifying detection techniques is according to the scope of analysis into target or non-target and suspect screening. Targeted analytical approaches use resolute analytical and data processing approaches to investigate specific chemicals or a group of chemicals of which the identity is known prior to analysis. In a non-targeted analysis for suspect screening, generic analytical methods for detection are applied, while data evaluation uses a list of suspects (Schymanski et al, 2015). Targeted analysis is performed when the source of recycled material and the potential contaminants are known or to verify whether a material complies with a list of restricted substances. Non-targeted analysis is required to screen for NIAS or when the origin of the recycled material is unknown.

Table 3. Examples of analytical techniques applied by a selection of studies to detect certain compounds in their tested material.

Origin of substance	Type of additive/contaminant*	Example of chemical*	Test method for identification of substance	Example references
1. Substances intentionally added during virgin plastic production (IAS)	Residual monomers (production residue)	Bisphenol (BPA, BPS, BPF) is a monomer for polycarbonate	Ultra High-Performance Liquid Chromatography-Tandem Mass Spectrometry (UHPLC-MS/MS) Flow-injection analysis electrospray ionisation high resolution mass spectrometry (FIA-ESI-HRMS)	Núñez et al., 2024
	Catalysts (production residue)	Zinc oxide	Targeted gas-chromatography tandem mass-spectrometry	Hakkarainen, Karlsson and Albertsson, 2000
	Plasticisers	Phthalates (e.g. BBP, DBP, DEP, DIBP)	Targeted gas-chromatography tandem mass-spectrometry	Wiesinger et al, 2024
	Flame retardants	Aromatic brominated flame retardants (e.g. DBDPE)	Gas chromatography coupled with mass spectrometry in negative ion chemical ionisation (GC-MS-NICI) Gas chromatography with electron ionisation using selective ion monitoring (GC-MS (EI/SIM)) Liquid Chromatography Tandem Mass Spectrometry (LCMS/MS)	Stubbings et al., 2021 Melkebeke et al., 2025
	Colourants or pigments	Titanium dioxide (TiO2)	Fourier Transform Infrared Spectroscopy (FTIR) X-ray fluorescence (XRF)	Dzoh Fonkou et al., 2025 Turner and Filella, 2023
	Fillers	Calcium carbonate	Ash test Raman spectroscopy Fourier Transform Infrared Spectroscopy (FTIR)	Wang et al., 2024
	Stabilisers and antioxidants	Butylate Hydroxytoluene (BHT) Alpha-tocopherol	Gas Chromatography with Electron Ionisation Mass Spectrometry (GC-(EI)-MS)	Wang et al., 2024 EFSA, 2016
2.Substances unintentionally added during product use phase and/or waste management	Cross-contamination with other polymers and their additives	All the above are possible	Differential scanning calorimetry (DSC) Temperature Rising Elution Fractionation (TREF) Stain K test Ultraviolet spectroscopy	Juan et al., 2021

(IAS and NIAS)	Legacy additives from other plastic waste	Brominated flame retardants (e.g. Hexabromocyclododecane - HBCD)	X-ray fluorescence (XRF) Solvent extraction followed by chromatography analysis (GC-MS, LC-MS/MS)	Mlelwa and Rother, 2025
	Adhesives	Isocyanates	Gas Chromatography Mass Spectrometry (GC-MS)	Cai et al., 2022
	Solvents	Methyl Ethyl Ketone (MEK)	Headspace Solid-Phase Microextraction Gas Chromatography-Mass Spectrometry (HS-SPME-GC-MS) Gas Chromatography-Flame Ionisation Detection (GC-FID)	Liu et al., 2021
	Coatings	Perfluoro-alkylated substances (PFAS)	Gas Chromatography Mass Spectrometry (GC-MS)	Wiesinger, 2024
	Cross contamination with non-plastic products or waste: metals, paper, food and other organic residues, moisture	Metals: Sb, As, Pb, Cd, Cr, Co, Cu, Ni, Hg, Al, Zn, Ca, P, Ti, Si, Ag	Inductively Coupled Plasma - Optical Emission Spectroscopy (ICP-OES) Inductively Coupled Plasma Mass Spectrometry (ICP-MS) Liquid Chromatography Tandem Mass Spectrometry (LC-MS/MS) Liquid Chromatography Electrospray Ionisation Positive Mode Tandem Mass Spectrometry (LC-(ESI+)-MS/MS)	Hakkarainen, Karlsson and Albertsson, 2000
3.Substances formed during recycling process (NIAS)	Breakdown products or by-products from the recycling	VOCs (e.g. acetophenone, benzene, styrene)	Gas Chromatography Time-of-Flight Mass Spectrometry (GC-TOF-MS) Thermal Desorption Gas Chromatography Mass Spectrometry (TD)-GC-MS) Gas Chromatography with Electron Ionisation Mass Spectrometry (GC-(EI)-MS)	Dong et al., 2023
	Reaction products of chemicals that are combined during the recycling process	Ethylbenzene	Gas Chromatography Mass Spectrometry (GC-MS)	González et al., 2021
	Substances derived from cross-contamination with other (plastic) waste streams	Chlorinated compounds derived from PVC	Pyrolysis Direct Analysis in Real-Time High-Resolution Mass Spectroscopy (pyro-DART-HRMS)	Halpern et al., 2024

*non-exhaustive list

Additional tests

While the analytical techniques described above provide essential information on the presence and identity of chemicals in waste plastics or recycled plastics, it is equally important to evaluate whether the recycling technology removes the substances of interest and their potential release. Challenge tests and migration tests are critical complementary tests, particularly for recycled plastics used in applications such as food or skin contact. These tests do not assess the chemical content of the recycled plastics and cannot be regarded as a substitute but are included because they are related to the subject of this report. They are included here to indicate that besides the chemical analysis of the materials other tests are performed to safeguard against the risks of chemicals in sensitive applications. These methods are described below.

Surrogate contaminant testing / challenge testing

Surrogate contaminant testing or challenge testing is a controlled method used to test the decontamination efficiency of recycling processes. Challenge testing is a critical procedure for evaluating the efficiency of a recycling process for recycled plastic intended for food contact. It simulates the introduction of contaminants into the recycling stream from potential consumer misuse and measures how effectively secondary and tertiary recycling steps can remove them.

Samples of virgin polymer are deliberately exposed to a standardised set of surrogate contaminants that represent a broad spectrum of chemical properties: volatile polar, volatile non-polar, heavy metal, non-volatile polar and non-volatile non-polar chemicals. The contaminated polymer is then processed through the recycling system, after which residual levels of each surrogate are measured. The results provide a quantitative measure of the process's ability to remove different types of contaminants.

This complementary testing is highly relevant because it is recognised by regulatory bodies such as European Food Safety Authority (EFSA) and the US FDA as the gold standard for demonstrating that the recycling process meets strict food-contact safety requirements. This does not mean that the recycled material meets the requirements, this depends on the ingoing material and its contamination. The EFSA guidance, updated in 2024, designates challenge testing as the reference method for proving that a recycling process can effectively decontaminate post-consumer plastics. Regulation (EU) 2022/1616 explicitly links approval for food-contact applications to showing that the process can achieve this level of decontamination (EFSA, 2024).

Migration tests

Under EU Regulation (EU) No 10/2011 on plastic materials intended to be in contact with food, a risk assessment is required for all migrating substances (Article 19). For recycled plastics, additional safety requirements apply under Regulation (EU) 2022/1616, including an assessment of the recycling process to ensure that the final material is safe for food contact.

Migration limits are established based on toxicological risk assessments and are specified across several EU regulations to ensure consumer safety. During migration testing, the material is exposed to specific testing conditions and food simulants that mimic the intended use. After a defined contact period, the concentration of target substances that have migrated into the simulants is measured and assessed for compliance with regulatory limits (EFSA, 2024).

Under Commission Regulation (EU) 2022/1616, recycled plastic materials and articles intended for food contact cannot be placed on the EU market unless specific conditions are met. These include evaluation, registration, and compliance with safety and traceability requirements. Recycling installations will need to be register with the European Commission and the local competent authority notified.

Summary and insights received from industry contacts based in OECD countries

Different analytical techniques exist but none can detect and quantify all possible substances of interest, therefore they are used in complementary combinations. Considerations in the selection of a method are based on trade-offs between a broad non-targeted screening or sensitive but selective targeted analysis, and between quantification of the contamination or detailed characterisation of a contaminant.

Within the recycling industry, testing often occurs at the output stage of the process (rather than at every upstream step), and the choice of analytical method is strongly influenced by the target end-market of the recycled material. Within large-scale recycling operations this means that instead of performing a full universal non-target screen of all possible contaminants, a more market-driven target strategy is typically adopted. For example, if the recycled plastics are not intended for food contact/skin contact applications, the testing may focus on a defined list of expected contaminants. On the other hand, where sensitive end-use are envisaged, a more extensive testing programme needs to be conducted.

This reflects the trade-off inherent in method selection: a broad non-targeted screening can identify unknown/unexpected contaminants, but at higher cost and complexity, whereas a target analysis can be more efficient but risks overlooking unexpected chemical contaminants.

In the absence of internationally recognised standards for recycled plastics that include requirements on chemical analysis, the extent to which these analyses are performed differs per recycler and application of the recycled plastic. Recyclers that produce ‘bulk’ recycled plastics for many different customers and applications commonly perform target analysis on batches for a limited range of expected and regulated list of chemicals and might do non-targeted screening at extended intervals. Recyclers that produce material for specific applications in collaboration with customers or for high-end applications (skin contact, food contact, medical use) have a more thorough approach, guided by requirements set by customer. They combine a broad non-targeted analysis of their input materials with more targeted analysis for known or expected chemical contamination. The results are compared to a list of permissible requirements determined for the recycled plastic by the customer.

From an industry-wide perspective point, it is also evident that:

- The decision of which substances to test for is often driven by the end-market of the recycled material: the stricter the market (e.g. food contact, cosmetics, medical use), the more extensive the list of substances.
- Testing is costly and represents a non-negotiable cost of doing business for many recyclers in regulated markets: chemical analyses are expensive but increasingly required to obtain market access and certification.

Traceability schemes (e.g. third-party certification) are increasingly used across the recycling value chain to ensure material origin and lifecycle tracking. However, such traceability frameworks do not replace the need for chemical testing, they complement it.

- Where the input waste streams are less stringent (e.g. large industrial plastic items rather than post-consumer household packaging, food-contact or toy plastics), industry experience suggests compliance is relatively more straightforward, and the risk of process or product rejection is lower.

The variability in testing regimes and their intensity reflects both the application context of the recycled material and the regulatory/market demands associated with that application.

4 Limitations and challenges in chemical content validation of recycled plastics

There are technical challenges and limitations to analytical techniques that arise from their inherent design, practical and economic challenges in applying these techniques to large scale, and additional practical and technical challenges that arise when plastics recycling rates increase.

Financial and economic challenges

The handling of recycled plastics is resource intensive due to the diversity and variability of the materials, even before analytical testing for chemical content can be determined. Establishing the necessary laboratory infrastructure and performing these analyses involve significant capital and operational costs.

The wide range of potential chemicals of interest in recycled plastic requires a full laboratory with complementary analytical techniques which requires a high upfront investment. Operation of the laboratory equipment requires highly skilled personnel which add recurring costs. While interviewees from the plastics recycling industry mentioned the high costs of establishing an adequate laboratory, they emphasise that the highest costs are incurred for highly trained personnel.

For large companies that have in-house testing capabilities, the cost of each individual procedure is hard to determine, since a full laboratory needs to be established, operated, and maintained. For recyclers or converters that outsource the analysis to specialised external labs, costs per procedure are incurred. However, according to interviewees cost considerations are only a minor factor in the selection of which analytical techniques are used. The requirements set to recycled plastic, defined by the intended application, applicable regulation and customer, determine the techniques that are used to analyse the materials. Cost considerations can influence the number of tests that are performed, and whether they are repeated for each batch. Interviewees identified the risk that some competitors in the market for recycled plastics may reduce testing to cut costs to compete on price, thereby possibly reducing information on chemical content.

There is limited potential for automation to reduce operational costs. Task-specific software can support operators. In the future, artificial intelligence could assist with predictions of potential contaminations and analysis of the results. However, the analytical techniques require skilled manual operation and potential AI interpretation of the results will require a critical review by a trained expert.

Compared to virgin plastics, recycled plastics are often more expensive due to a number of factors. Virgin raw materials, sourced from consistent cracker processes, reliably meet specifications with predictable impurities. In contrast, plastic waste involves greater variability and uncertainty, necessitating more extensive testing of recycled output that add additional cost. which can be a factor that negatively influences the substitution of virgin plastic production by recycling.

Technical limitations and challenges

One main limitation of these techniques is the aggregation state of the sample. As stated before, gas chromatography can only analyse volatile compounds, that are normally extracted from the samples by heating them and trapping the analytes into a head space or a solid phase (as solid phase microextraction or injection), transferring them to the column. Specific examples of potential substances in recycled plastics that cannot be extracted as volatile compounds are complex polymers with high molecular weights or thermally unstable compounds such as bisphenols. On the other hand, liquid chromatography can only analyse compounds that can be dissolved into a list of solvents that are normally employed as mobile phase, which in the case of reverse phase, applied to polar compounds, means that the analyte needs to be soluble in water. This limitation is also encountered for elemental analysis by ICP-MS, as the analyte needs to be dissolved in a liquid phase that is normally water. This technical limitation to the techniques underscores the need for multiple complementary techniques for a reliable chemical content validation.

The aggregation state of the sample is no limitation for FTIR or Raman, as these techniques can analyse the material directly without requiring dissolution or extensive preparation. However, when dealing with heterogenous batches (such as plastic waste or recycled plastics), the representativeness of a single sample can affect the reliability of the results. If the analysed sample does not adequately capture the variability present in the batch, the measurements may not reflect the composition. In addition, it must be noted that the extraction techniques normally employ very low quantities of sample (Yamashita et al., 2009) and in a heterogeneous batch of plastic waste or recycled plastic (both input and output), this means that many samples need to be taken and analysed.

Another limitation consists of the analytical limits of each technique. Broadly speaking, there are two limits. The quantification limit (QL) is the lowest concentration at which an analyte can be quantified with a specified degree of certainty, while the detection limit (DL) is the concentration at which the analyte can be detected in a sample but not reliably quantified. The limits are influenced by multiple factors: the sensitivity of the instrument, how the sample is prepared (whether it needs to be diluted), interference of other components in the sample, and by the type of analyte measured (due to the different signal they provide on detectors) (US EPA, 1991). As a result, GC (Gas chromatography) or HPLC (High-performance liquid chromatography) coupled with mass spectrometry can provide detection limits in the range of parts per billion (ppb) while ICP-MS (Inductively coupled plasma mass spectrometry) has a detection limit in parts per trillion (ppt). In some cases, the limit of detection of the technique is higher than the limit of a substance necessary to be detected.

A fourth limiting factor to consider for all these techniques is the need to compare the signal/measurement to a reference, this is, previous information about the analyte/sample. The strategies available for chromatography or spectroscopy can be divided into target/ non-target method and suspect analysis. The target method confirms the presence of analytes of interest (potential contaminants or target compounds) in the sample. By comparing retention time (RT), high-resolution mass spectra (HRMS), and if possible, and tandem spectra (HRMS-MS) with those of a reference standard measured in-house, it is possible to reliably identify and confirm whether a given compound is present, rather than only observing differences in chromatographic signals. On the other hand, a non-target screening method is used for detecting and identifying all other components present in a sample where no prior information is available. This method relies on the experience of the user for the analysis of the fragmentations obtained for each unknown substance and to predict the possible structure. Again, when more previous information is available about the sample, the easier this prediction becomes. This method can be helped by data analysis and AI for the prediction of the substances. In between these two methods, there is the suspect screening, which is employed when prior information suggests that a specific compound may be present in the sample, based on various sources of information. For example, an analyst could search from a list of common IAS of the analysed plastic. The list of suspects can be extended to NIAS, degradation products during recycling, and expected cross-contaminations if the information is available. The obtained peaks and fragmentations are compared to a library of possible compounds proceeding thus to the identification of the analytes. From a risk perspective, it is also important to determine the concentration levels that require measurement.

In addition to the limiting factors mentioned above, there are also challenges related to the chemical structure of the target compounds, particularly in cases involving enantiomers, a type of isomer with the same molecular formula and mass, but different spatial configurations (chirality) and potentially dissimilar hazard properties. Because enantiomers have identical physical and chemical properties in achiral environments, they typically exhibit the same retention times in standard chromatography, making them difficult to distinguish using conventional methods such as Gas Chromatography (GS) or High-performance Liquid Chromatography (HPLC). This presents a challenge when analysing certain chiral additives where one enantiomer may be more hazardous or persistent than the other, as it happens for example with thalidomide in pharmaceutical applications (Debnath et al., 2024). In such cases, accurate identification and quantification requires chiral HPLC, typically by attaching a chiral column to the chromatograph, which increases the cost and complexity of the analysis (Mruc and Antos, 2025).

Increased rates of open loop mechanical recycling will increase likelihood of cross-contamination with chemicals used in various product categories, increase the risk for combination of chemicals and the formation of reaction products, and accumulation of degradation products in the recycled plastic. When the variety and likelihood of chemical contamination in recycled plastics increase, the need for thorough validation increases and simultaneously becomes more complex.

In the previous section, challenges and limitations related to identification and quantification of the chemicals were discussed. A further limitation is that when chemicals can be identified and measured, for many, hazard information is not available. Therefore, even if all substances present in a batch of recycled plastics can be identified and quantified, uncertainty about its safety can remain.

The described detailed and comprehensive analytical techniques are mostly carried out in a laboratory and can require considerable time and resources. They cannot be used on a continuous industrial scale. Trade-offs are made between demonstration of compliance for each batch and the operational disruption and additional economic costs. As standards and associated technologies relating to chemical testing in recycled plastics become more harmonised, experience from industries who currently conduct continuous process sampling can be leveraged for larger scale implementation.

Recycled plastic may contain impurities or contaminants that interfere with detection techniques and affect the accuracy of results. Such impurities may even corrupt analytical equipment, with the operational and economic impact that this would entail. The removal or separation of these impurities can be a challenge in plastic recycling facilities with a continuous industrial scale throughput.

In the section on financial and economic challenges, the costs related to establishment and operation of a laboratory are discussed. A related practical challenge is the availability of trained personnel. An increase in recycling rates directly correlates with a growing demand for suitably qualified and experienced laboratory workers.

Production of certain plastic products (e.g. electronics and automotive parts) is concentrated in a limited number of geographic regions, while their disposal occurs globally. As previously discussed, to reduce potential and variety of chemical contamination and create high quality recycled plastics for these applications, closed loop recycling is preferred. However, this would either require the shipment of highly sorted plastic waste to these production regions or local specialised recycling capacity and the required analytical facilities, which involve the practical and financial challenges.

Regulatory challenges

There is an absence of internationally recognised standards for recycled plastics that set comprehensive requirements for the analysis of potential chemicals of interest in recycled materials. Regarding chemical composition, most standards are limited to a list of particular restricted substances of concern.

OECD countries have implemented regulations on content of some chemicals of concern in plastics in specific applications in various forms, limiting the potential chemical contaminations in the plastics after recycling. However, strict control on import of products from regions without these requirements is not guaranteed. This jeopardises the traceability of input streams, increases the need for broad screening of input materials, and potentially allows entry of chemicals of concern into the local plastic waste streams.

One interviewee called for stricter enforcement of regulation on analysis of chemical content of recycled plastics. Specifically mentioned was monitoring of substances that are allowed in limited concentrations or should be reported to occur below the detection limit (such as the restricted substances listed in Annex II of RoHS (European Union, 2011)). It should be monitored more strictly whether the correct analytical techniques are used that can detect the substances below the specified minimal detection limit.

5 Deliberation of the main obstacles to be considered regarding chemical quality and safety of recycled plastics

To achieve increased plastic recycling rates and application of recycled plastics in final products beyond current levels, chemical safety of the recycled materials must be demonstrated. While current scientific knowledge on the extent to which chemicals of concern in recycled plastics may pose risks to human health has uncertainties and limitations, the following can be raised regarding the chemical safety of recycled materials.

- The large variety in potential chemical contamination of recycled plastic that can occur during the initial lifecycle of the plastic product, up to and during the recycling.
- The challenges and limitations in the validation of the chemical content of the plastic waste and recycled plastic, as described in this report. The main barriers being technical limitations of the analytical techniques and practical and economic challenges to apply them in a market-scale recycling process.
- A lack of harmonised information, traceability and transparency in the whole value chain. This includes incomplete disclosure of the chemical composition of plastic products, incomplete or unknown hazard information of the chemicals on the market, limited traceability of long-lived products (with potential legacy chemicals) in an open global market, and limited traceability of plastic waste in the waste collection systems.
- The difficulty of eliminating chemicals of concern in the recycling process. Currently, commonplace recycling technologies are not capable of removing all chemical substances of concern, to align with regulatory limits, nor are standards and monitoring capabilities sufficiently in place across countries. While more advanced recycling technologies may not be developed enough to be economically feasible, remain largely unproven on a larger scale, and concerns remain about their environmental impacts (see Brown and Börkey, 2024 for further discussion).

Policy measures can be further considered to overcome or decrease these barriers. When considering the introduction of these diverse policy measures, it acknowledged that current knowledge of the potential human health and environmental risks from chemical content of recycled plastics has limitations and uncertainties. Therefore, future policy decisions should be informed by careful cost–benefit and socio-economic analyses that integrate scientific evidence on potential health and environmental impacts in order to assess the overall appropriateness of proposed measures.

Upstream/design stage measures

- Investigating where there can be opportunities for reducing complexity of the chemical composition per application type by limiting and standardising the permissible additives.
- Restricting problematic chemicals, either those that impede recycling or impart human or environmental risks, including consideration of market restrictions for chemicals with unknown or incomplete hazard profiles.
- Designing for recycling with additional consideration of chemical selection consequences. This could include incentives based on modulation of extended producer responsibility (EPR) fees for particular product types taking into account targeted chemical-content considerations of materials derived from both virgin and recycled plastic feedstocks.

Transparency of chemical content of plastic products

- Use of mandatory chemical disclosure requirements, harmonised reporting formats and use of (digital) product passports.
- Application of market-based recognition schemes rewarding transparency.
- Complementing disclosure requirements by potential modulation of extended producer responsibility (EPR) fees for chemical transparency.

Downstream measures

- Expansion of source-separation collection where possible to reduce the heterogeneity of plastic waste. This remains the main route to cleaner and more predictable feedstock for recyclers. EPR schemes can strengthen waste quality by setting minimum collection and sorting performance targets or integrating deposit-refund systems that encourage clean material streams.
- Expansion of closed-loop recycling systems which offer an even higher-quality pathway for feedstock, but they are technically and economically difficult to establish and generally only viable for product categories with consistent waste streams. Producer Responsibility Organisations (PROs) can be encouraged to pursue closed-loop recycling systems for percentages of their waste streams.
- Support for the development and scaling-up of advanced recycling technologies, including both chemical and innovative mechanical recycling processes capable of removing or reducing contaminants should be further strengthened. However, it is equally important to assess the potential risks and sustainability implications of these emerging approaches, including possible emissions, releases, and leakages during processing, as well as their technical scalability and financial viability.

Common standards

- Development of internationally recognised standards for recycled plastics that include requirements on chemical content analysis that support compliance with heterogeneous regulatory requirements. This will require corresponding test protocols to be developed in tandem with the standards. In addition, aligned regulatory thresholds for chemical detection across jurisdictions enable the development and use of analytical methods that can reliably detect substances at or below the strictest limits applicable to global markets. These types of international standards would also support further uptake of recycled materials in high-end applications (such as skin contact, food contact, medical use).

- Economic support options for chemical identification and analysis of recycled plastic
- Consideration of targeted levies for compounders or producers that subsidise chemical analysis of recycled plastics.
- Development of a publicly available chemical database to support material screening, which is periodically updated with detected contaminations per waste or material stream. This will reduce the time and effort required for predicting contaminations for targeted screening and could also support prioritisation of chemicals to be managed. Existing initiatives, such as the European Chemicals Agency Plastics Additive Initiative (ECHA, 2018) and the ICCA Plastic Additives Database, which list substances commonly used in virgin plastics, could serve as complementary references for identifying priority chemicals.
- Collaboration between the plastics industry and research institutes should be incentivised. Research could focus on breakdown products and reaction products in plastics recycling and other under investigated chemical sources.

The priority of implementation of the above measures will depend on the chemical and waste management regulatory and policy contexts and industry practices in different countries.

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Chemical content validation of recycled plastics

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Plastics are versatile materials that are used across multiple applications and sectors delivering many benefits to society. Plastics may include thousands of different chemicals, including some that raise particular concern and may have negative impacts on human health and the environment if not properly managed. Identifying these substances becomes even more challenging when materials are recycled, as chemical information may be incomplete or lost along value chains and new contaminants, degradation products or reaction products can emerge during use and recycling. The heterogeneity of plastic waste, with limited source separation of closed loop systems, increases this complexity. This report provides an overview of the chemical considerations integrated into standards, certifications and quality control measures for recycled plastics, and examines analytical techniques used to characterise the chemical content of secondary materials. Overall, ensuring chemical safety in recycled plastics requires an integrated approach combining harmonised international standards, robust analytical techniques, chemical traceability systems, economic incentives and research collaboration. Together, these elements can support safe and sustainable circularity while maximising recycling rates.