The Consumer Goods FORUM

Plastic Waste

Chemical Recycling in a Circular Economy for Plastics

A Vision and Principles Paper

A paper developed by members of The Consumer Goods Forum's Coalition of Action on Plastic Waste

www.tcgfplasticwaste.com

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About The Consumer Goods Forum's Coalition of Action on Plastic Waste

The Consumer Goods Forum ("CGF") Coalition of Action on Plastic Waste was founded in 2020 with the aim of developing a more circular approach to the development and processing of plastic packaging in the consumer goods industry. The development of the Coalition builds of the CGF's 2018 endorsement of the Ellen MacArthur Foundation's New Plastics Economy. As a CEO-led group of 40 committed and innovative retailers and manufacturers, the Coalition's vision of accelerating progress towards the New Plastics Economy is embodied by its central aims for members to work towards implementing impactful measures through multi-stakeholder collaborations that will help make circularity the norm in the industry.

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Executive Summary

What Is This Paper?

16 companies under the umbrella of the Consumer Goods Forum Plastic Waste Coalition of Action (PWCoA) have co-authored this paper to provide a shared view of the role of pyrolysis-based Chemical Recycling[1] (Py-CR) in a circular economy for plastics, and to outline a shared vision and principles for their potential development and deployment for plastic-to-plastic recycling.

This paper focuses on pyrolysis-based chemical recycling (Py-CR), which breaks down plastics into simpler building blocks for plastics manufacturing. This contrasts with mechanical reprocessing, which only uses physical methods (but doesn't alter the chemistry) to recycle different types of plastics.[2]

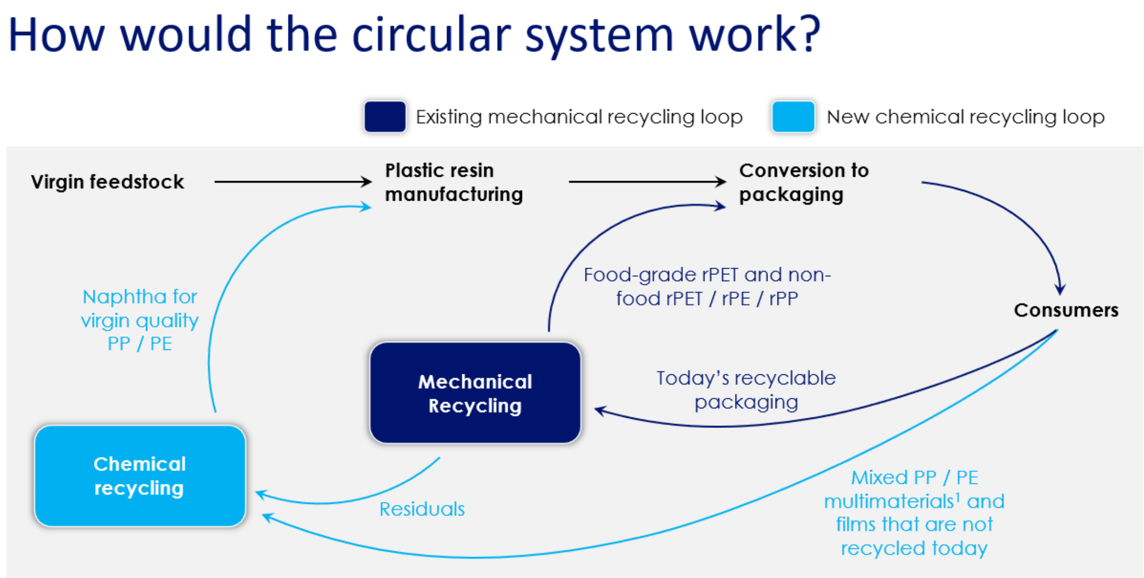
Why Is It Important?

Chemical recycling is the only way to recycle large volumes of flexible plastics packaging and other mixed polyethylene/polypropylene (PE/PP) into food grade PE/PP recycled content (under current European regulations). Once operating at industrial scale, chemical recycling has the potential to recycle post-consumer flexible plastics "in practice and at scale». This could increase packaging recycling rates which could enable recyclability targets to be met[3], and allow the reprocessing of flexible plastics into pure PP or PE suitable for use in new food-grade plastic applications.

PWCoA member companies were asked to estimate their potential European demand for chemically recycled PE/PP, if it meets their quality and safety standards and is "reasonably priced". The estimated aggregated volume demand for 780,000 tonnes per year of chemically recycled PE/PP (of which 680,000 tonnes per year is food grade) from 22 member companies responding to this survey demonstrates the potential market demand for chemically recycled plastics. Meeting just this volume of demand would require 60-70 new medium-sized chemical recycling plants.[4]

How Will Chemical Recycling Work?

EXHIBIT 1: Plastics loops within a circular economy



The vision is for Py-CR to increase recycling rates, by providing a complementary recycling "loop" for plastics that are not recycled in practice and at scale in today's system (Exhibit 1). This new loop will involve a broader set of infrastructure and players than today's mechanical recycling system, as Py-CR interacts with the petrochemicals value chain.

What Shared Principles Should It Adhere To?

We believe that Py-CR can play an important role in a circular economy for plastics if it is developed and operated under credible, ethical, safe and environmentally sound conditions. To help encourage this we have outlined six key principles specific to Py-CR, that complement existing principles and standards guiding all recycling (mechanical or chemical).

1. Py-CR increases overall recycling volumes. Input material for Py-CR does not include material that can be economically recycled by mechanical recycling in practice and at scale.
2. Recycled content from Py-CR is accurately traced from plastic waste inputs to recycled plastic through a mass balance protocol that is widely accepted and applied.
3. Plastic production from Py-CR is maximised, other recycled outputs (e.g. bitumen/asphalt, waxes) are de-prioritised, and non-recycled outputs such as fuels are minimised.

4. Life cycle environmental impacts (with a focus on climate) of chemically recycled plastics are credibly demonstrated as equivalent or lower than fossil fuel-based virgin plastics in a comparable system.

What Is Our Vision?

Our vision is for Py-CR to develop in line with the above key principles so that by 2025 it reaches industrial scale. By 2030 we aim for it to be scaled sufficiently to:

- Enable recycling of flexible and hard to recycle plastics at scale, to hit targets for recycling rates and recyclability.
- Help meet recycled content targets set by many companies and governments, by producing food-grade recycled plastics at scale.

The Role of The Consumer Goods Forum Plastic Waste Coalition of Action (PWCoA) in Delivering This Vision

The PWCoA has a unique role to play in further advancing the scale-up of Py-CR. Opportunities include:

- Providing a clear vision for Py-CR and a consistent message on key topics such as mass balancing
- Engaging with stakeholders on the topic
- Building the evidence-base to help ensure Py-CR scales in line with the principles (for example through a peer reviewed, credible life-cycle assessment)
- Highlighting the demand for chemically recycled plastics by sharing collective demand for recycled content and thus encouraging investment

Introduction and Focus of This Paper

Achieving a circular economy for plastics requires committed work to eliminate all problematic and unnecessary plastic items, innovate to ensure that the plastics we do need are reusable, recyclable, or compostable and circulate all the plastic items we use to keep them in the economy and out of the environment.

Under current European regulations, pyrolysis-based chemical recycling (Py-CR)[5] is currently the only route capable of "at-scale"[6] processing of flexible plastic packaging and other mixed, degraded or contaminated PE/PP streams into pure PP or PE suitable for use in new food-grade plastic – a circular system for high-quality materials. Current (mechanical) recycling systems can recycle some post-consumer flexible plastic packaging, but their recycled material outputs generally have fewer applications, lower value, and cannot be used in food-grade packaging.

This paper provides a shared vision for Py-CR in a circular economy, and a shared set of principles that we believe provide guidance for the positive development of Py-CR. It is intended to aide alignment between diverse stakeholders, from policy makers to technology providers, petrochemical players and NGOs. The paper does not provide an in-depth review of technologies, or offer an evidence assessment of Py-CR's feasibility, although a brief technical background and definitions can be found in Appendix 2. The vision is based on our current knowledge, and we are continuing our work to verify the feasibility of the technology and system adhering to our principles. The positions stated in this paper are subject to change as new information about the technology emerges over time.

Although none of the underlying technologies used for Py-CR are new, there is increasing interest in their application as potential solutions to complement mechanical recycling and build a circular economy for plastics. Despite interest in Py-CR, the CGF members continue to support the development of mechanical recycling of food contact approved plastics in future.

Technological Focus of This Paper

The different chemical recycling technologies could each play an important role in achieving a circular economy (see Appendix 2). Pyrolysis technologies are furthest advanced as a source of food-grade recycled PE and PP and are the focus of this paper. Future versions of the paper could expand this scope, for example to include gasification and depolymerisation technologies, which could play a role in the future vision, but have significant differences to pyrolysis.

Pyrolysis technologies for chemical recycling have gathered significant tailwind in recent years, particularly in Europe[7], with involvement of petrochemical companies aiming to integrate these technologies into their value chains and announcements from major consumer brands aiming to meet ambitious recycled content commitments.

A Vision for Chemical Recycling in a Circular Economy for Plastics

Our vision is for Py-CR to develop in line with the key principles outlined below so that by 2025 it reaches industrial scale. By 2030 we aim for it to be scaled sufficiently to:

- **Enable recycling of flexible and hard to recycle plastics** at scale, to hit targets for recycling rates and recyclability.
- **Help meet recycled content targets set by many companies and governments, by producing food-grade recycled plastics at scale.**

A circular economy for plastics is built on the principles of resource efficiency, the prevention of waste and pollution, and a low-carbon footprint. We start with the reduction of packaging material and reusable packaging wherever possible. For essential packaging that cannot be reused, recycling is preferable to disposal, incineration or littering.

Accordingly, mechanical recycling of plastics is preferred to Py-CR (for suitable materials) due to its lower energy demand (and therefore climate impact) and lower costs when compared to Py-CR, but it has several limitations:

- Challenges in producing food grade PP and PE[8] and other higher quality recycled content grades (e.g. natural/ivory) to meet growing market demand;
- Losses in material properties and a build-up of additives and other (potentially hazardous) contaminants, limiting recycling loops before quality deteriorates;
- Limited yield arising from the mixed, degraded or contaminated nature of plastic waste streams, which causes high sorting and processing losses; and
- Challenges in handling, sorting, and processing post-consumer flexible plastic packaging materials, combined with lower value end markets for the recycled plastics that are typically produced from these materials.

Mechanical recycling technologies and value chains are improving to mitigate the challenges above. This is a welcome direction. We view pyrolysis as a complementary technology to produce food-grade recycled PE/PP packaging from materials that are not processed through mechanical recycling (see Exhibit 1 and Appendix 3). It currently offers the most advanced method of recycling mixed, degraded or contaminated PE/PP streams into high-value end applications in Europe and is the only technically viable option today for large-scale production of food-grade recycled PE and PP (outside of some regions' ability to make food-grade recycled PE from bottles). As these polymers make up the largest component of consumer plastic packaging (~60%[9]), advancing an at-scale solution for PE and PP would bring an immediate impact to the plastic waste challenge.

Demand for recycled food-grade PE and PP is currently greater than the supply, and Py-CR of flexible packaging could reduce the use of virgin plastic and provide substantially greater volumes of food-grade recycled materials to meet companies' recycled content commitments.

Our vision therefore requires change to the end-to-end system, including packaging design (for both mechanical and chemical recycling)[10], waste collection and sortation, accelerated technology development and deployment, and acceptance of Py-CR as a positive solution by regulators and other key stakeholders. The plastic-to-plastic recycling pathway is yet to reach scale. The industrial development of pyrolysis is at an inflection point where potential challenges and unknowns must be addressed and tested as it scales in order to offer confidence to regulators, investors, industry players and consumers. The priorities are:

- Ensuring the system economics work, including investments needed, operational costs, collection, and sorting
- Proving sufficient quantity and quality of PP/PE feedstock can be secured to enable acceptable process yields into recycled plastic, without diverting feedstock from mechanical recycling
- Measuring environmental impact, including climate impact, chemical toxicity and resource depletion
- Achieving acceptance from regulators and other stakeholders, and alignment on terms and definitions such as mass balance.

Principles for Chemical Recycling

We believe that Py-CR can play an important role in a circular economy for plastics if it is developed and operated under credible, ethical, safe and environmentally sound conditions. To help encourage this we have outlined six key principles to guide the development of pyrolysis Py-CR technologies in line with the vision for Py-CR in a circular economy for plastics. They should be complementary to existing principles and standards guiding all recycling (mechanical or chemical).[11]

1. **Source of Input Materials**
Py-CR increases overall recycling volumes. Input material for Py-CR does not include material that can be economically recycled by mechanical recycling in practice and at scale.[12]

2. **Material Traceability**
Recycled content from Py-CR is accurately traced from plastic waste inputs through to recycled plastic using a mass balance protocol that is widely accepted and applied. This enables Py-CR to contribute towards both recycling and recyclability targets and recycled content targets.

3. **Process Yields**
Suppliers demonstrate they have maximised the plastic-to-plastic portion of outputs from Py-CR processes, de-prioritised the portion being used for other recycled outputs (e.g. bitumen/asphalt, waxes), and minimised non-recycled outputs such as fuels.[13]

4. **Environmental Impact**
The life cycle impact (with a focus on climate[14]) of chemically recycled plastics is credibly demonstrated as equivalent to or lower than fossil fuel-based virgin plastics in a comparable system.[15]

In addition, two further principles have been identified for inclusion in this paper because of salience with stakeholders, even though they would also apply to other recycling processes:

5. Health and Safety

Emissions and pollutions from chemical recycling processes are properly managed to safeguard health and safety of people and the environment.

6. Claims

Claims about chemical recycling made by companies purchasing plastics produced by chemical recycling are communicated credibly and transparently to support consumer decision-making.

For further description of plastic-to-plastic and plastic-to-fuel technologies, and mass balancing protocols, see Appendix 4.

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- Tetra Pak
- Unilever

This document has been written in accordance with competition laws. By way of example, members which have co-authored this document have not discussed, communicated nor exchanged any commercially sensitive information, and co-authorship was made on a voluntary basis on the basis of fair, reasonable and non-discriminatory grounds.

Addendum

Section 1: What is This Paper?

This is an addendum to the "Chemical Recycling in a Circular Economy for Plastics: Vision and Principles Paper" developed by the Consumer Goods Forum Plastic Waste Coalition of Action. This addendum paper is co-authored by the same companies as the original Vision & Principles paper.

The addendum refers only to plastic-to-plastic pyrolysis-based chemical recycling (Py-CR), using a mass balance approach to allow for mixing between recycled and virgin feedstocks in plastic manufacturing. Other chemical recycling technologies such as depolymerisation of PET may not require mixing of feedstocks or mass balance approaches and these other technologies are not covered by this addendum.

This addendum has two objectives:

1. Provide information on how the key principles from the Vision and Principles paper are covered under the most prominent certification schemes: ISCC PLUS, RSB Standard for Advanced Products, and REDcert2, and
2. Provide a shared perspective from the co-authors on "where we would like the chemical recycling industry and certification schemes to be by 2025" on each of the key principles. This perspective can aid CGF member companies in their collaboration and communication with certification schemes, suppliers and broader stakeholders (policy makers, technology providers, petrochemical players and NGOs)

Section 2: Key Principles for Pyrolysis-based Chemical Recycling (Py-CR) in a Circular Economy for Plastics

We believe that the key principles are essential to ensure a credible, ethical, safe, and environmentally sound role for chemical recycling in a circular economy for plastics. For each key principle, the table below summarises the key elements that are currently covered by three examples of certification schemes[16] and provides a shared perspective from the co-authors on the proposed goal for the chemical recycling value chain, by 2025. The co-author companies have proposed a time horizon of 2025 for suppliers and certifiers to align to these goals although we would welcome earlier alignment.

Our intention is that by sharing these proposed goals from a "customer" perspective we will support more robust development of the chemical recycling value chain and certification schemes in line with our key principles.

Information related to claims is not part of this section and will be addressed in another paper.

Key principles outlined by co-authors of the PWCoA Vision and Principles paper (2020)	Key elements covered by certification standards and methodologies[17]	Shared position of co-author companies on the proposed goals for the chemical recycling value chain and certification schemes, by 2025
1. Source of Input materials does not include material that can be economically recycled by mechanical recycling in practice and at scale.	• **RSB** requires evidence that all practical and cost-effective efforts to remove (mechanically) recyclable material[18] have been made or that (mechanical) recycling would result in poor product properties or in a higher environmental impact.[19] • **ISCC PLUS** requires that sorting companies have sufficient measures and processes in place to take these issues into consideration and to determine, how plastic waste will be recycled. Chemical Recycling should be applied where mechanical recycling is not technically feasible, economically viable, leads to low-quality products or has a higher negative environmental impact. • **REDCert** do not have specific provisions that would apply to this principle.	• Implementing robust systems and processes to ensure that waste plastic input materials for chemical recycling do not include material that can be economically recycled by mechanical recycling in practice and at scale..
2. Material traceability is accurately achieved from plastic waste inputs through to recycled plastic using a mass balance protocol that is widely accepted and applied	**2.1 Avoiding Double Counting of Materials** *Explanation: Deliberate or accidental "double-counting" of recycled plastic production creates legal and reputational risks for buyers of recycled plastics, and risks to the credibility and success of chemical recycling overall.* • **ISCC PLUS, RSB**, and **REDCert²** all have provisions for avoidance of double counting of materials	• Continued integrity and robust defence against double counting.

Key principles outlined by co-authors of the PWCoA Vision and Principles paper (2020)	Key elements covered by certification standards and methodologies[17]	Shared position of co-author companies on the proposed goals for the chemical recycling value chain and certification schemes, by 2025
	2.2 Differentiating Energy Carbon from Feedstock Carbon in a Mass Balance Protocol *Explanation: Energy carbon refers to the share of the plastic waste (by weight) that is used to generate energy at any stage of the end-to-end process from plastic waste through to new plastic or sold as a fuel. Feedstock carbon refers to the share of the plastic waste (by weight) that is converted into new materials (recycled plastics or other non-fuels materials).* • **RSB** requires that energy carbon cannot be counted in the mass balance protocol. The operator shall document the amount of feedstock based on non-biobased end-of-life products or production residues that is used as material in the system. The following feedstock shall not be considered in balance: Feedstock that is used as energy or other auxiliaries, which will not be present in a final product (e.g. solvents, catalysts): • **ISCC PLUS** in general allows the free attribution for the determination of the sustainable share of input material to the output material. Energy carbon can be counted in the mass balance protocol and attributed to the respective output at the certified unit (site-specific mass balances for each production step).[20] (see the limitations of the free attribution in the end note[21]**).**	• Only counting feedstock carbon and not energy carbon in the allocation of feedstocks to material outputs in a mass balance protocol. (This means that the share of plastic waste input that is used to generate energy at any stage of the end-to-end process or that is sold as fuel cannot be counted in the allocation of feedstock to material outputs).

Key principles outlined by co-authors of the PWCoA Vision and Principles paper (2020)	Key elements covered by certification standards and methodologies[17]	Shared position of co-author companies on the proposed goals for the chemical recycling value chain and certification schemes, by 2025
	• **REDCert²** allows the possibility to count energy carbon as feedstock carbon if the recycled input can power the thermal chemical producing unit with energy to produce chemically recycled intermediate output, for example pyrolysis oil, to reduce the carbon footprint.	
	2.3 Physical connection in a Mass Balance Protocol[22] *Explanation: Physical connection refers to a physical chain that could transport material between input (feedstock/recycled content) and output (plastic products). Physical connection can be in form of pipeline (the strictest), or road / rail / water.* **ISCC PLUS, RSB**, and **REDCert²** all allow for multi-site boundaries within a mass balance protocol, without physical connection, with different requirements: **ISCC PLUS:** • allows credit transfer between sites that are not physically connected if they are part of the same company (or the same corporate group or joint venture) and are located within national borders or within neighbouring countries (sharing an inland border).- • Applicable only for the same kind of product (e.g., it would not be possible to transfer credits between PE and PP)	• Provide transparent reporting on the approach that is taken to physical connection in a mass balance protocol, so that companies purchasing plastics produced by chemical recycling can make informed decisions.

Key principles outlined by co-authors of the PWCoA Vision and Principles paper (2020)	Key elements covered by certification standards and methodologies[17]	Shared position of co-author companies on the proposed goals for the chemical recycling value chain and certification schemes, by 2025
	• requires each site to be ISCC certified and audited separately by the same certification body. • Mass balances also must be kept site-specific (Site-specific credits must be calculated and verified). **RSB:** • allows credit transfer between sites that are not physically connected if the operator can avoid double-booking e.g., by limiting the boundary to one legal entity or by having specific contractual relationships in place. • no physical or chemical connection means the claim must not refer to ‘recycled content’, but can only link to positive impacts (e.g., amount of virgin fossil displaced, or amount of climate impact (% GHG reduction) • allows one certification for all sites within a single company (risk-based approach) **REDcert2:** • allows credit transfer between sites that are not physically connected if the sites are part of the same company with a maximum distance of 2,000 km between sites (called Extended Mass Balance) • requires all operating sites to be certified	

Key principles outlined by co-authors of the PWCoA Vision and Principles paper (2020)	Key elements covered by certification standards and methodologies[17]	Shared position of co-author companies on the proposed goals for the chemical recycling value chain and certification schemes, by 2025
	• **2.4 Chemical connection in a Mass Balance Protocol** *Chemical connection refers to a verifiable chemical link (at least qualitatively) between the input (feedstock derived from plastic waste) and output (plastic products).* *Note: due to the complexity of chemical facilities and processes, detailed tracing of chemical reactions is unfeasible. No requirement for chemical connection would mean any recycled molecule entering a petrochemical facility could be attributed to any product even if it is not chemically possible to manufacture that product from that recycled molecule.* • **ISCC PLUS** only allows attribution to process outputs that can potentially contain parts (molecules/atoms) of the sustainable input after its processing/chemical reaction (no attribution to output, which cannot (chemically/ technically) include the sustainable input). • **RSB** allow attribution without chemical connection, but it will affect the claim (see the same point in the physical connection above) • **REDcert²** allows free attribution without chemical connection.	• Provide transparent reporting on the approach that is taken to chemical connection in a mass balance protocol so that companies purchasing plastics produced by chemical recycling can make informed decisions.

Key principles outlined by co-authors of the PWCoA Vision and Principles paper (2020)	Key elements covered by certification standards and methodologies[17]	Shared position of co-author companies on the proposed goals for the chemical recycling value chain and certification schemes, by 2025
3. Process yield is maximised for plastic-to-plastic, other recycled outputs (e.g. bitumen/asphalt, waxes) are de-prioritised, and non-recycled outputs such as fuels are minimised.	• This principle is not directly addressed by any certification yet	• Set a minimum threshold for the end-to-end yield (plastic waste to recycled materials or chemicals), using a consistent definition / methodology
4. Life-cycle environmental impact (with a focus on climate) of chemically recycled plastics is credibly demonstrated as equivalent or lower than fossil fuel-based virgin plastics in a comparable system	• **RSB** requires at least "10% lower lifecycle GHG emission calculated on a cradle-to-grave basis relative to the lifecycle GHG emissions of a comparable (fossil) product". • **ISCC PLUS** have a voluntary option to report on GHG emission reductions. Chemical recycling should be applied where mechanical recycling is not technically feasible, economically viable, leads to low-quality products or has a higher negative environmental impact.[23] Note that ISCC PLUS provides it own GHG methodology in addition to the ISO ones described below. • **REDCert**[2] have a voluntary option to report on GHG emission reductions. • All three schemes have guidelines on GHG emissions calculation methodology and standard according to ISO 14040 and/or 14044.[24]	• Demonstrate that GHG emissions associated with the production[25] of chemically recycled plastic (using a consistent definition / methodology) are lower[26] compared to fossil fuel-based virgin plastics in a comparable system (using a consistent definition / methodology)

Key principles outlined by co-authors of the PWCoA Vision and Principles paper (2020)	Key elements covered by certification standards and methodologies[17]	Shared position of co-author companies on the proposed goals for the chemical recycling value chain and certification schemes, by 2025
5. Health and safety. Emission and pollutions from chemical recycling processes are properly managed to safeguard health and safety of people and the environment.	The three certification schemes have guiding principles that cover this principle.[27] . • **ISCC PLUS** requires environmentally responsible production to protect soil, water and air (Principle 2 of ISCC's Sustainability Requirements). • **RSB** requires that the use of technologies shall seek to maximise production efficiency and social and environmental performance and minimise the risk of damage to the environment and people (principle 11 of RSB's Principles). • **REDcert²** requires sustainable management as per sustainability requirements of European Directive 2009/28/EC	• Maintain continued high attention on health and safety of the Py-CR process

Appendices

Appendix 1: The Work of the Chemical Recycling Workstream of the PWCoA

The 2021 ambition for the chemical recycling workstream of the PWCoA is to guide the development of pyrolysis technologies as a source of food-grade recycled content and a positive recycling option for hard-to-recycle plastic packaging, in line with the principles laid out in this document. The (initial) material focus is post-consumer[28] PE or PP-based plastic films (mono-material or multi-material), and mixed, degraded or contaminated PE/PP streams as they are the most challenging common packaging types to recycle mechanically in the current system.

Manufacturers of packaged goods and retailers have a unique position in the value chain with the ability to shape standards, drive end-to-end system changes and work towards acceptance by regulators and stakeholders. This is amplified when they come together in a coalition such as the PWCoA.

Specifically, through the PWCoA, manufacturers and retailers can help catalyse the industrial scale development of plastic-to-plastic Py-CR by addressing the questions listed above and building confidence across the stakeholder landscape through activities such as:

1. **Creating and communicating a clear vision and narrative:** Develop a clear and aligned narrative and messaging on topics including our vision for Py-CR, terminology, definitions, principles for a safe, ethical and credible Py-CR system, mass balance etc.

2. **Engaging with stakeholders:** Engage critical stakeholders to understand any concerns and ensure they are addressed.

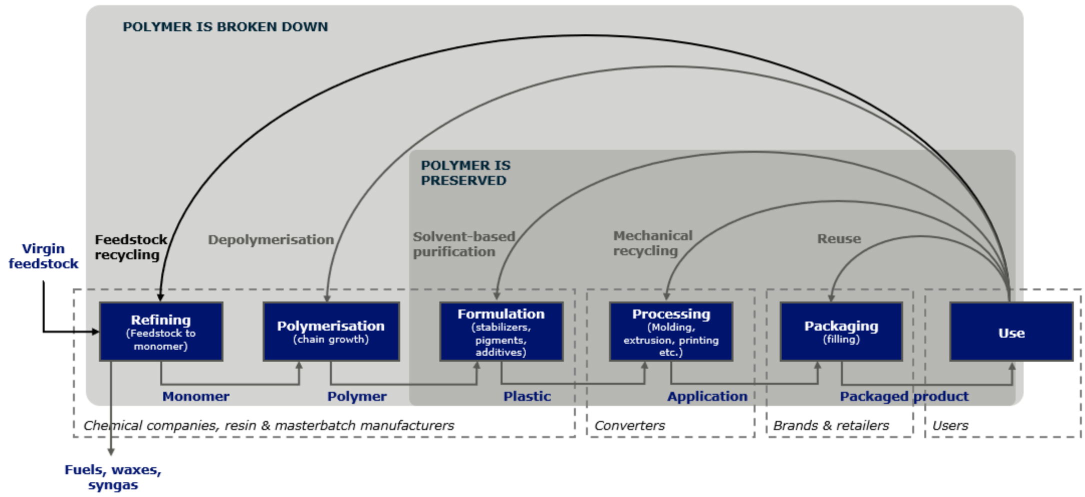
3. **Strengthening credibility:** Build the evidence base to help ensure Py-CR scales in line with principles, for example through life-cycle assessment of environmental impacts of Py-CR, by building chemical-recycling-specific design of protocols, aligning on on-pack claims etc.

4. **Signalling demand:** Provide a clear signal of long-term demand for PE and PP from Py-CR to offer confidence to the petrochemical players, technology developers and investors who need to mobilise significant capital to scale collection and infrastructural technology for Py-CR.

Appendix 2: What Are the Different Chemical Recycling Technologies?

A number of chemical recycling technologies exist, differing by which types of polymers they can process and how much they break down the plastics.[29] Exhibit 1 outlines the different loops for plastics within a circular economy, including the three main types of new technologies described below:

EXHIBIT 1: Plastics loops within a circular economy



Source: Adapted from De Smet, M. & Linder, M. (Eds.), *A circular economy for plastics – Insights from research and innovation to inform policy and funding decisions*, European Commission, Brussels, Belgium (2019)

Solvent-based purification (not classified as chemical recycling by some definitions; also referred to as dissolution recycling, physical recycling, and solvolysis) is a process that creates pure streams of polymer by dissolving plastic in solvent(s) and using a series of purification steps (removing additives and contaminants that are not removed in mechanical recycling for example). The resulting polymer remains unaffected by the process and can be reformulated into plastic.[30]

Depolymerisation can be conducted through a biological method (using enzymes) or through chemical catalysis and creates an "unzipping" of polymers that is the reverse of polymerisation. It yields either shorter fragments called oligomers or single monomer molecules. The fragments can be used to make virgin-grade polymers again. These technologies have been demonstrated for certain polymers such as PET and polyamide[31], but not yet for polyolefins (polyethylene and polypropylene).

Feedstock recycling (e.g. pyrolysis or gasification technologies) converts polymers into multiple simpler molecules, and it requires thermal processes with significant heat inputs. It processes mixed streams of polyolefin polymers, notably PP and PE which make up ~60% of consumer packaging.[32] The two main technology groups are pyrolysis and gasification.[33] Pyrolysis uses an oxygen-deprived environment and produces ash (for disposal), a light gas portion (which can be used to power the thermal processing), and "pyrolysis oil" which contains many different hydrocarbons that can be fed to a refinery and eventually converted to monomers for plastics manufacturing (using a catalytic or steam cracker) or other petrochemical products. Plastics with heteroatoms (e.g. PET, PAs, PVC) are not target materials for pyrolysis as they negatively impact yield and could lead to unwanted (potentially hazardous) by-products. Gasification is conducted with a limited oxygen supply and can generate a mix of carbon monoxide and hydrogen called syngas. Syngas is a versatile feedstock that is used in countless chemical processes. Its relevance for the plastics value chain comes from the possibility to convert it to methanol, which can be further processed into ethanol and propanol which are precursors for ethylene and propylene. As with pyrolysis, these outputs could also be used as fuels. The feedstock to gasification can be any plastic, including PET, PVC (to some extent), Nylon, etc.

Appendix 3: Differences Between Mechanical Recycling and Pyrolysis Recycling

	Mechanical recycling (MR)	Pyrolysis recycling (Py-CR)
Complementarity	Suitable for clean streams, sorted by polymer (rigids, semi-rigids, mono-material films)	Suitable for a wide range of clean mixed PE and PP plastic streams without a viable MR pathway (e.g. multi-material films)
Energy demand	Lower; a PET bottle from mechanically recycled PET takes as little as 20% of the energy of a virgin PET bottle to make	Significant energy demand, higher than MR
Feedstock tolerance	Relies on homogenous, well-sorted streams, with plastics of different grades and pigments harming output quality	Can process mixed grades of PE and PP. Tolerance for contamination depends on what the final output is going to be and specific processing capabilities. Generally, PVC is corrosive and needs to be avoided. Contaminants such as PET, polyamides and aluminium can generally only be tolerated at low levels of contamination. It is likely that pre-sorting would be required to provide an acceptable PE/PP stream
Process yields	Highly dependent on purity of input materials, but 1 tonne of sorted plastics entering a recycling facility creates approximately 0.7[34] tonnes of recycled plastics after processing losses	Variable and not proven at scale, in general plastic-to-plastic yields are expected to be lower than mechanical recycling.
Contamination	Sensitive to contamination from product residue (e.g. food), mixing additives and external contaminants	Since the plastics are broken down to simpler chemicals that get refined to virgin-grade polymer, the process is less sensitive to contamination (though some e.g. metals and minerals can be problematic)
Quality retention	Recyclate quality is diminished by mixing of grades. In addition, heat and mechanical stress degrades the polymer each time it is re-extruded, mainly by shortening the average chain length	

Appendix 4: Explanatory Notes on Plastic-to-plastic and Mass Balancing

Plastic-to-plastic vs. Plastic-to-fuel

The petrochemical compounds that pyrolysis produces can either be:

a) Reintroduced into the petrochemical value chain to produce virgin-grade plastics[35] – a route recognised as plastic-to-plastic Py-CR and considered a type of **recycling.**[36]

b) Refined into hydrocarbon fuels, such as diesel – a route known as plastic-to-fuel and considered to be a type of **energy recovery** by the European Commission[37] (not recycling) as it does not allow carbon to be utilized for additional anthropogenic loops (ISO15270:2008). Therefore, in many jurisdictions and voluntary reporting frameworks plastic-to-fuel processes cannot be counted towards fulfilling companies' recyclability and recycling targets.

Our vision is to advance the establishment of plastic-to-plastic Py-CR, maximising the yield of plastic waste into new plastics as laid out in the Principles of this paper

How is the Recycled Content Tracked Through the Supply Chain?

The pyrolysis process outputs a synthetic oil with fractions that are suitable for plastic resin manufacturing (naphtha) and others that can be converted to fuels or other chemical applications.[38] In at-scale plastic-to-plastic recycling, naphtha is inputted into industrial-scale petrochemical crackers where recycled feedstock is blended with virgin feedstock and the outputs can be used as feedstock to produce virgin quality PP and PE. Users of this recycled PP/PE can claim recycled content based on a robust mass balance certification which accounts for blending of virgin and recycled feedstocks in the plastic manufacturing process.[39]

In mass balancing, recycled content then allocated to certain products using a chain-of-custody protocol,[40] resembling how renewable electricity (or Fairtrade cocoa or FSC forestry) is allocated to different buyers. The mass balance principle is not new in the chemical industry either. It has been used for years to introduce renewable feedstocks into chemical production. What is new is applying mass balance specifically to recycling. There is an ongoing, industry-wide discussion on how to standardise mass balancing to ensure stringent allocation rules, physical tracing, transparency, and a level playing field to build confidence in the approach.[41] A credible mass balance protocol is critical to enable pyrolysis-based plastic-to-plastic CR to develop at scale. Through mass balance, existing infrastructure can be modified, and we can administratively track recycle materials co-processed together with virgin feedstock.

Figure 1: simplified illustrative example of mass balance system, system boundaries vary between different physical connection approaches (adapted from ISCC PLUS' illustration)

End Notes

[1.] The terms ‘chemical recycling’, ‘advanced recycling’, ‘advanced chemical recycling’ and ‘enhanced recycling’ are interchangeable. All of these terms help differentiate chemical recycling from the more widely known recycling processes that use mechanical technologies to recycle used plastics

[2] A Circular Economy for Plastics, European Commission, 2019. Other technologies than pyrolysis are commonly described under the umbrella term ‘chemical recycling’, as laid out in Appendix 2.

[3] For this to be the case, regulators would need to consider chemical recycling as recycling. Current assessment is that this is likely in many European countries, but the situation beyond Europe is still developing.

[4] In March 2020 and September 2021, PWCoA companies were asked to share what volume chemically recycled polypropylene (PP) and polyethylene (PE) they would need to purchase from EU markets to meet their commitments, to be used for either conversion to packaging within the EU or exported to non-EU markets for conversion, assuming it could be attained at a reasonable price, the same quality and food safety as virgin plastic, and the certified material would count towards targets. ‘Medium-sized’ corresponds to a 25,000 tonnes per year input capacity.

[5] The term ‘chemical recycling’ is an umbrella term currently used to describe reprocessing technologies other than mechanical reprocessing, which only uses physical methods to recycle different types of plastics but does not alter their chemistry. See Appendix 2 for an overview of technologies commonly referred to as Py-CR. While this Appendix uses the definition of the EU Commission for consistency, the PWCoA does not take a position for any given terminology.

[6] The Global Commitment, signed by many of the PWCoA member, sets as threshold for proving recycling **works ‘in practice and at scale’ (for a representative packaging** category) is a 30% post-consumer recycling rate achieved across multiple regions, collectively representing at least 400 million inhabitants.

[7] Pyrolysis has a stronger presence in Europe (and Asia) than the USA as it is compatible with existing petrochemical infrastructure in these regions tailored to naphtha.

[8] Apart from mechanical recycling of rigid HDPE (e.g. milk jugs) into food-grade rHDPE in some markets

[9] UK data, WRAP 2018, “PlasticFlow 2025”

[10] The CGF introduced the Golden Design Rules of which rule 6 on flexible packaging was written to support both mechanical and chemical recycling

[11] Such principles include for example: A) Recycled content claims should be standardised, clear and credible, such as ensuring it is derived from pre-consumer and post-consumer waste. B) Input material to recycling processes must be sourced in alignment with the principles of ethical sourcing. C) Recycled content must meet equivalent quality and safety standards (including food safety) as virgin-grade plastic for the corresponding application. D)The recycling process must not produce unmanaged emissions or pollution that contravenes international accepted levels for impact on human or wider ecosystem health

[12] Beyond this principle, this paper does not specify which sources of plastics are preferred although it recognises that polyolefins of good enough quality are preferred in pyrolysis (see Appendix 2). The paper’s vision is Py-CR is used to recycle post-consumer packaging plastics back into plastics.

[13] If maximizing the outputs for plastic-to-plastic leads to a higher environmental impact or a sub-optimal process, further research would be required to ensure this principle is maintained.

[14] Including GWP (CO2e) and other indicators e.g., resource depletion, energy use and toxicity such as local air pollution

[15] Taking into account both the manufacturing emissions and the potential for lower end-of-life emissions in a system that has chemical recycling operating at scale. ‘Equivalent or lower’ is taken to mean the same overall impact (within reasonable boundaries), recognising that Py-CR and virgin production will impact different LCA indicators differently.

[16] This paper does not intend to provide a comprehensive view of the certification schemes. Instead, it aims to provide information on relevant key guiding elements of the certification schemes that apply to the key principles. For more information on the certification schemes, see their website: https://www.iscc-system.org/, https://rsb.org/about/, https://redcert.org/en/

[17] Information obtained through publicly available documents and verified by the secretariat or management of respective certification scheme. Main documents used: ISCC (https://www.iscc-system.org/wp-content/uploads/2020/01/ISCC-PLUS-System-Document_V3.2.pdf); RSB (http://rsb.org/wp-content/uploads/2018/03/18-03-22_RSB-STD-02-001-v2.0-RSB-

Standard-for-Bio-based-and-Advanced-Products_rev.pdf), REDCert2 (https://redcert.org/images/SG_RC%C2%B2C_Sustainablematerialflows_Vers.1.1.pdf) – accessed on 22nd April 2021

[18] Recyclable material: Material such as glass, paper, metal, plastic, textiles, and electronics that a) can be diverted from the waste stream through regionally established recycling programmes that are available to a significant portion of the consumers or communities in the region of operation, and b) are cost-effectively collected, processed, and returned to use in the form of raw materials and products (Adapted from ISO 14021 and FTC Green Guides, 260.12).

[19] ISCC PLUS System Document v3.3

[20] This requires taking into account real production data and losses at each step in the supply chain after individual certification. The certified attribution approach can be further specified and handled in a more restrictive way, i.e. by excluding fuels in the calculation of sustainable shares. Information on a more restrictive approach can be included on the sustainability declaration. Attribution to auxiliaries or outputs that are not chemically/technically possible to produce from the output is not allowed.

[21] Free attribution means that the sustainable share can be attributed to one or several output materials. The free attribution approach is limited to: (1) Mass balancing must be site-specific, (2) The conversion factor id determined based on operational data, (3) Information on the used option for mass balance (attribution) and on multi-site mass balance must be provided via sustainability declaration, (4) It must be chemically/technically possible, that the input molecular/atoms are included in the attributed output, (5) The attributed sustainable output cannot be higher than the physical output in a mass balance period.

[22] For more information on three approaches to the physical connection in determining system boundaries (batch level, site-level, and group-level), see ISEAL document on "Chain of custody models and definitions", page 11-15: https://www.isealalliance.org/sites/default/files/resource/2017-11/ISEAL_Chain_of_Custody_Models_Guidance_September_2016.pdf - accessed on 22nd April 2021

[23] ISCC PLUS System Document v3.3

[24] For complete guideline, see: ISCC (https://www.iscc-system.org/wp-content/uploads/2017/02/ISCC_205_GHG_Emissions_3.0.pdf); RSB (https://rsb.org/wp-content/uploads/2020/06/RSB-STD-01-003-01-RSB-GHG-Calculation-Methodology-v2.3.pdf); REDCert2 (https://www.redcert.org/images/SP_EU_GHG_calculation_Vers.04.pdf) – accessed on 22nd April 2021

[25] Production in this case includes the avoidance of GHG emissions that would have been generated by the disposal or incineration of the plastic waste feedstock used for chemical recycling, if it were not chemically recycled.

[26] In this addendum paper, the companies agreed to further specify the proposed goal on the life-cycle climate impact of chemical recycling to be lower compared to fossil fuel-based virgin plastics in a comparable system. This updated view reflects the latest development on the topic by key stakeholders. For example, the European Commission's EU Taxonomy Climate Delegated Act (adopted on 4 June 2021) stated that chemical recycling contributes to climate change mitigation if *"the plastic in primary form is fully manufactured by chemical recycling of plastic waste and the life-cycle GHG emissions of the manufactured plastic, excluding any calculated credits from the production of fuels, are lower than the life-cycle GHG emissions of the equivalent plastic in primary form manufactured from fossil fuel feedstock"*. See: https://ec.europa.eu/finance/docs/level-2-measures/taxonomy-regulation-delegated-act-2021-2800-annex-1_en.pdf (last accessed on 7 July 2021)

[27] See ISCC Sustainability Requirement document: https://www.iscc-system.org/wp-content/uploads/2017/02/ISCC_202_Sustainability_Requirements_3.0.pdf; RSB's Principles and Criteria document: https://rsb.org/wp-content/uploads/2020/06/RSB-STD-01-001_Principles_and_Criteria-DIGITAL.pdf, and REDcert EU's scope and basic requirement document that also guides the basic principle of REDcert2: https://redcert.org/images/SP_EU_Basic_Vers.05.pdf – accessed on 22nd April 2021

[28] As defined in the Ellen MacArthur Foundation's Global Commitment, from ISO14021: "material generated by households or by commercial, industrial and institutional facilities in their role as end users of the product which can no longer be used for its intended purpose".

[29] For a more detailed overview, see Zero Waste Europe, El Dorado of Chemical Recycling (2019)

[30] Since solvent-based purification does not change the constitution of the polymer itself, it has been argued that it should be seen as mechanical rather than chemical recycling, or as a separate class (see also ISO 15270:2008). For practical purposes, the Appendix follows the European Commission 2019 report's terminology, which uses the logic that since chemicals are used in solvent-based purification to change the formulation of the plastic (by removing additives and extracting the base polymer(s)), it can be described as one of several chemical recycling technologies. Note that the inclusion of solvent-based purification in this overview does not reflect the position of individual PWCoA members.

[31] In principle, any so-called polycondensate can be depolymerised, which includes polymers like PET, PU, PA, PLA, PC, PHA & PEF. The exceptions to the rule are polystyrene

and PVC, which can be depolymerised into styrene or vinyl chloride using processes that differ from polycondensate depolymerisation.

[32] UK data, WRAP 2018, "PlasticFlow 2025"

[33] European Commission, A Circular Economy for Plastics (2019). 'Pyrolysis' as a term is often used to describe several methods (new and existing methods can differ significantly in their approach) to thermally break down plastic polymers in the absence of oxygen

[34] Pew Charitable Trusts and SYSTEMIQ 2020 (upcoming), "Breaking the Plastic Wave"

[35] Plastic-to-plastic recycling processes also create fuels as an unavoidable output (which can be used to power the recycling process or not); these are not considered recycling by the Ellen MacArthur Foundation. Other non-fuel, non-plastic outputs that are created such as waxes and asphalt are somewhat a grey area.

[36] By, for example the Ellen MacArthur Foundation, ISO15270:2008, some European countries such as the Netherlands, and possibly in future legislation by the European Commission. However, it is not necessarily accepted in all countries (cf. Germany) that plastic-to-plastic recycling destinations will count towards recycling targets which may be specific to mechanical recycling.

[37] European Commission, The role of waste-to-energy in the circular economy (2017)

[38] According to ISO definitions (ISO15270:2008), only the fractions that are effectively turned into new materials can be considered recycled; fractions going into fuel or losses cannot.

[39] Requires acceptance by regulators

[40] Ellen MacArthur Foundation CE100 collaborative project white paper: Enabling a circular economy for chemicals with the mass balance approach (2019)

[41] https://blog.americanchemistry.com/2020/03/how-do-we-measure-sustainability-just-one-word-standards/. Several certification providers have started to offer standard certificates for recycled content, e.g. RSB, ISCC+ and RedCert.

About The Consumer Goods Forum

The Consumer Goods Forum ("CGF") is a global, parity-based industry network that is driven by its members to encouage the global adoption of practices and standards that serves the consumer goods industry worldwide. It brings together the CEOs and senior management of some 400 retailers, manufacturers, service providers, and other stakeholders across 70 countries, and it reflects the diversity of the industry in geography, size, product category and format. Its member companies have combined sales of EUR 4.6 trillion and directly employ nearly 10 million people, with a further 90 million related jobs estimated along the value chain. It is governed by its Board of Directors, which comprises more than 55 manufacturer and retailer CEOs. For more information, please visit: www.theconsumergoodsforum.com.

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