SUSCHEM
European Technology Platform
for Sustainable Chemistry

Sustainable Plastics Strategy

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Sustainable Plastic Strategy

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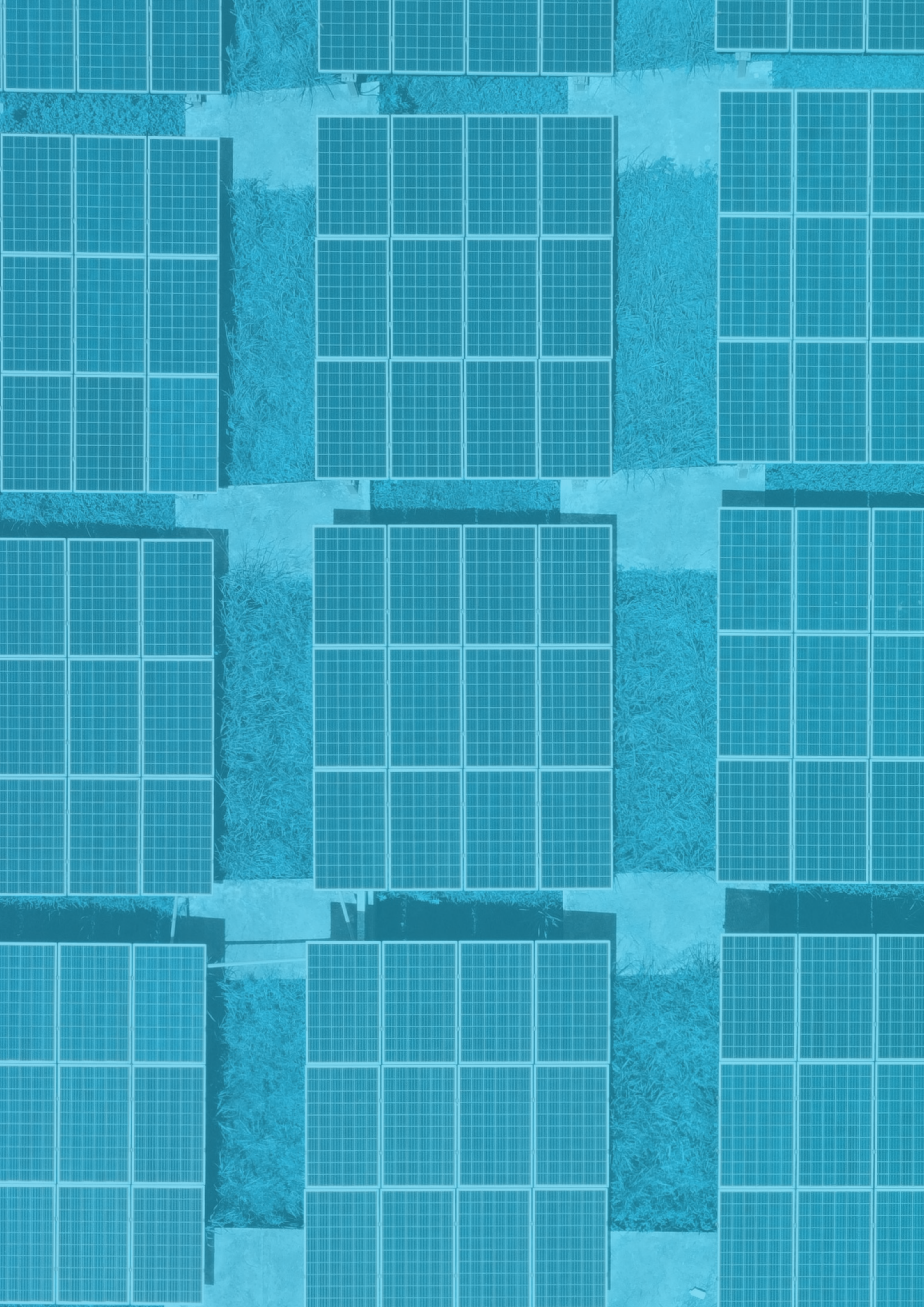
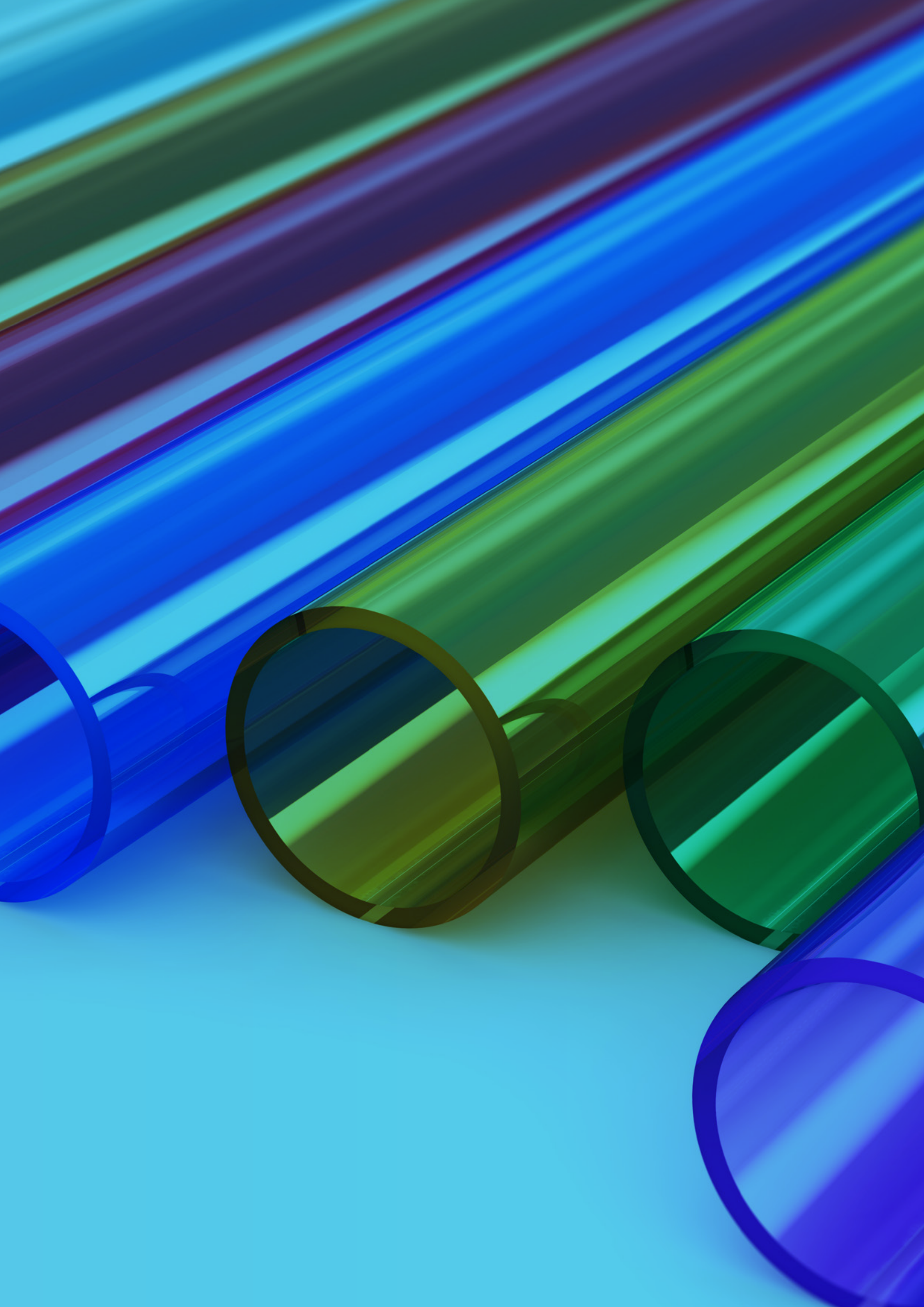


Content



Introduction

Plastic waste is ending up in the environment, and unmanaged, is amongst the greatest global environmental challenges of our time[1,2]. As an industry, we believe plastic waste in the environment is unacceptable and represents a massive loss of a valuable resource.

One of the keys to tackling plastic waste is the creation of a circular economy. In contrast to the make, use, then dispose, of linear economy; in a circular economy we keep resources in use for as long as possible, extract the maximum value from them whilst in use, then recover and regenerate products and materials at the end of their life. The circular economy is about recognising and capturing the value of plastics as a resource, with the least impact on the climate. We have over recent years accelerated the transition to a circular economy, amongst other actions.

However, the circular economy for plastics is not just about waste. Whilst eliminating leakage and the increased use of secondary materials is one part of the picture, the transition to renewable feedstock completes this picture. Long-term, plastics production should also decouple from fossil feedstock. This means using more renewable energy and more alternative feedstock from waste and renewable resources and investing in carbon capture solutions.

Much of the plastic in use today can already be recycled in some way, but according to an analysis by the Ellen MacArthur Foundation, roughly one-third of the world's plastic packaging waste is lost in the environment. In comparison, about 14% is collected for recycling, and 40% is disposed of in landfill. The remaining 14% is incinerated, sometimes with energy-from-waste recovery. In view of this, chemical technologies are needed to improve the labelling, identification and separation of waste plastics and composites into single-component polymers. These polymers should be reprocessed for reuse in new products and/or fully recycled as feedstock for pure polymers by using chemical recycling.

We need a holistic approach to plastic waste based on a measurable science-based framework that aims at preventing waste, enabling consumer awareness, and implementing eco-design-based solutions towards a circular economy. To achieve this, we need to continue to harness the power of research and innovation to address the reduction, reuse and recycling. This is envisioned by the authors of this report to make circularity and resource efficiency a reality for plastics.

Versatile and durable, plastics are a remarkable material. They allow us to meet a myriad of functional and aesthetic demands, whether this is drinking clean water, playing sport, staying connected, enjoying the comfort of home, visiting loved ones near and far, or helping us to live longer and healthier lives. Plastics have become a key part of our society, defining the way we live today, improving the quality of life for millions of people in Europe and across the globe. They make our lives easier, safer, and more mobile, while significantly increasing energy efficiency and lowering CO_2 emissions.

The European Green Deal[3] aims to make the EU's economy sustainable by turning climate and environmental challenges into opportunities and making the transition just and inclusive for all. The European Green Deal action plan will boost the efficient use of resources by moving to a clean, circular economy, restore biodiversity and cut pollution. The EU aims to be climate neutral in 2050 and this objective will require action by all sectors of the economy to invest in environmentally friendly technologies, support industry to innovate, roll out cleaner, cheaper and healthier forms of private and public transport, decarbonise the energy sector, ensuring buildings are more energy efficient and

1 https://science.sciencemag.org/content/360/6384/28.full
2 https://pubs.acs.org/doi/10.1021/acs.est.9b02900

3 https://ec.europa.eu/info/strategy/priorities-2019-2024/europe-an-green-deal_en

improving global environmental standards.

Plastic is an essential material to ensure a sustainable future and has a vital role to play in helping Europe achieve its Green Deal ambitions. As an industry we are committed to increasing circularity and resource efficiency through our voluntary commitments launched in 2018[4,5]. Innovation as a global framework will play a key role together with ongoing cooperation along the whole plastic value chain. The complexity of this value chain (made up of producers of plastics and chemical raw materials, converters, brand-owners, retailers, actors of waste management...) makes the creation of innovation ecosystems necessary to tackle the sustainability challenge. To achieve this, we need to continue to harness the power of research and innovation to significantly increase reuse and recycling. In doing so, plastics will accelerate their contribution to the European Green Deal objectives of reduced greenhouse gas (GHG) emissions and resource efficiency.

Developing high-quality and high-performance products and solutions that are sustainable can be highly complex and challenging. It requires innovative technologies and some of the best scientists, engineers and most innovative minds, and has been the bedrock of the leaders of our industry for over a century. We believe our industry has an essential role to play in making plastics more sustainable. Developing the necessary levers requires a concerted effort by everybody who can contribute.

The European Commission launched the Circular Plastics Alliance (CPA)[6] in December 2018 to help plastic value chains boost the EU market for recycled plastics to 10 million tonnes by 2025 under the European Strategy for Plastics in a circular economy (2018)[7]. The CPA initiative is based on voluntary pledges by industry[8]. In September 2020 more than 200 organisations are signatories of the CPA.

EuPC, EPC4, PlasticsEurope and a number of the SusChem platform participants are proud to be actively involved members of the CPA contributing in the five main value chains or plastics-using sectors, namely: packaging, automotive, construction, agriculture and electronic and electrical equipment ("EEE").

R&D needs have been identified across the five main CPA value chains (packaging, automotive, construction, agriculture and electronic and electrical equipment ("EEE"). The CPA commitment embraces R&D[9] and Investments including chemical recycling, Design for recycling, Collection and sorting, Recycled content, Monitoring and Governance.

To achieve overall increased sustainability based on full life cycle thinking, it is important to:

Innovate advanced recycling and sorting technologies to increase the value retrieved from plastic waste,

- Optimise and redesign value chains for optimal value (retention): from sorting to renewed raw materials,
- Secure feedstock quality with the application

4 The European Plastics Industry Circular Economy Voluntary Commitments (PETCORE, VINYLPLUS, ECRA and PCEP)
5 Plastics 2030, PlasticsEurope's Voluntary Commitment to increasing circularity and resource efficiency (PLASTICSEUROPE)

6 https://ec.europa.eu/growth/industry/policy/circular-plastics-alliance_en
7 https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1516265440535&uri=COM:2018:28:FIN
8 https://ec.europa.eu/growth/industry/policy/circular-plastics-alliance/commitments-and-deliverables_en
9 https://ec.europa.eu/docsroom/documents/43693

of testing technologies to meet purity and quality requirements,

- Incorporate alternative feedstocks in the production of plastics: waste or by-products from other sectors and processes, such as biological feedstock from the agricultural industry, carbon-based feedstock from the chemical industry and chemical and secondary plastics from the plastic industry,
- Design materials with enhanced separation and recycling properties,
- Design articles/products and business models that facilitate and encourage reuse,
- Develop repair solutions that extend the lifetime of plastic articles,
- Develop technologies for the characterisation of "recycled" or "bio-based" (drop in) feedstock,
- Set a comprehensive methodology to evaluate the environmental impact of each product to enable reliable benchmarking of different approaches,
- Develop methodology to calculate Environmental, Social and Governance (ESG) parameters for standard and renewable approaches on feedstock and durability, to make a comparable evaluation for investment decisions over the short, middle and long term.
- Further research actions are required to take advantage of these ecosystems to make plastics more sustainable. This report presents a shared vision and demonstrates how collaboration within the plastic value chain can be a driving force for change. It outlines the future research needed to fulfil the objectives of the European Strategy for Plastics and the Green Deal priorities, where the technology solutions described are part of an integral approach to render plastics more sustainable.

Methodology

The “Plastics Strategic Research and Innovation Agenda in a Circular Economy”[10] was published in 2018 and since then, several relevant initiatives have been set up (Circular Economy Action Plan, Circular Plastics Alliance, Horizon Europe Green Deal, etc.) The Plastics SIRA was conceived as a living document to be updated to address the current situation and R&I needs in the plastic sector and include new items if needed. All previously involved partners (SusChem, Plastics Europe, EuPC, ECP4) provided their input with the aim to compile the current document “Sustainable Plastics Strategy”.

Thus, this document was elaborated based on input from numerous experts of the plastics value chain, involved in the European Technology Platform for Sustainable Chemistry - SusChem, the European Composites, Plastics and Polymer Processing Platform – ECP4 , European Plastics Converters – EuPC, and PlasticsEurope.

10 http://www.suschem.org/files/library/Final_Brochure_Plastic_strategy_digital.pdf

Furthermore, the research and innovation priorities defined by the European Circular Plastic Alliance initiative are presented in the following tables 2 and 3 with their correspondence to the respective R&D area described in this document.

Table 1: Polymer types and value chains considered

Polymer types		Value chains
Fossil-based	**Bio-based**	
PU/PUR	PLA	Packaging
PS, PS-E, PS-EI	Starch-based	Building & Construction
PE, PE-LD, PE-LLD, PE-HD, PE-MD	PHA/PHB	Automotive
ABS-SAN	TPS	Electrical & Electronics
ABS-HIPS	PEF	Household, Leisure & Sports
PET	PBS/PBSA	Agriculture
PP	PT	Medical
PA	Bio-PET	Healthcare
PVC	Bio-PE	Textile
PMMA	Bio-PP	
PBT	Bio-PA	
POM	Bio-PUR	
PTFE		
DCPD	**CO2/CO-based**	
PC	PPC	
	PU	
Fibre Reinforced Polymer (FRP) matrices	PC	
Epoxy	PEC	
PU	PE	

Table 2: CPA Strategic R&I needs common to 3 or more industrial sectors

CPA R&I PRIORITY	RELEVANT TO INDUSTRIAL SECTOR	CORRESPONDANCE WITH SUSCHEM/ PLASTICS EUROPE/EPC4/EUPC CHAPTER and priority
Chemical and physical recycling process development	Packaging, automotive, construction, agriculture and EEE	**Sustainable by Recycling:** 4.1 Chemical recycling of plastic waste by pyrolysis 4.2 Chemical recycling of plastic waste by gasification 4.3 Chemical recycling of plastic waste by depolymerization/solvolysis 4.4 Recycling by dissolution of multi-polymer systems 4.5 Mechanical recycling
Chemical and physical recycling purification/separation technologies	Packaging, automotive, construction, agriculture and EEE	**Sustainable by Recycling:** 3. Sorting and separation
Polymer chain recycling stability	Packaging, automotive, construction, agriculture and EEE	**Sustainable by Recycling:** 1. Plastic stream preparation (waste pre-treatment) 2 Plastic waste preparation
Quality control and consistency of recyclate	Packaging, automotive, construction, agriculture and EEE	**Sustainable by Recycling:** 3.2 Improve separation
Develop and standardise methods for traceability	Packaging, automotive, construction, agriculture and EEE	**Sustainable-by-Design:** 1.5 Addressing micro and nano-plastics **Sustainable by Recycling:** 1. Plastic stream preparation (waste pre-treatment) 2. Plastic waste preparation 3. Sorting and separation
Improved recycled materials properties	Packaging, automotive, construction, agriculture and EEE	**Sustainable-by-Design:** 1.1 Extend lifetime 1.3 Increase recyclability 1.4 Biodegradation
Better separation of different plastics	Packaging, automotive, construction, agriculture and EEE	**Sustainable-by-Design:** 1.3 Increase recyclability 1.4 Biodegradation **Sustainable by Recycling:** 1. Plastic stream preparation (waste pre-treatment) 3. Sorting and separation
Detect and separate substances in waste	Packaging, automotive, construction, agriculture and EEE	**Sustainable by Recycling:** 1. Plastic stream preparation (waste pre-treatment) 2. Plastic waste preparation 3. Sorting and separation

Table 3: CPA Specific R&I needs common to 2 or less industrial sectors

CPA R&I PRIORITY	RELEVANT TO INDUSTRIAL SECTOR	CORRESPONDANCE WITH SUSCHEM/ PLASTICS EUROPE/EPC4/EUPC research priority
Recyclable biobased polymers	Agriculture	**Sustainable-by-Design:** 1.3 Increase recyclability 1.4 Biodegradation **Alternative Feedstock:** 1. Agriculture and forest biomass waste raw materials
Resistance to sun and crop input	Agriculture	**Sustainable-by-Design:** 1.1 Extend lifetime 1.3 Increase recyclability 1.4 Biodegradation 2.1 Design for dismantling 2.2 Decrease material usage
Collection schemes	Agriculture	**Sustainable-by-Design:** 2.1 Design for dismantling 2.2 Decrease material usage **Sustainable by Recycling:** 1. Plastic stream preparation (waste pre-treatment) 2. Plastic waste preparation 3. Sorting and separation
Waste preparation and pre-treatment	Agriculture	**Sustainable by Recycling:** 1. Plastic stream preparation (waste pre-treatment) 2. Plastic waste preparation
Biodegradability in soil	Agriculture	**Sustainable-by-Design:** 1.3 Increase recyclability 1.4 Biodegradation
Plastic separation	Automotive and EEE	**Sustainable by Recycling:** 1. Plastic stream preparation (waste pre-treatment) 2. Plastic waste preparation 3. Sorting and separation
Using recyclates in a middle layer	Construction	**Sustainable-by-Design:** 1.3 Increase recyclability 2.1 Design for dismantling
Pre-cleaning of waste	Construction	**Sustainable by Recycling:** 1. Plastic stream preparation (waste pre-treatment) 2. Plastic waste preparation 3. Sorting and separation

CPA R&I PRIORITY	RELEVANT TO INDUSTRIAL SECTOR	CORRESPONDANCE WITH SUSCHEM/ PLASTICS EUROPE/EPC4/EUPC research priority
Understanding of kind of products could use recycled materials (design FROM recycling)	Construction	**Sustainable-by-Design:** 1.3 Increase recyclability 2.1 Design for dismantling 2.2 Decrease material usage
R&I for packaging and electrical and electronic equipment > FOOD CONTACT	Packaging and EEE	**Sustainable-by-Design:** 1.2 Material usage vs. performance
Sensor and detection technologies	Packaging and EEE	**Sustainable by Recycling:** 3. Sorting and separation
Post-consumer plastic waste recycling technologies meeting food contact qualification	Packaging and EEE	**Sustainable-by-Design:** 1.3 Increase recyclability 2.1 Design for dismantling 2.3 Monolayer pouch and inmold labelling 2.4 Refillable and recyclable PET bottles
Delamination technologies	Packaging	**Sustainable-by-Design:** 1.3 Increase recyclability 2.1 Design for dismantling 2.3 Monolayer pouch and inmold labelling **Sustainable by Recycling:** 1. Plastic stream preparation (waste pre-treatment)

Sustainable-by-Design

The Sustainable-by-Design concept aims to integrate safety, circularity and functionality of materials and products. It embraces the economic, environmental and social pillars of sustainability while maximising the opportunities offered by the materials and chemicals industries. Sustainable-by-Design calls for an innovative systemic approach throughout the full material cycle, from design to end of life. Industrial relevance, societal empowerment and regulatory preparedness are essential to the successful implementation of the Sustainable-by-Design concept as also recently addressed by the European Commission.[11]

The key components of Sustainable-by-Design plastics embrace safe by design concepts (i.e. plastics free from hazardous chemicals, addressing micro and nano-plastics), circular and resource efficient materials (i.e. durable, re-usable and recyclable; easy to dismantle and with the use of alternative resources including plastic waste and biomass). Sustainable-by-Design plastics need to offer adequate performance and functionalities (i.e. lightweight, mechanical strength) while also enable their sustainable production at industrial scale and drive the opening of new markets and business models enhancing social awareness and investments for Sustainable-by-Design innovation.

This section addresses technologies at the material or article level that allow the dismantling of plastic products and the capabilities to recycle the polymers they are made of. The simulation, material and manufacturing steps are the key stages to reach an optimum of sustainability by design. Moreover, plastic production, use and disposal may result in the release of chemicals which may give rise to health and environmental problems. The development of a common understanding and the transition to safe- and sustainable-by-design materials, including plastics, is a societal urgency.

11 Plastics Sustainable-By-Design. EU Factsheet https://op.europa.eu/en/publication-detail/-/publication/e1e5fcad-fc84-11ea-b44f-01aa75ed71a1/

1. Material design

This section elaborates on the technologies applied at the material design phase, aiming to improve the material sustainability.

1.1. Extend lifetime

a) **Specific Challenges:** Repairing and preserving polymer properties.

Technologies aiming at reducing end-of-life plastic waste and saving resources by extending the lifetime of polymer materials and hence the article lifetime. Repairing and preserving polymer properties using i.e. self-healing polymers is a solution in a medium long-term range.

Scope:

Several applications of polymers need to maintain their structural and physical properties for long periods of time, and often withstand extreme conditions, erosion and other wear mechanisms. Structural repair is a major challenge particularly for advanced composites in aerospace, windmill or automotive applications. Different defects are initiated during manufacturing and in-service use. Delamination and matrix cracking which cannot be repaired with existing technologies can occur which leads to high scrap rates, up to 20-30% depending on the part complexity. The solutions proposed to address such specific challenges comprise self-healing polymers based on thermally reversible Diels-Alder reactions, disulphide-thiol exchange reactions, repair polymers based on dynamic hardeners, etc… Further improvements are possible applying more accurate and effective signals to trigger the healing process when needed (e.g. UV, pH, temperature). Accelerating the exchange reactions using linkers in order to develop more accurate and effective detection signals, novel repairing technologies based on the reshuffling of chemical bonds by applying heat and pressure should also be considered.

Technology Readiness Level

Activities are currently at TRL 3 and shall achieve TRL 5-6 at the end of the project.

Expected Impact:

Significant reduction of the time and resources for material development and upscaling with respect to established conditions, with a return on investment of less than 5 years for specific market sectors. Quantifiable enhancement of the quality and reliability of products, with consequent improvement of product lifetime and associated environmental and economic benefits.

b) **Specific Challenges:** Improving ageing.

External conditions such as extreme temperatures, pressure, UV exposure, humidity, mechanical stress and others can degrade material properties and decrease their performance. In order to increase article lifetime, it is desirable to limit the degradation due to the ageing mechanisms and improve the ageing performance. Different approaches have been developed like the addition of chemical additives in the plastic or composite matrix and their controlled application in relevant areas throughout the matrix structure. To control the improvements on the nano-reinforcement and polymeric matrix interface, there is a need to improve chemical compatibility and dispersion stability as well as increasing mixing efficiency when necessary.

Scope:

Additives and nano-additives show potential in improving polymers performance by adapting each material to its application requirements. Material properties at the nano- and microstructure level can be programmed by changing their morphology in order to control and adapt them to the different conditions (e.g. improving barrier properties, increasing the diffusion path for gases and water, adjust stiffness, rigidity, sealability). Recipe ingredients may be optimised to adjust material properties to meet environmental and application requirements thereby extending its service lifetime without undermining the efficiency and quality of the recycling process.

Technology Readiness Level

Activities are currently at TRL 4-5 and shall achieve TRL 6-7 at the end of the project.

Expected Impact:

At least 20% faster verification of material performances is expected for highly promising applications. At least 20% improvement in industrial productivity, reliability, environmental performance, durability, and reduction of life-cycle costs of these materials.

c) **Specific Challenges:** Improving ageing performance of bio-based materials.

To improve the final properties of bio-based materials and their basic surface properties without chemical treatment and use of liquids. One solution is based on single-polymer approach and a confined crystalline structure of PLA or PHA with low gas permeability. This could improve barrier, anti-fog, anti-fouling and antistatic surface properties of those bio-based materials.

Scope:

Different approaches have been developed like the addition of chemical additives in the bio-based plastic or composites matrix or a good control at nanoscale of the matrix structure. Additives and nano additives can improve polymer performances by adapting each material to its application requirements.

The application of available or emerging technologies (Chemical Vapor Deposition, Physical Vapor Deposition, nanolithography) to get smart surface design for all types of bio-based polymers or get a good control of the surface or the internal polymer structure through processes shall be contemplated. The development of active bio-based packages to meet the needs of both fresh and pre-treated food applications for specific flexible and rigid food packages in diverse market segments is required as well as the scale up of existing laboratory level of smart functionally technologies to prototype pilot scale level.

Technology Readiness Level

Activities are currently at TRL 5 and shall achieve TRL 7 at the end of the project.

Expected Impact:

At least 20% improvement of materials performance is expected for promising applications. At least 20% improvement in industrial productivity, reliability, environmental performance, durability, and reduction of life-cycle costs of these bio-based materials.

1.2. Material usage vs performance

Technologies that aim at decreasing material usage while maintaining or improving the mechanical behaviour of existing materials.

a) **Specific Challenges:** Improve performance.

Growing demand for high performing materials and more complex products increases the need for material usage, in terms of quantity and variety.

Scope:

Composites can improve the material performance by providing high strength and stiffness without undermining the aesthetical appearance of the final product. Composites, as well as multilayer materials require less amounts of material for a given functionality and have the potential to perform as well as, or better than, conventional materials such as metals decreasing thus the final amount of material use. The innovation would be in new precursor formulations, improved reinforcement and manufacturing technologies to reduce costs. The development of automated manufacturing technologies is required to reduce cycle times and cost of manufacturing. With respect to the circular economy approach, the improvement of separation of dissimilar materials and recyclate properties are real needs. A complementary option is making composites from carefully chosen waste plastics.

Technology Readiness Level

Activities are currently at TRL 5 and shall achieve TRL 8 at the end of the project.

Expected Impact:

At least 20% improvement in industrial productivity, reliability, environmental performance, durability, and reduction of life-cycle costs of these materials, at least 15% improved industrial process parameters and 20% faster verification of materials performance for highly promising applications are expected.

1.3. Increase recyclability

Technologies aiming at increasing inherent recyclability of polymers.

Specific Challenges:

Common petrochemical-derived polymers such as polyethylene and polypropylene take many years to break down as their carbon chains do not contain chemical groups that could act as obvious ‘break points’ for chemical or biological reactions. These polymer chains form crystalline regions that confer excellent thermal and mechanical properties, making the material extremely durable, but also less amenable to degradation after use. In order to address these issues **new plastics** shall be designed to **facilitate recycling**[12]. This could allow to produce materials able to 'degrade on demand', with the degradation products being chemically recycled to polymer or transformed into other building blocks. New plastics capable of maintaining desirable material properties for re-use should also be targeted, for example through self-healing processes. Recycling of multi-layer films, or recycling of waste from electrical and electronic equipment (WEEE) is difficult due to the multiple types of polymers included in such products and the difficulty in separating them.

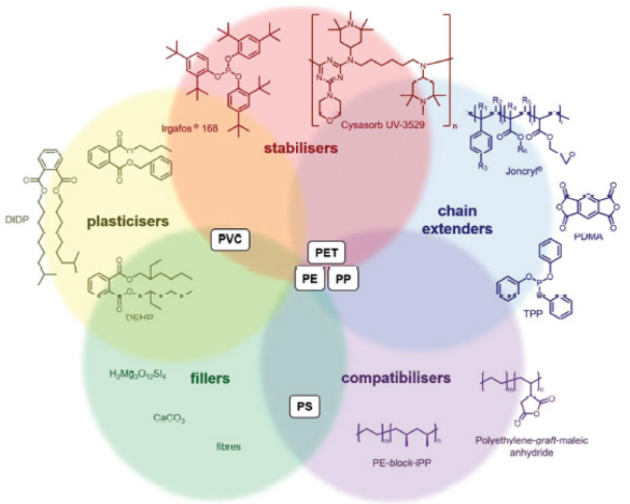
Scope:

The transformation from multicomponent (multilayer or blend of polymers) compositions to one compatible multiphase mixture which can be more easily reprocessed by incorporating compatibilizers is one of the possible options. Homoplastic composites, where a single polymer chemistry performs multiple functions through control across chain length could allow a single type of material used for the packaging, adhesive, and barrier layer that would simplify recycling. Multi-layer materials can have an overall benefit with the parallel deployment of dissolution recycling. The development of new generation of compatibilizers could offer a wider range of potential compatible mixture of polymers from such multicomponent products. The compatibilizer can upgrade mechanical properties of waste streams through compatibilization of contaminant and/or the different phases. Also, separation of layers based on specific adhesives or additives could facilitate higher purity of the output. Whenever possible, recyclability can be further enhanced using surface nano-textures replacing additives for certain functionalities and using additives to reduce the need of multilayers. The use of waxy products from plastic waste pyrolysis as a compatibilizer could serve two purposes:
a) a useful outlet for pyrolyzed plastic waste and
b) an increased recyclate quality. These would increase the recycling rate. Plastic containing additives which protect the polymer structure can also be contemplated. Another approach for thermoset products could be based on chemically modified polymers (e.g. PS), which can facilitate the thermal degradation without affecting mechanical properties. Bio-based compatibilizers and additives based on natural or recyclable raw materials that can further reduce the carbon footprint from a life cycle perspective can be an option too. Some of the proposed solutions are illustrated in Figure 1.

12 Beyond Mechanical Recycling: Giving New Life to Plastic Waste

Figure 1: Common polymer additives used to improve polymer recyclates

(Source: Mechanical Recycling of Packaging Plastics: A Review[13])



13 Mechanical Recycling of Packaging Plastics: A Review

Technology Readiness Level

Activities are currently at TRL 3-5 and shall achieve TRL 6-8 at the end of the project.

Expected Impact:

Improvement of the recycling yield, the purity of waste and the quality of the recyclable plastic. Increase the use of recyclable polymers in second-generation products.

1.4. Biodegradation

Specific Challenges:

Biodegradation depends on the interplay between the materials properties and the environmental conditions. Biodegradable plastics may bring benefits over conventional plastics in applications where it is challenging to collect a particular products from the environment after use (e.g. agricultural mulch films), where it is difficult to separate plastic from organic waste (e.g. compostable food bags) or for certain applications in the medical and personal care fields. For these applications, the key is to make separate collection of bio-waste. Such biodegradable polymers should not be considered a substitute for recycling, or an excuse to dispose of plastics in the environment. Life time of biodegradable plastics in different conditions are key, but so far there is a lack of experimental data to predict breakdown in complex natural environments. Harmonisation and development of standards is needed. Furthermore, environmental claims regarding biodegradability or compostability should comply with appropriate standards such as ISO 18606 or EN 13432 and EN 14995.

Scope:

Careful examination of standards and labelling of polymers will ensure a proper understanding of terms such as recyclable, compostable, biodegradable. Research is needed to understand the biodegradation of polymers in a broad range of industrial and environmental conditions, how it is influenced by humidity, pH, temperature, solvent, catalyst, light, micro-organisms and enzymes, as well as the interplay between these factors in a range of real processes and environments. The fate and impact of the degradation products must also be fully considered, as should any additives in these plastics. In parallel, strategies to understand and improve the biodegradability of the currently non-degradable polymers are of high relevance. Environmentally degradable polymers will need to be competitive in performance and cost to become scalable, efficient, economical, and sustainable. Different biodegradable polymers are needed, tailored towards specific applications. Compostable films can have a shelf life of one year, with identical mechanical properties of non-compostable films and can be converted through extrusion. At their end of life, they can be composted domestically, achieving more than 90% disintegration in less than 6 months. Biodegradable polymers can be produced from bio-sources as well as fossil sources. Different approaches towards biodegradation have a high potential such as the enzymatic route. The design of material-adapted bacteria is another approach, as some microbes can degrade plastics like PP, PE, PS to shorter hydrocarbons. Additionally, efficiency of microbial plastic degradation can be enhanced with metabolic engineering. Whatever the solution, there is a need to get good repeatability, purity of monomer, duration, thermal stability. In fact, still some progress is necessary to improve properties and control the biodegradation which needs to comply with internationally recognised biodegradability standards.

Technology Readiness Level

Activities are currently at TRL 4 and shall achieve TRL 7 at the end of the project.

Expected Impact:

Reduce the environmental impact associated with the end-of-life phase of developed packaging products by at least 30 % compared with existing products for similar applications. Improve sustainability performance (in terms of biodegradability, compostability or recyclability) compared with existing plastics. Develop at least two applications utilising 'outperforming' biodegradable polymers, with improved properties compared to the current alternatives based on fossil-based counterparts.

1.5. Addressing micro and nano-plastics

Specific Challenges:

Analytical methods are needed to study micro and nano-plastics of different types and shapes and at different size and time scales. These include high-throughput spectroscopy and microscopy techniques that generate reproducible data about the size distribution, structure and properties of microplastics in the environment. Predictive models can simulate the transport and distribution of micro-plastics, which will help to understand the location, fate and persistence of plastic waste and they may also allow to predict the environmental impact of new plastics before they get to market. A proper understanding of the process of formation and degradation in the environment of secondary micro-plastics and nano plastics, across a range of environments including soils, freshwater, oceans as well as the health effects of micro and nano-plastics is essential. Most of the plastic waste is generated on land, but plastic pollution ends up in the marine environment, and plastic particles are reported to occur from tropical to polar areas and from beaches to deep-sea sediments and even in remote mountain lakes. Plastic particles have been found in the atmosphere and in terrestrial ecosystems, such as urban and agricultural soils. The size of a piece of plastic is an important factor in determining its impact on the environment. Possible risks associated with plastic particles cannot be generalized because they comprise a very heterogeneous group of particles that vary in polymer composition, additive content, size (macro-plastics: larger than 2.5 centimetres, meso-plastics: 5 millimetres to 2.5 centimetres, microplastics: 1 micrometres to 5 millimetres, nano-plastics: smaller than 1 micrometre), shape, ageing state, and consequently in their physicochemical properties.

Scope:

Technologies to analyse and quantify micro-plastics in the environment and study their distribution and pathways in the environment as well as their mechanical, chemical and biological degradation from macro- to meso-, micro- and nano-plastics. Micro-plastics analytical process include sampling, extraction, quantitation and quality assurance/quality control (QAQC), each of them requiring further method development and harmonisation. The most common approach to extracting micro-plastics is filtration and density separation. Following extraction, visual counting with an optical microscope is the most common technique for quantifying micro-plastics. But this technique is labour intensive and prone to human error. Spectroscopic approaches (FTIR; Raman) are the most applied techniques for identifying polymers collected through visual sorting. Improvements and harmonisation on size fractions, sampling approaches, extraction protocols and units for reporting plastic abundance would help comparison of data generated by different research teams. Inter-laboratory proficiency testing is recommended to give an indication of the variation and reliability in measurements reported in the scientific literature that may be under- or overestimations of environmental burdens. Numerical modelling is one of the key tools to gain insight into the distribution of micro-plastics in the nature. A series of numerical simulations have been constructed, with focus in marine environments, including the effects of currents, waves, and wind as well as a series of processes that impact how particles interact with ocean currents, including fragmentation and degradation highlight the importance of knowing accurately the sources or entry points of marine plastic debris, including potential sources that have not been incorporated in previous studies (e.g., atmospheric contributions). These numerical models should be contrasted with experimental data, further improved and shall integrate other environments such as rivers, water treatment plants, agricultural fields or urban agglomerations. Secondary micro-plastics are derived from the breakdown of larger plastic debris, both at sea and on land. Over time, physical, chemical, photochemical and biological degradation might further degrade them to be smaller in size converting them into nano-plastics that can reach the food chain or be completely degraded to CO_2. The kinetics of these processes under different environmental conditions is not known yet and it is essential to predict and minimize the accumulation of microplastics in nature and reduce their impacts on humans and the environment.

Technology Readiness Level

Activities are currently at TRL 4 and shall achieve TRL 7 at the end of the project.

Expected Impact:

Insight and better understanding of the environmental footprint associated with the end-of-life phase.

2. Article Design

This section elaborates on the technologies applied at the material design phase, aiming to improve its overall circularity.

2.1. Design for dismantling

Specific Challenges:

Most plastics are designed to be durable and to maintain their structure and performances during their useful life. But in sectors such as packaging this durability can give rise to pollution, because discarded waste plastic can persist in the environment for years or decades. Allowing for plastic articles to be reused multiple times in refillable packaging represent a more sustainable option than providing disposable packaged articles. Technologies aiming at easing dismantling of products containing plastic with the goal of increasing the volume and purity of the collected and sorted plastic waste, resulting in higher quantities and quality of the recycled or reused material shall be put in place.

Scope:

It is common that component parts of a same product have different characteristics and lifetimes. Dismantling considerations, not anticipated at the design stage, result in materials being discarded before reaching their end-of-life. Coupled with the growing complexity of products, materials that otherwise are easily recyclable lose most of their potential quality due to the incapacity of separating mono-material parts from each other. Design product parts to incorporate reversible adhesives could allow a better management of used articles through easy disassembly (i. e. adhesives based on Diels-Alder reaction, dithiol or disulphide exchange reactions).

Technology Readiness Level

Activities are currently at TRL 4- and shall achieve TRL 7 at the end of the project.

Expected Impact:

New business opportunities for the recycling industry across Europe, especially in the area of composites and plastics where the challenge is high. Proposals should prove that the target products are recyclable or compostable in various environments to reduce their overall environmental footprint. This will make their production and use more circular.

2.2. Decrease material usage

Specific Challenges:

The growing complexity of products, together with the wide variety of existing polymers, boosts the use of multi-material design in single applications. Designing a plastic to be durable in time, and reusable and/or recyclable (including organic recycling) at the end of its life, is a major challenge. For some applications, designing plastics to be more durable and longer-lived would be a more sustainable option and should be explored. Integrate environmental criteria and Life Cycle Assessment (LCA) methodology in design in order to minimise material use and environmental impact is an essential need. The final weight and the multi-material optimisation (the right material at the right place) need to be addressed

Scope:

Replace multilayer structures by materials with targeted thickness while ensuring the same performance level. Push and facilitate the use of composite solutions based on polymers, versus traditional solutions, e.g. based on metals. Design parts considering weight and multi-material optimisation (use the right material at the right place and optimise its form to limit weight, maximise resistance) Integrate environmental criteria in packaging design in order to minimise material use, e.g. mono-material design, whilst at the same time offering the same or better functionality.

Technology Readiness Level

Activities are currently at TRL 4 and shall achieve TRL 8 at the end of the project.

Expected Impact:

Reduce the environmental footprint associated with the end-of-life phase of developed packaging products by at least 30 % compared with existing products for similar applications. Produce multifunctional product with a minimum of multilayer/ multimaterial structures. Multi-material structures emerged over the last decades as highly efficient packaging material, combining such different features as: Oxygen barrier, thermoformability, seal behaviour, water barrier, transparency, etc. There is currently no single material that combines all those features. Hence, one shall not necessarily aim at avoiding multilayer composites if these materials can be efficiently recycled.

2.3. Monolayer pouch and in-mold labelling

Specific Challenges:

A reduction of packaging waste and efficient use of resources are required by legislations in the EU. This can be achieved through weight reduction of single use packaging. Light weighted containers are however difficult to handle and especially tedious to decorate. For example, thin containers (pouches) are light weighted and can achieve weight reduction targets. However, their multi-layered structure is not suitable for the current recycling processes since they are pre-printed, laminated and assembled into a pouch. To overcome this challenge, a recyclable monolayer (pouch) with decoration (in-mold labelling) needs to be developed.

Scope:

Demonstrations of the monolayer pouch prototype and in-mold labelling have been completed in some industrial production settings. Both technologies are ready to be used in the industrial scale. As a next step, the technologies should be installed in actual filling lines for an operational environment proof of concept.

Technology Readiness Level

Activities are currently at TRL 7 and shall achieve TRL 9 at the end of the project.

Expected Impact:

The development of monolayer pouches and in-mold labelling technologies will offer weight reduced packaging (i.e. PET/PE) to the market fulfilling the product requirements with a 20 to 25% weight reduction. In parallel, the technologies will support the envisaged recycling targets of the Packaging and Packaging Waste Directive[14] (PPWD) and the objectives of the European Green Deal and the new Circular Economy Action Plan (CEAP) to ensure that "all packaging on the EU market is reusable or recyclable in an economically viable way by 2030". It will also contribute to the objective of European Strategy for Plastics to ensure that by 2030 "all plastics packaging placed on the market can be reused or recycled in a cost-effective manner".

2.4. Refillable and recyclable PET bottles

Specific Challenges:

A reduction of packaging waste as well as the minimization of a product carbon footprint are required under several legislations in the EU. The deployment of a PET refillable bottles system could strongly support these targets as the excessive CO_2 emission can be minimized with PET material (e.g. in comparison to refillable glass bottles). Moreover, PET is a material that can be efficiently recycled with existing recycling infrastructures.

Scope:

Establishment of PET refillable products with special PET grades which are resistant to the high temperature washing lines.

Technology Readiness Level

Activities are currently at TRL 6 and shall achieve TRL 9 at the end of the project.

Expected Impact:

Single use plastic packaging is mainly used in many beverage markets including the milk market. Since the PET recycling infrastructure is already established, if the reuse solution is communicated to the market, at least 20% of the market is expected to accept PET refillable bottles.

14 https://ec.europa.eu/environment/waste/packaging/ongoing-review-packaging-waste-directive_en.htm

Sustainable Recycling

1. Plastic stream preparation (waste pre-treatment)

Specific Challenges:

Plastic articles to be recycled contain solid and liquid contaminants that result from their specific use and history. These contaminants can highly affect the quality of the recycling output and are not easily removable. Besides, they may convey notable odours that do not modify the plastic physical or chemical properties, yet it can make the recycled materials unfit for some specific uses. The contamination of used farm films is a typical example: In mulching, the contamination of the plastic films can represent up to 70% of the volume collected what leads to significant additional costs in terms of recovery operations and treatment. In the specific case of plastics used in packaging, an additional challenge resides in the removal of the inks which are often directly printed on the polymer films. Removal of these inks is difficult, costly and energy intensive. As a result, plastic waste with printed inks are often recycled as is and used in lower value products such as plastic shopping bags. To decrease this value loss, it is desirable to develop cost and energy efficient technologies for ink removal.

Scope:

Solutions applied through continuous processes are especially attractive. For example, the use of solvating fluids during continuous extrusion allows to treat flowable polymer mass by solvating and extracting organic, and especially non-volatile, contaminants from the polymer mass. The efficacy of such approach can be enhanced by employing sensors to detect and remove contaminants of different nature (stones, particles, additives) and sizes. The development of sensors with higher sensitivity/precision and lower cost would allow a better treatment of the films and a higher quality of the final recycled materials. As far as the removal of odour or ink is concerned, technologies like supercritical extraction, water-based oxidant treatments, use of a demulsifier in the washing step or biological treatments are especially attractive. But their implementation still requires further developments to reduce their respective costs.

Technology Readiness Level

Activities are currently at TRL 5 and shall achieve TRL 7/8 at the end of the project.

Expected Impact:

Meeting the EU's circular economy and environmental targets while demonstrating a clear benefit, i.e. more efficient or economic than the state-of-the-art in order to enable market uptake in the short to medium term. Reduction of the carbon footprint of the corresponding products by > 30% (based on a full LCA) and demonstrate a potential reduction in landfill waste volume by > 50%.

2. Plastic waste preparation

Specific Challenges:

The separation of the various polymers comprised in a stack is often difficult and still needs to be performed manually most of the time. Robotics could help and should be optimized. Especially after grinding, it is even more difficult to separate polymers, which results in contaminated input streams in the recycling process. Ensuring high purity and high value recyclate requires to separate the polymers in the stack in order to allow a proper sorting of the materials.

Scope:

The development of integrated solutions of grinding machinery with thermal, chemical, and magnetic separation should be considered and tested in pilot lines. The increase of production volume of the mills using cold base technology could offer some leverage upon the overall energy consumption of the mill internals and balance of systems material flow. Besides, the use of detection systems for ground particles from agglomerates in order to better separate coarse particles and consequently return them as rejects into the mill. Besides the use of mill, employing supercritical liquid could permit to separate the polymers in a stack in an efficient manner.

Technology Readiness Level

Activities are currently at TRL 5 and shall achieve TRL 7 at the end of the project.

Expected Impact:

Meeting the EU's circular economy and environmental targets while demonstrating a clear benefit, i.e. more efficient or economic than the state of the art in order to enable market uptake in the short to medium term. At least 20% improvement in industrial productivity, reliability, environmental performance, durability, and reduction of life-cycle costs of these materials Demonstrate a potential reduction in landfill waste volume.

3. Sorting and separation

Specific Challenges:

The composition of waste streams of polymer articles can have high variations. Typically, household plastic waste can be composed of a stream of rigid bottles (PET and PE) to streams containing additional trays, pots and films, with a wide range of different polymers. Rigid plastics can contain films which are often multi-layered, and hence difficult to separate. Bottles can be covered in PVC sleeve labels, or PET grade materials need to be separated from bottles and trays. Furthermore, applications polymers are often mixed with other materials (e.g. wood, metals,), and can contain legacy additives, such as brominated flame retardants (BrFR) but also organic additives such as plasticizers and dyes. The sorting and separation of the polymers according to the type of additive they contain is difficult. In order to recycle efficiently these streams, the sorting of polymer articles by their constituent materials is of primary importance. This sorting ensures a minimum of waste and a high quality and purity product. This sorting is particularly tedious for small or light plastic items due to their specific geometry, morphology, and low weight. The two main routes currently employed, namely wet and dry sorting, still require further technical enhancements and cost reduction to ensure a large deployment and an increase of the overall recovery yield of plastics. Special attention should be given to both the construction and the packaging sector as well as to bio-based polymers for which the current level of recycling is not as high as for fossil-based polymers due to the lower volumes in the market. The final goal of recycling being to reduce the environmental impact, the solutions developed should avoid using consumables, which generate a negative impact on the environment. High level economic, cost benefit analyses for various options should exist to come to best overall approach on separation vs recycling options, i.e. it is not always best to get monostreams, while other options exist for processing of mixed streams.

Scope:

In the case of wet sorting, approaches like hydrocyclone and flotation still require further developments to i) strongly reduce their cost and ii) offer a better selectivity on light polymers and polymers having the same density respectively. Process to eliminate contaminants, sorting for higher quality batches together with selective precipitation should be considered. In the case of dry sorting, polymer identification methods based on multi-dimensional column chromatography based technique either with Ultra Violet (UV), Mass Spectrometry (MS) or Nuclear Magnetic Resonance (NMR) detection or based on spectroscopic, on optical spectroscopies like Visible (VIS), Near Infrared (NIR) and RAMAN spectroscopies as well as Mid Infrared Thermography (MIR-T) and Laser-Induced Breakdown Spectroscopy (LIBS) would benefit from the improvement of optical sensors. A better spatial recognition would allow to automate sorting in higher speeds, a higher accuracy and lower detection limits and it would permit to identify legacy additive (like brominates) at lower concentrations and the detection of organic additives. X-ray based technics like X-Ray transmission imaging (XRT) and Energy Dispersive X-ray fluorescence (XRF) could be applied to smaller recycling units if their cost were reduced. Moreover, it would be beneficial to increase the detection capabilities of these tools in order to identify a wider range of additives and increase the speed of sorting. Terahertz spectroscopy offers interesting feature, although the plastic optical recognition needs some further improvement. When tracers are used, fast and low-cost detection technics to identify precisely the articles containing the said tracer should be developed up-front. All these technics should be coupled to enhanced sorting mechanisms (air valves, robotic handling), and should be tested in pilot scale. Artificial intelligence (AI) algorithms to reproduce human recognition could yield the fabrication and use of AI robot to replace hand pickers. LCA and Life Cycle Costs (LCC) should be considered thoroughly in the evaluation of the sorted materials.

Technology Readiness Level

Activities are currently at TRL 5 and shall achieve TRL 7/8 at the end of the project, although some are for the time being at lower level in novel fields (1 or 2, e.g. identification of organic legacy additives)

Expected Impact:

At least 20% improvement in industrial productivity, reliability, environmental performance, durability, and reduction of LCC of the materials. Demonstrate a potential reduction in landfill waste volume.

3.1. Improve sorting

Technologies aiming at improving the inherent sorting capabilities of polymers.

Specific Challenges:

The wide variety of plastics and diversity of characteristics make the plastic sorting process very complex and inefficient, resulting in great losses of material value. The identification of the different types of polymers among plastic waste is not efficient enough due to the variety of colours, properties and shapes. Multilayer materials, dark, and especially black coloured plastics and compostable plastics are especially challenging when it comes to detection, sorting and separation. Some mixed plastics streams could fit for a chemical recycling route, when sorting would not give good quality or is not economically sound for mechanical recycling.

Scope:

A lot of technologies exist to sort plastic wastes and methods for object classification comprising the steps of: Guiding a continuous stream of objects from a transport mechanism directly into an unsupported path, along which the stream is fed through a detection region; illuminating with a radiation band in a first direction; optically scanning the detection region to detect electromagnetic radiation reflected by the object in the detection region[15]. Other developments relate to sorting devices and methods for sorting products that are moved in a flow through an inspection zone, wherein a light beam is moved over the flow so that that all products are hit by the light beam in the inspection zone. The light of this light beam is on the one hand, directly reflected as of the point of impact on the products, and, on the other hand, it is reflected in a scattered manner as of a zone round the point of impact by the diffusion of the light beam's light in the products[16]. Generally,

15 European Patent Application EP3450029 A
16 European Granted Patent EP2234736 B1

the technics are based on surface markings through diffraction gratings, fluorescent markers or UV markers.Tracer-based sorting (TBS) is an optical technology which detects specific light signals emitted by the polymers, which have previously been exposed to a certain light source, but the cost and efficiency need to be improved. The optical response and sorting effectivity of different marker-plastic combination and thermal stability are some of the main bottlenecks with the recyclability of plastics containing markers. The repeatability and reproducibility need to be improved in order to increase the sorting efficiency and the quality of the recyclable plastics. The developed solutions can be applied to packaging as well as other applications. Progress in infrared detection does not require tracers. NIR based state-of-the-art detection systems can reliably sort styrenic plastics out of mixed plastic waste and very precisely differentiate between HIPS and GPPS, for example. Due to the fact that styrenic compounds have a unique signal that enable easy and very precise sorting, NIR sensor technology enables easy sorting of polystyrene from mixed post-consumer plastic waste using a multi-step process.

Technology Readiness Level

Activities are currently at TRL 3 and shall achieve TRL 8. The range is broad based on the development of new concept (low TRL) or improving existing ones. The particular NIR sensor technology to sort polystyrene from mixed post-consumer plastics waste has a TRL of 9.

Expected Impact:

Create new technologies and business opportunities for the recycling industry across Europe, especially in the area of plastics where the challenge is high. Towards 100% recycled plastic after sorting stage. Demonstrate a potential reduction in landfill waste volume by > 50%.
Meeting the EU's circular economy and environmental targets while demonstrating a clear benefit.

3.2. Improve separation

a) **Specific Challenges:** Polymers separation.

Technologies aiming at improving the inherent separation capabilities of polymers. Multilayer or multipolymer structures are some of the plastic waste streams which need an efficient separation in order to improve the quality of recycled plastics and to decrease the landfill. Multilayer polymers and composites present high limitations for separation, due to the different properties of each component. For example, the presence of dynamic chemical crosslinks in thermoset fibre reinforced polymer composites (TS FRP) enable the chemical separation of the matrix from fibre reinforcement.

Scope:

Cross Linked Thermosets (CLT) and FRP composites cannot be recycled throughout re-melting due to their cross-linked three-dimensional chemical structure and their complex structure, respectively. Combining nucleation and low crosslinking degrees could be a way to facilitate the separation of fibres from the polymer matrix. In multilayers or multi-materials, polymers should be easily separated into relatively pure mono-material streams. First reversible adhesives have been demonstrated with different approaches (shape memory- and hydrogen bonding, with conductive nano-ferromagnetic particles, incorporating enzymes, vitrimers). Such laboratory feasibility needs to be scaled up and show improvements of the chemical separation process efficiency, by optimizing time, temperature and the type of solvents. In order to get a high efficiency in separation, it is important to get adhesion between multi-materials with high bonding and quick bond breaking/remaking capability whatever the process uses to produce the multilayer or multi-material products (extrusion, injection, etc.). The optimisation of the process and separated material for the reuse of separated resins and fibre reinforcements is crucial for the final validation of the separation efficiency.

Technology Readiness Level

Activities are currently at TRL 4- and shall achieve TRL 7 at the end of the project.

Expected Impact:

Create new technologies and business opportunities for the recycling industry across Europe, especially in the area of composites and plastics. Demonstrate a potential reduction in landfill waste volume by > 50%; Reduction of the carbon footprint of the corresponding products by > 30% (based on a full LCA).

b) **Specific Challenges:** Separation-maceration of polyolefins and other polymers.

Polyolefin represent around 50% of the total annual plastic consumption in Europe. PE recycling however is still not allowing food contact at the PE streams coming back from the sorting centres. Furthermore, existing PE decontamination technologies generally require very high energy inputs. To fulfil the European recycling targets as well as the climate neutrality targets, a PE recycling and decontamination process needs to be developed to allow for food contact PE with minimum energy input.

Scope:

Certain treatments can cause a maceration of PE. This affects the PE matrix and expands the space between PE-chains in the matrix, enabling the washing out of contaminants such as smelly components, short chain fragments (oligomers) and additives and their degradation products. Selection of suitable conditions for PE maceration that reaches a maximum expansion without destroying the matrix of the plastic is a first step. Further, the search of the optimal conditions for the "wash out" process and to return the material to a processable state. Third, the processing in a way that is environmentally friendly and minimizes any carbon emissions. Fourth, limitation of residuals in the Polyethylene to fulfil the European Food and Safety Authority (EFSA) and the USA Food and Drug Administration (FDA) requirements.

Technology Readiness Level

Activities are currently at TRL 3 and shall achieve TRL 8 at the end of the project.

Expected Impact:

The aim is to find a way to bring back the PE for industrial re-use. This would mean increasing the recycling rate of PE in line with the EU regulation. The successful project would affect the HDPE recycling rate dramatically since it would bring back rHDPE for use in food contact application areas or even open the possibility to use rHDPE from non-food origins for packaging in the food industry. It would mean treated HDPE from health care, home care and other non-food application can be brought back to these markets, but without any of the restrictions of colour and smell. If the HDPE maceration is successful, this would open the way to work on recirculation of LDPE and most of the other PE species back into their original markets. Due to the absence of colour, smell and viscosity disturbing elements they could be used as "drop in" chemicals.

4. Recycling technologies

Plastic waste is one of the most complex material mixtures from a recycling perspective. The recycling effort includes various methods, such as chemical recycling (pyrolysis, gasification, depolymerisation), mechanical recycling, biotechnological processes as well as integrated upgrading options, like direct, ex-situ catalytic pyrolysis[17]. The most suited materials for chemical recycling by depolymerisation are the polymers with a ceiling temperature Tc (temperature at which the polymer decomposes into its monomers) slightly above the highest processing temperature. The de-polymerization of polystyrene, PMMA and PET is advantageous since they are mass-polymers having a "benign" ceiling temperature Tc, which is slightly below 400 °C in case of PS and HIPS. The de-polymerization of Polystyrene (HIPS and GPPS) works with high yield and selectivity and represents a technology/material combination for full circularity, enabling continuous recycling loops. By depolymerization, Polystyrene is easily reversed into its constituent monomer at high yield. The liquid state of the monomer facilitates purification. The resulting recycled monomer is identical to the virgin monomer and can be polymerised again to virgin quality polystyrene enabling all applications, including food contact. At the ceiling temperature, polymers decompose into their monomers, and a Tc in a.m. range allows to rapidly produce Styrene, with the upside potential of maximizing yield by

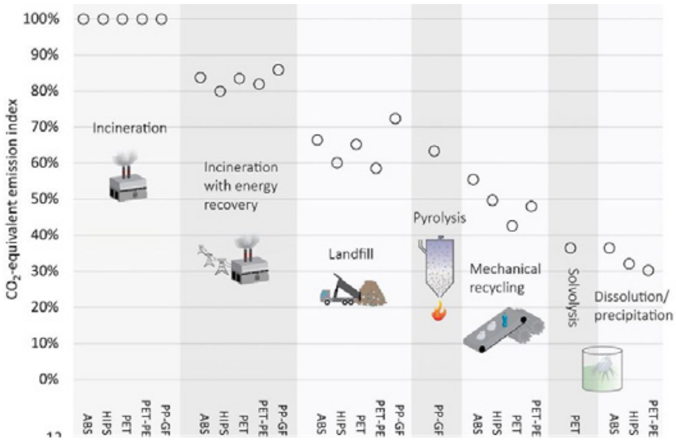
17 Effect of catalyst contact mode and gas atmosphere during catalytic pyrolysis of waste plastics https://www.sciencedirect.com/science/article/abs/pii/S0196890417302820

optimization of reaction conditions, especially the reactor residence time at depolymerization temperature. Agilyx has demonstrated in their Tigard (Oregon) plant the depolymerization of PS into monomers. The current challenge is to scale up reactor and purification (e.g. distillation) process. The waste-to-monomers through solvolysis and/or de-polymerization is relatively developed for some polymers such as PET, polyamides and PS as stated above but lacking behind for polyolefins. The chemical recycling of mass consumption plastics like PE or PP result in defined added-value products (such as waxes, oils). Pyrolysis technologies (conventional pyrolysis, plasma, microwave assisted pyrolysis, hydrocracking, pyrolysis with in-line reforming) have a range of maturities that go from concept all the way to small demo plants depending whether waste-to-fuel or waste-to-chemicals is considered[18]. Gasification processes (conventional gasification, plasma assisted gasification) which can possibly be combined with biological and chemical post-treatment- show a wide TRL range while currently pilot and demo plants are under investigation. Both recycling technologies (pyrolysis and gasification) can recycle plastic waste to chemical building blocks. Especially for polyolefins, these might be viable options. Biotechnological processes for plastic waste valorisation are currently at TRL 2-3. They can be suitable to be combined with integrated upgrading options, like direct, ex-situ catalytic pyrolysis[19].

18 Technologies for chemical recycling of household plastics – A technical review and TRL assessment https://www.sciencedirect.com/science/article/pii/S0956053X20300465
19 Effect of catalyst contact mode and gas atmosphere during catalytic pyrolysis of waste plastics https://www.sciencedirect.com/science/article/abs/pii/S0196890417302820

Figure 2: CO_2-equivalent emissions of different End of Life treatment technologies applied for several plastic-waste streams, in relative emissions indexed to incineration (100 wt%).

(Source: Beyond Mechanical Recycling: Giving New Life to Plastic Waste[20])



20 Beyond Mechanical Recycling: Giving New Life to Plastic Waste https://onlinelibrary.wiley.com/doi/10.1002/anie.201915651

More fundamental research is thus needed to reach a TRL 5 by 2030. The current CO_2 emission impacts of various recycling technologies is depicted in Figure 2.

4.1. Chemical recycling of plastics waste by pyrolysis

Scope:

Pyrolysis is conducted at relatively high temperatures and in the absence of oxygen; it is particularly applicable to mixed polymer waste that is not suitable for mechanical recycling. During the thermal decomposition, complex product mixtures of variable composition are produced. The decomposition products, in the form of liquid oil or gases, are valuable as fuel or chemical building blocks. A mixture of unreacted carbon char and ash remain as a residual. Pyrolysis is possible with or without a catalyst. Pyrolysis of mass consumption plastics like PE or PP result in defined value products (such as waxes, oils). Catalytic pyrolysis seems a viable route to plastic waste recycling. Integrated Cascading Catalytic Pyrolysis (ICCP) maximises product value with high Benzene, Toluene and Xylene (BTX) and aromatics yields, while being energy positive (overall generates heat). Feed composition flexibility is high due to orientation on aromatics, i.e. mixed plastics can contain aromatics-based polymers.

Specific challenges:

High energy-intensity required due to high process temperatures. Prevention and/or removal of hazardous and corrosive compounds that can be generated during the process add into process complexity, scalability and safety challenges. Reactor fouling due to by-products (ash). Dehalogenation procedures are necessary, because the oils collected in single pyrolysis process may contain halogenated organic compounds, which would detrimentally impact the reuse of pyrolysis oils. Recovery/trapping of dehalogenation (e.g. by basic salts formation) is necessary, because these can be further reutilized as raw materials. Avoidance of hetero-atoms in the input-stream by tailor made sorting technologies that reject those. Increase available input volume by tailor made sorting, e.g. Mixed Polyolefins (MPO) fraction for pyrolysis. Develop catalytic pyrolysis to increase monomer recovery from solid plastic waste. Efforts are needed to enhance catalytic performance by increasing conversion efficiency, selectivity and stability. Feedstock blend of plastic waste should still be used for obtaining chemicals/materials.

Technology Readiness Level

Activities are currently at TRL 6-7 and shall achieve TRL 8-9 at the end of the project.

Expected Impact:

Demonstrate a potential reduction in landfill waste volume. Create new technologies and business opportunities for the recycling industry across Europe, especially in the areas where the challenge is high. Reduce the environmental footprint associated with the end-of-life phase of plastic products.

4.2. Chemical recycling of plastic waste by gasification

Scope:

Gasification, as a thermochemical conversion process, can be considered as a promising technology for the chemical valorisation of plastics waste. The conversion process takes place at high temperatures - preferably higher than 1000 °C - to produce tar-free synthesis gas consisting mainly of H_2 and CO. Ash remains as a residual whereas the non-volatile carbon char that would remain from pyrolysis is converted into additional syngas. Partial oxidation of the feedstock provides the energy to reach the high temperatures. Therefore, oxygen is the preferred gasification agent. However, steam is also utilized to moderate temperatures in the process and to increase the yield of H2. Gasification has the potential to be applied where waste cannot be treated neither by mechanical recycling nor by pyrolysis. Temperatures below 1000 °C can be used to recover olefins from polyolefin plastic waste.

Specific challenges:

The feeding system of waste material at high pressure gasification in a continuous process together with the high temperature/energy requirements need attention. Fouling due to by-products (ash and particles) as well as the fact that tars, heavy metals, halogens and alkaline compounds can be released within the product gas, causing environmental and operational problems for some waste streams if the compounds are not properly separated and recovered from the gas stream has to be adressed. Moreover, process flexibility to cope with short-term and/or long-term variation of waste feedstock composition is needed.

Technology Readiness Level

Activities are currently at TRL 6-7 and shall achieve TRL 8-9 at the end of the project.

Expected Impact:

Demonstrate a potential reduction in landfill waste volume. Create new technologies and business opportunities for the recycling industry across Europe, especially in the areas where the challenge is high. Reduce the environmental footprint associated with the end-of-life phase of plastic products.

4.3. Chemical recycling of plastics waste by depolymerization/ solvolysis

Scope:

Depolymerization, as a conversion process applied on plastic waste, can deliver substantial advantages by leading back to the initial building blocks (monomers), with relatively high yield and selectivity at relatively low temperatures. In solvolysis, certain polar and semi polar solvents (e.g. water, alcohol, glycol) are excellent reaction media for depolymerization of plastics. During the decomposition, a mixture of monomers, oligomers, solvents and residues is created. The addition of catalysts can improve the reaction metrics. Polymers to be processed by solvolysis are for example polyurethanes, PET, textile polyesters. For composites, depolymerization also allows the recovery of fibres and fillers. In addition, circularity-by-design is expected to facilitate plastic waste treatment by depolymerization. Ultimately, solvolysis can also be applied as a pre-treatment for separation of certain polymer waste streams due to its high chemical selectivity.

Specific challenges:

Ensure constant input specification of end-of-life material. Critical pre-treatment step of input material. Robustness of process to deal with the potentially high content of impurities of end-of-life materials. Batch to continuous process to improve competitiveness at commercial scale. Downstream separation and purification of individual monomers after depolymerisation (as trace solvents and other contaminants influence the reprocessing). Large volumes of solvent and significant energy are required for solvent recovery. Catalyst developments to improve the depolymerization and to direct the process towards specific building blocks are required. Only a limited number of polymers exist in a sizable amount that can be converted via depolymerization, since one of the main issues is the accessibility of suitable end-of-life material (preferably mono streams). Beside the process optimization, collection systems and sorting technologies are essential to access easy-to-process waste.

Technology Readiness Level

Activities are currently at TRL 4-5 and shall achieve TRL 7 at the end of the project.

Expected Impact:

Create new technologies and business opportunities for the recycling industry across Europe, especially in the areas where the challenge is high. Reduce the environmental footprint associated with the end-of-life phase of challenging plastic products.

4.4. Recycling by dissolution of multi-polymer systems

Scope:

Efficient recycling technologies specifically suitable for multilayer materials need further developments. Approaches like immersion in chemical solutions for separation and catalytic depolymerisation processes require better understanding of key parameters like processing conditions, the nature of the polymers treated, the nature of the potential contaminants, etc. Besides, scale up from lab results to pre-pilot or pilot lines should be performed. The chemical recycling technologies described in the previous chapters, as far as they can deal with mixed plastics, will be very suited for these multi-layered materials.

Specific challenges:

Films with multiple layers made of different polymers are typically difficult to separate. This creates an issue at the recycling stage, as polymer types used for the different layers are not always compatible. The interaction of filling goods (food) with the multi-layer packaging containers often results in contamination of the polymers. Additionally, these articles often contain pigments, functional fillers, silicon layers or adhesive materials, which make the recycling even more difficult, as the different polymers and additives need to be separated before the recycling output can be used again, especially for food and medical applications.

Technology Readiness Level

Activities are currently at TRL 3 and shall achieve TRL 6 at the end of the project.

Expected Impact:

Demonstrate a potential reduction in landfill waste volume by > 50%. Create new technologies and business opportunities for the recycling industry across Europe, especially in the area of plastics where the challenge is high. Reduce the environmental footprint associated with the end-of-life phase of packaging products by at least 30 % compared with existing products for similar applications.

4.5. Mechanical recycling

Scope:

The most promising combination for enhanced mechanical recycling is a) a thorough pre-sorting, combined with analytics/quality control, followed by b) removal of unwanted by products (such as volatile organics and/or certain halogen-organic compounds). The latter stage (a de-volatilization of a recycling polymer melt) recently led to successful FDA approval of recycled-PE by using a degassing process of EREMA. In order to achieve the re-introduction of cross-linked polymers that cannot be reprocessed under normal conditions, stable reagents for high temperature processing by twin-screw extruders/compounding can be developed. New mechanical methods to break the chemical bonds by using twin screw extruders with the combination of high shear and high energy sources (radiations) offer a good potential. New chemical compounds to enhance this process can be added in combination with physical methods. New mixers based on extensional flow (specific reactor) to improve dispersion and distribution quality for a wide range of viscosity ratio and to avoid thermal degradation are needed. Fibre functionalisation and reactive compatibilization extrusion/pultrusion are relevant techniques as well as the reactive extrusion process to improve adhesion between the recycled fibre and polymer matrix (compatibilization). Additives can protect the polymers subjected to these processes. For smart mechanical recycling, a virgin polymer and/or chain repair agent can be fed to improve the quality of the recyclate. The development of mechanical recycling technologies to accommodate bio-based plastics is also required.

Specific Challenges:

Even with highly precise selection and sorting methods, polymer streams will often consist of a mix of different grades of polymers. Mechanical recycling allows the production of decently clean and defined materials without chemical treatment. The recyclate quality is affected by feedstock quality variations and polymer degradation. This lowers the value of the recycled products in many cases. Through smart recycling technologies this can be overcome. This is done through intelligent process monitoring and control. Mechanical recycling of ABS is very close to TRL 9 as for recent examples[22]. Mechanical Recycling of PS has a TRL of 9. Due to polystyrene's low diffusion properties, purity levels >99% of the polystyrene recyclate can be achieved. These enable the use of the high purity polystyrene recyclate in demanding applications, eventually in food contact. On the other hand, mechanical recyclability of FRP articles is difficult, showing usually low yield (particularly for the matrix). Besides, the fibres are significantly degraded, resulting in secondary uses in lower value applications after each lifecycle

Technology Readiness Level

Activities shall achieve TRL 7-9 by 2030.

Expected Impact:

Improve the industrial productivity, reliability, environmental performance, durability, and reduction of life-cycle costs of these materials Demonstrate a potential reduction in landfill waste volume. At least 15% improved industrial process parameters and 20% faster verification of materials performance for highly promising applications.

5. Post-processing

Specific Challenges:

After recycling, polymeric materials can still contain contamination residues of either molecular or elemental nature. This is especially true for the recycling of polymer articles that have been manufactured under older norms using additives that subsequently have been prohibited or restricted or face future prohibition/restriction. Polymers face limits on the number of times they may be recycled without decreasing

22 Recent examples of high quality mechanical recycled ABS grades Terluran® ECO GP-22 MR50 and Terluran® ECO GP-22 MR70, which contain 50 and 70 percent of recycled post-consumer waste from electrical and electronic equipment (WEEE), respectively. The product properties of these recycled ABS grades are well within the property profile of the virgin ABS Terluran

properties, e.g. clarity, strength, etc., further work is required to extend the number of times they can be subsequently recycled as feedstock for the production of new polymers when mechanical recycling is no longer feasible. The challenges for the decontamination of the recycled polymers are in particular: a) the smelly components. Undesirable smells hinder the use of i. e. rHDPE in many applications and they can also cause odour pollution in the production process; b) the short chain fragments (oligomers) as increase in short chain fragments i. e. in a PE matrix affect the flow index of the polymer, one of the critical parameters for the use of a recycled polyolefin and c) the additives and their potential degradation products with different chemical structure embedded in the polymer matrix which need to be removed.

Scope:

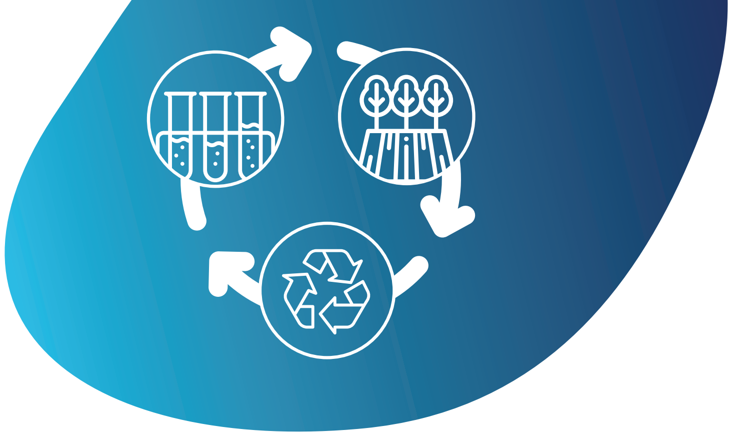
Developing an EFSA or FDA approved technology to decontaminate polyolefins (PE-LD/PE-LLD; PE-HD/PE-MD - Flexible Film (Blown or cast) in order to recover the food contact status after treatment similar to those existing for PET. New, versatile, conformable and low-cost processing technologies to prevent the release of contaminants through barriers/encapsulation (the exact development may be polymer specific). Identifying or optimise modifiers or compatibilizers andproving these additives to minimise degradation of polymer during the recycling steps. Property enhancers as impact modifiers, compatibilizers and coupling agents could also be contemplated to enhance the properties of recyclates. Development of specific compatibilizers with high number of active sites as well as reactive compatibilization processes by twin screw extruders can also be contemplated.

Technology Readiness Level

Activities are currently at TRL 5 and shall achieve TRL 7 at the end of the project

Expected Impact:

Create new technologies and business opportunities for the recycling industry across Europe. Reduce the environmental footprint associated with the end-of-life phase of developed products by at least 30% compared with existing products for similar applications.



Alternative Feedstock

This section covers the innovation on plastics based on alternative sustainable feedstocks, coming from waste/residues of biomass origin, industrial gases. There is a need to provide methodology and data to be useful to build a common baseline to estimate environmental impact of alternative feedstock and their outcomes compared to standard feedstock. This should include short, mid and long-term evaluation with economic impact for producers, suppliers, users. This baseline would be as a support to investments' decisions and should include the European Securities and Markets Authority (ESMA) sustainable finance deliverables[23]. For degradable polymers, it is vital to understand which conditions are required, how long it takes, and which breakdown products they leave behind, but current standards and test methods cannot predict breakdown in complex natural environments[24]. In addition, adequate collection and sorting facilities need to be established.

1. Agricultural and forest biomass waste based raw materials

Side streams of both agricultural and forest feedstock are a good source of feedstock for bio-based polymers.

23 https://www.esma.europa.eu/policy-activities/sustainable-finance
24 https://royalsocietypublishing.org/doi/10.1098/rsos.171792

Challenges:

Forest residues represent an abundant and potentially sustainable source of biomass, which could be used as a feedstock for a biomass to chemicals, fuels and materials in future, The C6 and C5 sugars can be converted into chemical intermediates. Lignin, if properly converted, can serve as a source of renewable aromatic building blocks. Also, ligno-cellulosic biomass in general can be converted to thermoplastic materials by chemical and/or enzyme treatments. Materials in which natural fibres are combined with bio-based thermoplastic matrix, such as Sulapac, can provide sustainable bio-based solutions to certain applications, e.g. in the area of packaging. Major challenges are associated with conversion inefficiencies for this bio-mass-to-product approach. The main specific challenge for biomass conversion into aromatics BTX (Benzene, Toluene, Xylene) is finding the optimal feedstock and process to maximise yield in order to get a cost-efficient process

Scope:

In the area of C6 sugars conversion, catalytic process can achieve higher yields and better selectivity during the conversion of sugar from agricultural sources to industrial feedstock for renewable polymer production. Specifically, furan dicarbocylic acid (FDCA) as a monomer for polyethylene furanoate (PEF) to replace fossil PET and muconic acid as a monomer for biobased polyamides are promising leads. It is important to establish proper recycling routes for these new bio-based polymers. Cellulose can be esterified to produce thermoplastic. Technologies like Integrated Cascading Catalytic

Pyrolysis (ICCP) can be used to produce building blocks for ABS, PS, PET, PO. Development of the suitable additives and process so that these bio-based polymers are commercially viable options. Another possibility are the wood-plastic composites that can be used for construction applications such as decking or cladding.

Technology Readiness Level

From TRL 5 to TRL 9 in 5 years.

Specific Challenges:

High-energy demand of enzymatic processes. Lignin, hemicellulose, cellulose, polymers are available in large volumes and do not interfere with food applications. However, they exhibit high structural complexity (composite structures, higher O/C ratios, at the same time low densities) currently resulting in high-energy demand for manufacturing them in a biomass-to-product strategy. Major challenges are associated with conversion inefficiencies. Development of the suitable additives and process so that these bio-based polymers are commercially viable options. Discrepancy of mixed feedstock and specifically active enzymes. Agricultural and forest waste streams are very often mixtures of different bio-based products. In contrast most of the enzymes used are specific to certain polymer groups.

Scope:

Fundamental research is necessary to find highly active and selective catalysts, high-yield fermentation processes, and atom-economic metabolic reaction pathways in order to increase the overall process efficiencies. A chemical approach is the use of bio-based feedstock with a given specification in traditional, established processes and assets. This mass allocation of biomaterials into a fossil-based cracker feed creates a mixture of hydrocarbons that are partly of plant origin instead of being 100% fossil. An advantage of this technology is the use of existing assets reducing necessary investment cost and manufacturing costs compared to fermentative down-stream technologies. Also, the derived products have the same performance

Technology Readiness Level

TRL 3 to 7 in 5 years.

2. CO_2/CO-based

This section covers technologies able to convert CO_2 and or CO into polymers or building blocks which can in turn be converted into polymers.

Specific Challenges:

The capture CO_2 as feedstock is yet uneconomic for applications in commodity plastics since the costs of CO_2 capture are too high. New technologies and upscaling and optimisation of state-of-the-art CO_2 capture technologies is needed to bring these costs down, as well as optimisation of the processes that convert the CO_2 into plastics. Transforming CO_2 via several pathways into usable building blocks to produce various types of polymers is required.

Scope:

Industrial gases need to be captured in order to be used as feedstock and sometimes can be used directly if the CO_2 content is high enough. For capture, a strong area of innovation is the development of membranes or solid sorbents for CO_2 separation, for example solvent free processes or porous dimension optimisation. For conversion of CO_2 to base chemicals, improved catalytic systems need to be developed both with respect to catalyst composition and shape. With the direct conversion of CO_2, polycarbonate-etherols (polyol) for polyurethanes, Poly(propylene) carbonate or polyesters can be developed. CO_2-derived (poly)-olefins, PS, PMMA can be made through different pathways. CO_2-derived vinyl monomers can derive into many different polymers. Polymers from CO_2-derived non-olefinic intermediates for example PTHF or PU without isocyanate can also be developed.

Technology Readiness Level

Activities are currently at TRL 5 and shall achieve TRL 7 at the end of the project.

At date July 2020 the following organisations are signatories of the CPA:

A+C Plastic Kunststoff GmbH: ABN PIPE SYSTEMS; AGORIA; Agriculture Products Europe (APE Europe); AIMPLAS; Alliance Plasturgie et Composites du Futur (Plastalliance); ALPLA Werke Alwin Lehner GmbH & Co K; Ampacet Europe S.A.; ANL Packaging; APIP - Associação Portuguesa da Indústria de Plásticos; APK AG; Aquafil S.p.A.; Arla Foods; Armacell Benelux SCS; ARMANDO ALVAREZ GROUP; Asociación Española de Industriales de Plásticos (ANAIP); Aspla s.a.; Associação das Empresas Portuguesas para o Sector do Ambiente (AEPSA); Associação Smart Waste Portugal; Association of Chemical Industries of Slovenia at the Chamber of Commerce and Industry of Slovenia; Association of Cities and Regions for Sustainable Resource Management (ACR+); AST Kunststoffverarbeitung GmbH; AST Plastic Containers UK LLP; AST Plastic Packaging Benelux bvba; Aurora Kunststoffe GmbH; Avery Dennison; BANDESUR; BASF; BERICAP Holding GmbH; Berry Global Group, Inc; Berry RPC Verpackungen Kutenholz GmbH; Borealis; C.M.G. SpA; CAPEC - CAJAS Y PALETS EN UNA ECONOMIA CIRCULAR; CEFLEX, A Circular Economy for Flexible Packaging; CEN-CENELEC; Chemical Recycling Europe; Chevron Phillips Chemicals International NV; CICLOPLAST; Circular Economy Research Center, Ecole des Ponts Business School; Cirplus; Citeo; Cobelplast NV; Coca Cola in Europe; COEXPAN; Comité Français des Plastiques en Agriculture; Coop Italy; Coopbox Group; Copa and Cogeca; Covestro; CROCCO SpA; CYRKL waste2resource marketplace; Danone; Dart Products Europe; Deceuninck NV; Der Grüne Punkt- DSD Duales System Holding GmbH & Co. KG; Digital Europe; DION S.A.; Dutch federation rubber and plastic industry, NRK; Eco Baltia group Ltd; ECODOM; Ecoiberia S.A.; EDANA; Electric SRL; Elipso; EMSUR; EREMA Group GmbH; ERGIS S.A.; Essenscia; Essentra Components; EURECAT; Eurocommerce; Eurocord AiSBL; EUROMAP - European Plastics and Rubber Machinery; EuroMouldings BV; European Association of Automotive Suppliers (CLEPA); European Automobile Manufacturers' Association (ACEA); European Brands Association (AIM); European Carpet and Rug Association (ECRA); European Chemical Industry Council (CEFIC); European Composites Industry Association (EUCIA); European Composites, Plastics and Polymer Processing Platform (ECP4); European Federation of Bottled Waters (EFBW); European Federation of Waste Management and Environmental Services (FEAD); European Manufacturers of Expanded Polystyrene (EUMEPS); European Organisation for Packaging and the Environment (EUROPEN); European Plastic Pipes and Fittings Association (TEPPFA); European Plastics Converters (EuPC); European Plastics Recycling Organisations (EPRO); European PVC Profiles and Related Building Products Association (EPPA-profiles); European Recycling Industries' Confederation (EuRIC); European Resilient Flooring Manufacturers' Institute (ERFMI); European Snacks Association (ESA); Evertis Ibérica, S.A.; ExcelRise; Extended Producer Responsibility Alliance (EXPRA); FAMA PLAST SRL; FCIO - Association of the Austrian Chemical Industry; FECC; Fédération de la Plasturgie et des Composites (FED-Plasturgie); Federation of Reinforced Plastics (AVK); Fernholz GmbH & Co.KG; Ferrero; Flexible Packaging Europe; FoodDrink Europe; Fördergemeinschaft für das Süddeutsche

Kunststoff-Zentrum e.V.; Formteile - Ben Neudel GmbH; Fuerst GmbH; GCR GROUP; Gesamtverband Kunststoffverarbeitende Industrie e. V. (GKV); GKV/TecPart - Verband Technische Kunststoff-Produkte e.V.; GREEN PLASTURGIE; Greiner Packaging International; Groupe Barbier; Groupe Guillin; Gruppo Fabbri Vignola SpA; GSK Consumer Healthcare; Henkel AG & Co. KG; Home Appliance Europe (APPLIA); Ibacplast, s.l.; IFFPG; IKEM – Innovation and Chemical Industries in Sweden; Incoplas; INDESLA PACKAGING, SL; Industrievereinigung Kunststoffverpackungen e.V. (IK); Infiana Germany GmbH & Co. KG; International Association for Soaps, Detergents and Maintenance Products (AISE); INTRAPLAS - Indústria Transformadora de Plásticos, S.A.; ipa-plast KG; Italian Plastics and Rubber Processing Machinery and Moulds Manufacturers Association (AMAPLAST); IVK Europe; IVL Swedish Environmental Research Institute; Joh. Sieben GmbH; Jokey SE; KIMIDE e.K. Resource & Waste Management; KISICO GmbH; Klöckner Pentaplast – KP Films; Komunala Kranj d.o.o.; Kurtz Holding GmbH & Co. Beteiligungs KG; LATI Industria Termoplastici S.p.A; Leygatech; Lightweight Containers; Liveo Research GmbH; L'Oréal; MAAG GmbH; MACPAC SA; Madreperla spa; Magyar Márkaszövetség (Branded Goods Association Hungary); Mars; Menshen Group; MEPOL S.R.L.; Mixer Spa; MKV GmbH Kunststoffgranulate; MOL Group; Mondelēz International; MULTIVAC Sepp Haggenmüller SE & Co. KG; Municipal Waste Europe (MWE); MURAPLAST d.o.o.; Nestlé; Norwich Plastics; OIKOKIKLIOS S.A.; OneCircle; Online Laminating & Technology Center GmbH & Co KG; Orgalim; Orkla ASA; PEKU Folien GmbH; Pepsico; Petcore Europe; PET-Verpackungen GmbH; pielleitalia; PIEP-Polo Inovação Engenharia de Polímeros; Plasta d.o.o.; PLASTIC SENSE FOUNDATION; Plastics Europe; Plastics Recyclers Europe (PRE); PLASTIGAUR S.A.; PLASTIKA KRITIS SA; Plastika Skaza d.o.o.; Plastikourgeio; Plastipolis; Plastship GmbH; Polyolefins Circular Economy Platform (PCEP); Pöppelmann Holding GmbH & Co. KG; Portugal; PREMATÉCNICA S.A.; Pro Form Kft.; Producer Responsibility Organisations Packaging Alliance (PROsPA); Recticel; Reifenhäuser GmbH & Co. KG Maschinenfabrik; REMONDIS Recycling; RENOLIT SE; RETAL; Ribawood, S.A; RKW SE; ROBOPLAST S.R.L.; Schwarz Gruppe; Serioplast Global Services S.p.A.; Seufert Transparente Verpackungen GmbH; Siemens AG; Silver Plastics GmbH & Co. KG; Simap Srl; SINTAC RECYCLING; SIRAP GEMA SPA; SiriusPro GmbH; SKYTECH SAS; Soft Drinks Europe (UNESDA); Stabilplastik; Stelioplast Roland Stengel Kunststoffverarbeitung; Styrenics Circular Solutions (SCS); Südpack Verpackungen GmbH & Co.KG; SULAYR GLOBAL SERVICE; Sund Holding; Tama Group; Texplast GmbH; The Compost Bag Company nv; Thees Plastic Recycling; Thrace Group; TNO; TOMRA; TRIA S.p.A.; Trioplast Industrier AB; UAB Putoksnis; Unilever; Unionplast - Federazione Gomma Plastica; Valencian Plastics Companies Association (AVEP); Verpa Folie Weidhausen; Versalis SpA; Vinylplus; VTT; WEEE Forum; Wellplast AB.

Glossary

ABS-HIPS	Acrylonitrile-butadiene-styrene – High Impact polystyrene
ABS-SAN	Acrylonitrile-butadiene-styrene – Styrene acrylonitrile
AI	Artificial intelligence
BrFR	Brominated flame retardants
BTX	Benzene, Toluene Xylene
CLT	Cross-linked thermosets
CO_2	Carbon dioxide
CVD	Chemical vapour deposition
DCPD	Polydicyclopentadiene
DEHP	Di-2-ethylhexyl phthalate
EFSA	European Food Standards Agency
EPS	Expanded polystyrene
FDA (US)	Food and Drug Administration
FRP	Fibre reinforced polymer
HBCD	Hexabromocyclododecane
ICCP	Integrated Cascading Catalytic Pyrolysis
LCA	Life Cycle Assessment
LCC	Life Cycle Costs
LIBS	Laser-Induced Breakdown Spectroscopy
MIR-T	Mid Infrared Thermography
MPW	Mixed post-consumer waste
NIR	Near infrared
PA	Polyamide (aka Nylon)
PA6/PA66	Nylon 6 / Nylon 66
Pb	Lead
PBS/PBSA	Polybutylene Succinate / Polybutylene Succinate Adipate
PBT	Polybutylene terephthalate (also PTMT)
PC	Polycarbonate
PE	Polyethyene
PE-HD	Polyethyene - high density
PE-LD	Polyethyene – low density
PE-LLD	Polyethyene - linear low density
PE-MD	Polyethyene - medium density Glossary
PEC	Polyester carbonate
PEF	Polyethylene Furanoate
PET	Polyethylene terephthalate
PHA/PHB	Polyhydroxyalkanoates / Polyhydroxybutyrate
PLA	Polylactic acid
PMMA	Polymethyl methacrylate
PO	Polyolefin
POM	Polyoxymethylene
PP	Polypropylene
PPC	Polypropylene carbonate
PS	Polystyrene
PT	Polythiophene
PTFE	Polytetrafluoroethylene
PTHF	Polytetrahydrofuran
PU/PUR	Polyurethane
PVC	Polyvinyl chloride
PVD	Physical vapour deposition
SIRA	Strategic Innovation and Research Agenda
TBS	Tracer based sorting
TPS	Toughened polystyrene
TRL	Technology readiness level
TS FRP	Thermoset Fibre reinforced polymer
UV	Ultraviolet
VIS	Visible
WEEE	Waste from electrical and electronic equipment
XRF	X-ray fluorescence
XRT	X-ray transmission

About the partners

SusChem is the European Technology Platform for Sustainable Chemistry. It is a forum that brings together industry, academia, policy makers and the wider society. SusChem was officially launched in 2004 as a European Commission supported initiative to revitalise and inspire European chemistry and industrial biotechnology research, development and innovation in a sustainable way.
www.suschem.org

The European Chemical Industry Council - Cefic is a committed partner to EU policymakers, facilitating dialogue with industry and sharing broad-based expertise. Cefic represents large, medium and small chemical companies across Europe, which directly provide 1.2 million jobs and account for 14.7% of world chemical production. Based in Brussels since its founding in 1972, Cefic interacts on behalf of its members with international and EU institutions, non-governmental organisations, the international media, and other stakeholders.
www.cefic.org

PlasticsEurope is a leading European trade association with centres in Brussels, Frankfurt, London, Madrid, Milan and Paris. The association networks with European and national plastics associations and has more than 100 member companies that produce over 90% of all polymers across the EU28 member states plus Norway, Switzerland and Turkey.
www.plasticseurope.org

European Plastics Converters (EuPC) is the EU-level trade association, based in Brussels, representing more than 50 000 companies in Europe, which produce over 50 million tonnes of plastic products every
year. Plastics converters (sometimes called «Processors») are the heart of the plastics industry. They manufacture plastics semi-finished and finished products for an extremely wide range of industrial and consumer markets - the automotive electrical and electronic, packaging, construction and healthcare industries, to name but a few.
www.plasticsconverters.eu

The European Composites, Plastics and Polymer Processing Platform (ECP4) is an industry-driven collaboration that unites 25 members from 13 countries amongst the top-level European research institutions, regional plastic clusters, and EU-level industrial organisations of plastics and composites converters. ECP4 brings innovation partners together to identify opportunities for collaborative research.
www.ecp4.eu

About SusChem

SusChem is the European Technology Platform for Sustainable Chemistry. It is a forum that brings together industry, academia, policy makers and the wider society.

SusChem's **vision** is for a competitive and innovative Europe where sustainable chemistry and biotechnology together provide solutions for future generations.

SusChem's **mission** is to initiate and inspire European chemical and biochemical innovation to respond effectively to societal's challenges by providing sustainable solutions.

At SusChem we believe that sustainable chemistry can inspire a change of pace and the new mind-set that society needs in order to become (more) sustainable, smart and inclusive. In partnership with European and national public authorities, SusChem contributes to initiatives that aim to provide sustainable solutions to society's big challenges. Together we develop and lead large-scale, integrated research and innovation programmes with chemical sciences at their core. These public private initiatives link research and partners along the value chain to real world markets through accelerated innovations.

SusChem across Europe

SusChem has established a network of National Technology Platforms (NTPs) in 17 countries across Europe: Austria, Belgium, Bulgaria, Czech Republic, France, Germany, Greece, Italy, Netherlands, Poland, Romania, Slovenia, Spain, Switzerland, Sweden, Finland, and United Kingdom.

NTPs help to connect SusChem thinking with national and regional programmes. It also facilitates transnational collaboration and advice SusChem at the European level on collective national priorities that need to be considered in European initiatives.

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SusChem Secretariat

Address

The European Technology Platform
for Sustainable Chemistry
Rue Belliard 40

1040 Brussels

Contact us

T +32.2.436.94.18
E suschem@suschem.org
www.suschem.org
@SusChem