CreaSolv® Process

Solvent-based Purification/Dissolution

Position Paper

Material Recycling in a Circular Economy for Plastics
A Critical Assessment

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Solvent-based purification is an effective and efficient technology for material re-use of plastics polluted with impurities and harmful substances like expanded polystyrene from construction;
© PolyStyreneLoop (left), EPC (right)

The authors describe the status quo of plastics recycling and evaluate the available processes in terms of their weaknesses, strengths and environmental compatibility. They place particular emphasis on defining and positioning solvent-based purification as a physical process that closes the gap between mechanical and chemical recycling. They specifically address the technically and practically proven CreaSolv® Process, which offers a new solution as an alternative to incineration for the treatment of contaminated plastic waste from applications in construction, packaging, electrical and electronic equipment, etc. They identify weak points with regard to imprecise, insufficiently differentiated definitions in existing waste directives and, based on this, formulate recommendations for the creation of specific directives that could finally also pave the way for a viable Circular Economy for plastics.

Material Recycling in a Circular Economy for Plastics A Critical Assessment

The initiated transition to a circular economy requires a further increase of material recycling. For the area of plastics, this means processing them in such a way that the polymers they contain can be reused, thus making a valuable contribution to reducing the environmental impact caused by plastic waste.

Achieving the recycling targets of the EU Plastics Strategy requires new, advanced technologies. These must go beyond the limits of traditional mechanical recycling, which today is mainly responsible for the reported recycling rates.

The Fitness Check of the EU Waste Directives (2014) and the EASAC report «Packaging Plastics in a Circular Ecomomy»[1] identified a need for more specific requirements and a number of systemic flaws in the current linear economic model for plastic packaging (e.g., that recycling of low-grade mixed plastic waste is uneconomic). The report considers it «essential to develop an integrated recycling system that is capable of processing all plastic waste, while reducing emissions and resource consumption.»[1]

Comparative Assessment in line with the Natural Sciences is required

An elementary step on the way to a Circular Economy is the evaluation of all current and innovative recovery technologies in combination with a more specific (more precise) definition of the term "recycling". This must

- understand plastics as a *synthetic material* consisting of organic polymers produced from fossil or other oils,
- be in line with the knowledge of physics and chemistry,
- follow the concept of the waste hierarchy (reduce - reuse - recycle),
- be based on the value chain for plastics (*chemical element -> intermediate -> monomer -> polymer -> plastic*), and
- define *material recycling* (polymer to polymer) as *preparation for reuse of the polymer component*.

Currently, in this context, *chemical recycling* (depolymerization, pyrolysis and gasification), based on chemical processes, is generally considered as only available alternative to mechanical recycling and able to treat waste streams, which are considered as non-recyclable.

Solvent-based Purification / Dissolution closes the Gap

This picture is wrong and incomplete, because it does not take into account the *physical dissolution as a process of material recycling*. This separation process is a selective extraction and, like mechanical recycling, it is based on physical processes. Only the aggregate state (solid to liquid to solid) is changed, but not the polymeric structure, and the energy used for polymerization is retained. In contrast to chemical processes, which destroy the polymer chains, so that a new polymerization is required to close the cycle[17], physical dissolution allows to reuse polymers (**Fig. 1**).

Solvent-based purification begins with the dissolution of plastic waste sorted by polymer type. It is followed by filtration to remove insoluble impurities, precipitation of the clean polymer (separation), drying and finally preparation for extrusion to produce granulates which can then be used to manufacture new plastic articles. The solvents are distilled and reused, the separated impurities are disposed of (**Fig. 2**).

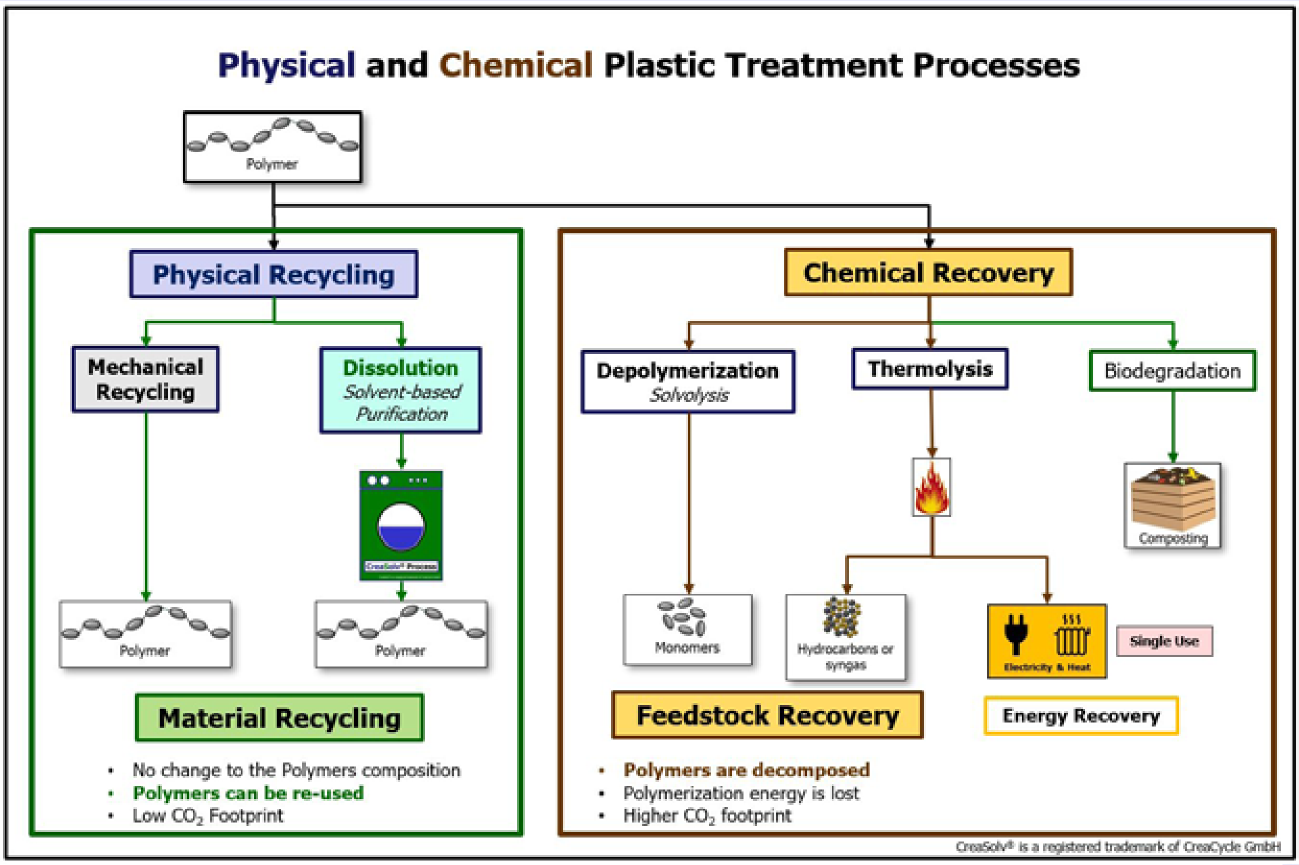

Figure 1. *Mechanical and solvent-based recycling as physical processes compared to chemical recovery.*

Effective, efficient and compliant

Solvent-based purification is proving to be an effective and efficient (economical) way to reuse polymers in plastic waste streams for which mechanical recycling is not applicable for a variety of reasons, because it allows almost complete separation of

- additives and legislated or hazardous substances, such as flame retardants, plasticizers, etc.,
- degradation products of polymer chains, as they are generated during any thermal processing, thus allowing to increase the number of possible recycling cycles,
- other polymers from composite materials, such as multilayer laminates for packaging, and metals (automobiles / ELV and electr(on)ical articles / WEEE), as well as
- carbon and glass fibers in reinforced plastics (ELV, WEEE).

Dissolution meets the *recycling definition* of the Waste Framework Directive 2008/98/EC (2018/851 EU) and the Waste Electrical and Electronic Equipment Directive 2012/19/EC (WEEE), as the polymers are reprocessed for the original or other purposes. However, solvent-based purification also qualifies as *preparation for reuse*, as it is cleaning of the polymer components of plastic articles as a requirement for reuse (material recycling, polymer to polymer). In addition, it meets *the recycling definition* of Directive 94/62/EC on Packaging and Directive 2000/53/EC on end-of-life vehicles, both which require material recycling for waste materials for the original or other purposes (polymer to polymer).

Approved process

A technically and practically proven process for solvent-based purification is the CreaSolv® Process developed jointly by CreaCycle GmbH and Fraunhofer Institute for Process Engineering and Packaging (IVV) (**Fig. 3**). Here, proprietary CreaSolv® Formulations are used that have a minimized risk potential for the user and the environment (i.e. ideally do not require labeling according to GHS criteria). The technology works like a washing machine for polymer chains at the molecular level and is clearly explained at https://www.youtube.com/watch?v=43rqKlblsl8.
With reference to the CreaSolv® Process,

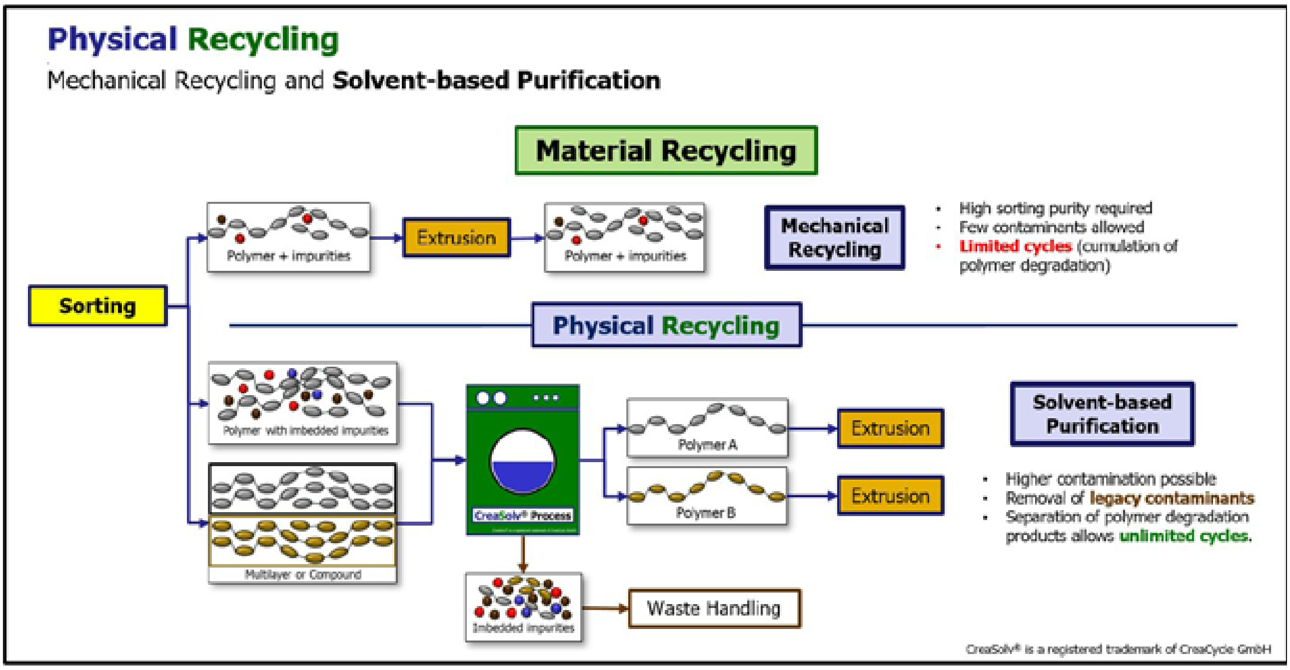

Figure 2. *Comparison of mechanical and solvent-based recycling as physical processes.*

the German Federal Environment Agency (UBA) classifies solvent-based purification/ dissolution technologies as material recycling because they are based on physical processes and the polymer structure is preserved[2]. They also fall into categories c1 or c2 of the waste hierarchy of the Dutch Waste Management Plan (LAP3), as the polymers are recovered as original materials and thus contribute to the fulfillment of the VANG (Van Afval Naar Grondstof - From Waste to Basic Material) targets[3].

Specifically related to the recycling of flame retarded polystyrene foam waste from the construction sector, in 2017 dissolution using the CreaSolv® Process was included in the *Basel Convention Technical Guidelines* as a "Best Available Technique" (BAT) for the removal of persistent organic pollutants (POPs)[18].

In 2016, DEKRA prepared a life cycle assessment (LCA) for the Vinyloop® process[4] for PVC, and TÜV Rheinland published the life cycle assessment for the CreaSolv® Process for construction EPS (PolyStyreneLoop)[5] in 2017. Both show 40 to 45% lower CO_2 emissions compared to incineration with energy recovery.

In an effective circular economy, the reuse of materials has priority. It is therefore oriented to the value chain and the environmental impact of various recycling processes. **Fig. 4** shows the position and function of solvent-based purification alongside mechanical recycling and feedstock recovery.

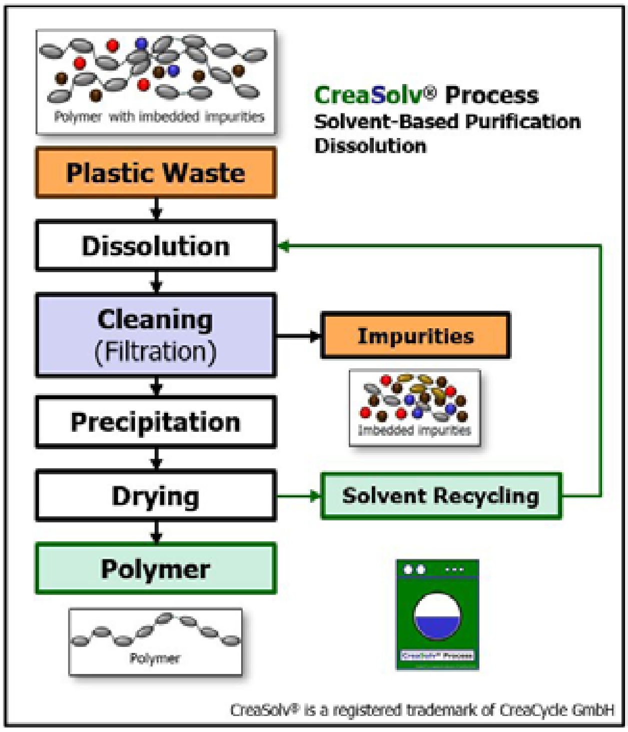

Figure 3. *Solvent-based purification using the CreaSolv® Process as an example.*

Definition: Solvent-based Purification / Dissolution

Material recycling of plastics or polymers in which adhering or embedded impurities, pollutants or composite materials are dissolved and separated by physical processes, changing only the aggregate state but not the composition of the polymers, in order to be able to use them again for the original or another purpose.

Obstacle: unspecific and contradictory requirements

Although the technological conditions exist, unspecific and in part contradictory requirements for plastics recycling continue to prevent an effective circular economy. This is expressed, among other things, in the recycling rates. These are currently over 70% for metal, glass and paper, while plastic only achieves around 30%.

A functioning circular economy must strive to preserve materials and design products suitable for recycling. Downcycling is only to be accepted as an alternative if no better solution exists. In addition, the use of recycled plastics is to be preferred, and boundary conditions must be implemented so that this is possible in a competitive manner. Unfortunately, the current official guidelines are not always target-oriented here.

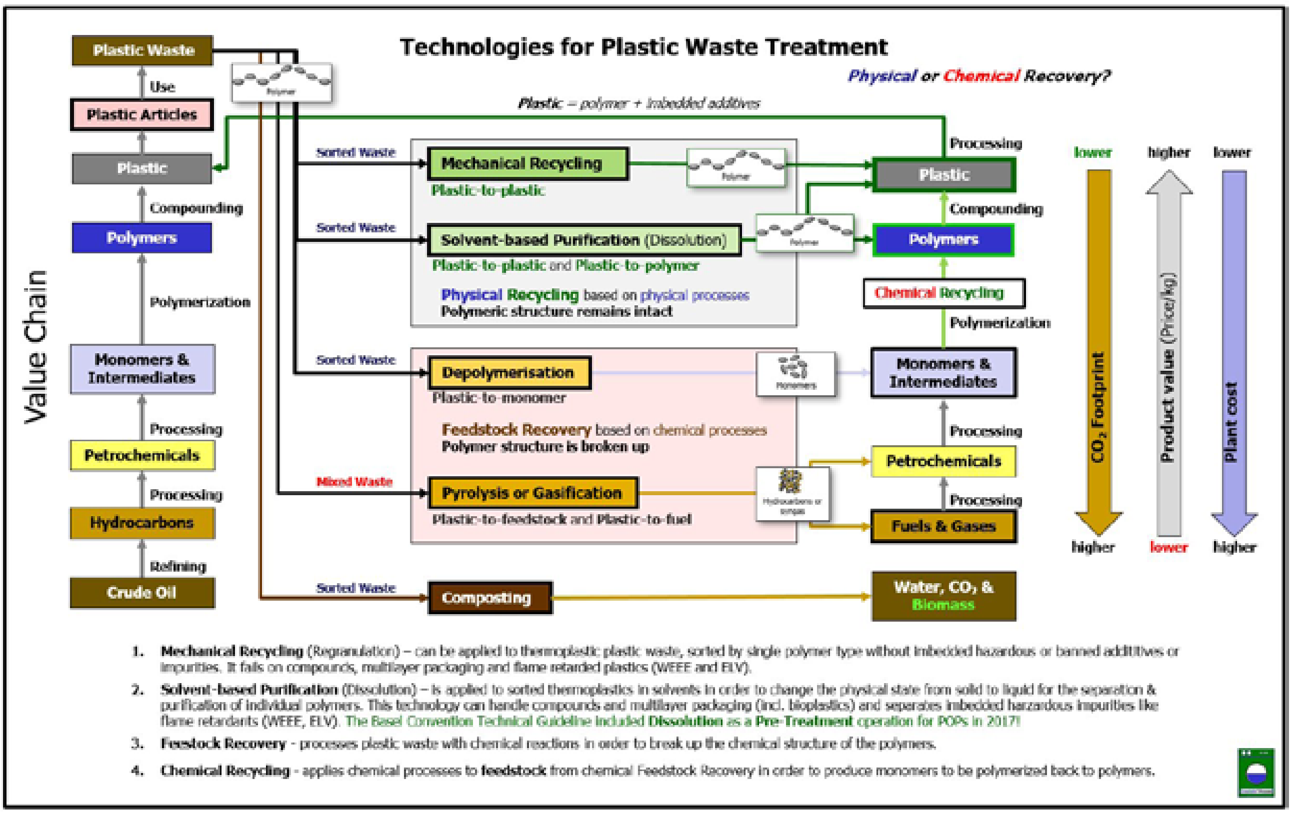

Figure 4. *Comparison of currently available processes for processing plastic waste in terms of value chain, environmental impact and value of the products.*

History of Solvent-based Purification

Solvent-based purification has long been known and practiced for decades. However, cheap landfilling, incineration and export of plastic waste to Asia has limited, prevented or ended the commercialization of this technology to date.

- In 1996 - using the Orange R-net system developed by Sony, expanded polystyrene (EPS) packaging was collected in D-limonene solution in Tokyo and recycled back into expanded PS for packaging. After about 10 years, the project was abandoned for cost reasons.

- 2002 - Solvay operates the 10,000 t/a Vinyloop® plant for the recycling of polyvinyl chloride (PVC) in Ferrara, Italy until 2018, when the plant is closed because the process was not designed to separate DEHP, a plasticizer banned from 2018.

- 2011 - Polystyvert in Quebec, Canada, collects polystyrene foam (EPS) packaging in p-cymene solution (a terpene like D-limonene) and recycles it into polystyrene.

- 2018 - Unilever builds and operates a pilot plant for the CreaSolv® Process with a capacity of 700 t/a to recycle pouch packaging waste (multilayer sachets) in Indonesia - constructed by LOEMI.

- 2018 - APK operates a Newcycling® process plant with 8,000 t/a capacity for industrial polyethylene/polyamide multilayer packaging waste in Merseburg, Germany.

- 2019 - PolyStyreneLoop builds a demonstration plant for the CreaSolv® Process with 3,300 t/a capacity for recycling polystyrene insulation foam from the construction sector (EPS and XPS), which contains the legislated flame retardant additive HBCD. Start-up in Terneuzen, the Netherlands, is scheduled for the 2nd quarter of 2021. Plant construction will be carried out by EPC Engineering & Technologies.

- 2020 - CreaSolv® pilot plant with 700 t/a capacity for multilayer plastic packaging waste from LÖMI in Bavaria, Germany - Circular Packaging and MultiCycle project.

- 2020 - PureCycle completes US$250 million financing and begins construction of a 48,000 t/a polypropylene recycling plant in Ohio, USA.

- 2021 - CreaSolv® Pilot plant with a capacity of 15-20 kg/h at the Fraunhofer Institute IVV for recycling PVC flooring (Circular Flooring Project) with removal of legislated plasticizers (phthalic acid esters). Commissioning is planned for the 2nd half of 2021.

Metal:	inorganic chemical element (iron, copper, etc.) from minerals
Glass:	inorganic molecule (silicate) from minerals (sand)
Paper:	organic polymer (cellulose) from plants
Plastics:	**synthetic** organic polymers from fossil fuels or oils

… *Different definitions for recycling in the EU Waste Directives*

- The Waste Framework Directive and the Waste Electrical and Electronic Equipment Directive do not distinguish whether waste materials are reprocessed into products, materials or substances. They include the definition *preparation for reuse*.
- The Packaging and ELV Directives both define *reprocessing of waste materials for the original purpose or for other purposes*. *Preparation for reuse* is not included in either directive.
- Neither of the waste directives contains definitions for an *article*, a *material*, a *substance* or a *component of an article*.

… *No clear target-oriented guidelines for plastics recycling by using generic terms.*

- The chemical industry sells chemical products of the entire value chain such as plastics (polymer with additives), polymers, monomers and elements. Product and article are synonyms.
- Plastic products made of composite materials consist of one or more polymer components to match product properties to requirements (e.g. packaging films: flexibility, oxygen and water-vapor barrier, adhesion, etc.). Materials are substances that are processed in production processes and enter the final products.
- Polymers and additives fall under REACH, where polymers, monomers, molecules, and elements are generally defined as substances.

… *Lack of a Recovery Hierarchy - too little differentiation*

The EU lacks a recovery hierarchy. In addition, the current waste directives for polymer-based waste are not differentiated enough, and they do not consider conditions for repeated reuse of the same material or substance (material recycling of polymers). Recycling is used as a generic term that defines reuse and downcycling as equivalent. This allows high recycling rates to be achieved through reuse for metals, glass or paper, but this creates conflicts for plastics, as reuse and recycling occupy two different positions in the waste hierarchy (**Fig. 5**).

… *No distinction between physical and chemical recovery processes*

Industry consultants, lobby groups and environmental organizations repeatedly confuse physical and chemical processes for recycling plastics and incorrectly refer to solvent-based purification/dissolution as chemical recycling[6-15]. However, the German Federal Environment Agency (UBA) has explained the technical and legal basis in detail in its background paper "C*hemical Recycling*". It also includes the clarification that solvent-based purification is not chemical recycling[2] because it is based on physical processes and should therefore be classified as material recycling.

The lack of *specific requirements for reuse and recycling* allows conflict with the natural sciences and the waste hierarchy and blocks the path to a circular economy. This is all

	Recycling		Preparing for re-use		Recovery Processes	
	Input	Output	Input	Output	Physical Recycling	Chemical Recovery
WFD	*materials*	products *materials* substances	products **components**	products ***components***		
	plastic *polymer*	for the original or other purposes *plastic* *polymer* *polymer* *monomer* *intermediate* *element*	plastic article *plastic* *polymer*	*plastic* *polymer*	mechanical recycling / purification purification	depolymerization pyrolysis gasification
WEEE	*materials*	products *materials* substances	products components	products components		
	plastic *polymer*	for the original or other purposes *plastic* *polymer* *polymer* *monomer* *intermediate* *element*	plastic article *plastic* *polymer*	*plastic* *polymer*	mechanical recycling / purification purification	depolymerization pyrolysis gasification
ELV	*materials*	*materials*	**Preparing for re-use** is not defined/available			
	plastic *polymer*	for the original or other purposes *plastic* *polymer*			mechanical recycling / purification purification	
Packaging	*materials*	*materials*	**Preparing for re-use** is not defined/available			
	plastic *polymer*	for the original or other purposes *plastic* *polymer*			mechanical recycling / purification purification	

WFD Directive 2008/98/EC - Waste Framework Directive (WFD)
WEEE Directive 2012/19/EU on waste electrical and electronic equipment (WEEE)
ELV Directive 2000/53/EC on end-of-life vehicles (ELV)
Packaging Directive 94/62/EC on Packaging and Packaging Waste

Purification = Solvent-based Purification (SBP) / **Dissolution**

Figure 5. *„Recycling" and „preparation for reuse" in EU waste directives and their influence on plastic waste.*

the more unacceptable as the *2002 draft EU Packaging Directive* already contained clear definitions for different types of recycling and reuse. Prof. Arnold Tucker (TNO) noted them in his article *Plastics Waste - Feedstock Recycling, Chemical Recycling and Incineration*[16].

1. *reuse* implies the use of the same product without essential changes in a new use cycle (e.g. refillable packaging after cleaning);
2. *material recycling i*mplies the application of the material used, without changing the chemical structure, for a new application;
3. *chemical recycling i*mplies the application of the material used, but in such a way that the resulting chemicals can be used to produce the original material again;
4. *feedstock recycling* implies a change of the chemical structure of the material, where the resulting chemicals are used for another purpose than producing the original material;
5. *recycling with energy recovery i*mplies input into a device where the energy content of the input material is used.

These simple and straightforward definitions make a lot of sense, sound familiar and capture everything for a logical distinction - but have never been applied. Instead, ISO standard 15270/2008 *Plastics - Guideline for the recovery of plastic waste*[19] today defines feedstock recycling and chemical recycling as synonyms!

… *New production of polymers and plastics ignores end-of-life costs*

Falling oil prices repeatedly lead to falling prices for polymers as the basis for virgin plastics. This causes plastic recyclers to lose their business base as they have to pay for collection and sorting. Although they are not the originators of the plastic waste, they must purchase sorted plastic waste. In industries with high material consumption, such as the packaging, automotive and electrical (electronics) industries, plastic recyclates are considered a cheap opportunistic source of raw material that competes with virgin material and is turned on or off depending on the price situation.

Recommendations for an effective Circular Economy for plastics

From the explanations, comments and overviews presented so far, there is a clear demand for measures that finally also pave the way for plastics to become a true circular economy.

… *Clear definitions as part of plastic-specific guidelines to be drawn up*

Plastics are synthetic materials that are used today in all areas of daily life. The quantities used are constantly increasing, but the resulting waste does not fit into our current waste guidelines. The development and introduction of an EU directive specifically for plastic waste should therefore be demanded. This is a serious global issue that deserves our full attention. These waste directives must distinguish between products, materials, substances and components! We need definitions for all terms to establish clear descriptions. This can then point the way to upcycling instead of downcycling.

… *Introduction of a recovery hierarchy based on physical and chemical processes*

Future directives must clearly define and specify the terms reuse, recycling, and recovery of materials. These should then be incorporated into a recovery hierarchy that is applicable to all waste directives, is consistent with the natural sciences and the waste hierarchy, and supports a circular economy. The terms used should be equally applicable to both plastics and materials in general, without any adverse effect on the current (high) recycling rates for materials such as metals, glass, paper, etc.

Fig. 6 shows how such a hierarchy should be structured. With only a few modifications, it is based on the proposal from the 2002 draft packaging directive by taking into account experiences and improvements that have been made in the meantime (e.g., the distinction between physical and chemical processes). For all other directives, one can replace the term *plastic waste* with *waste materials* and *polymers* or *plastics* with *materials*. The various recovery processes for plastics can be omitted for these areas.

… *Knowledge of economic efficiency and environmental impact*

A sensible decision on which route to take in the recycling hierarchy requires knowledge of all available recovery technologies with their specific advantages and disadvantages. Only then these can be used in the sense of an optimal sustainable handling of the growing plastic waste volumes by taking into account the consumption of resources and the amount of environmentally harmful emissions.

… *Responsibility for products with the producers*

The general requirement is that producers of virgin plastics should also bear the end-of-life costs. In this context, an EU plastics tax should primarily support the commercialization of new recycling technologies and the capacity increase of recycling processes that preserve (physical recycling) or re-generate (chemical recycling with polymerization) polymer chains. At the same time, it should contribute to the improvement of sorting capacities and quality to enable more material recycling and to minimize the share of chemical feedstock recovery.

The demand for *recycling-friendly design* goes in the same direction. This should be based on the available recycling technologies. The focus should primarily be on *physical recycling* in order to be able to reuse polymer components and reduce single-use. The introduction of extended producer responsibility (EPR) principles serves the goal of increasing the proportion of recycled plastics in new products in order to establish a stable, profitable recycling business that is no longer dependent on the price of oil.

Re-use, Recycling and Recovery of Plastic Waste

Recovery Hierarchy - Definitions for a Successful Circular Economy

1. **Reuse** implies the use of the same product without essential changes in a new use cycle
2. **Material recycling** implies the processing of **plastic waste** with **physical processes**, without changing the chemical structure of polymers, **for a new or a similar application** through
   a. Melting (mechanical recycling)
   b. Dissolution (solvent-based purification)
3. **Chemical recycling** implies the processing of **plastic waste** with **chemical processes**, thus changing the chemical structure of the polymers through
   a. Depolymerization (Solvolysis)
   b. Pyrolysis (Cracking)
   c. Gasification

   in such a way that the resulting chemicals (Feedstock) will be used to process and **polymerize the original polymer or plastic**;
4. **Feedstock recovery** implies the processing of **plastic waste** with **chemical processes**, thus changing the chemical structure of the polymers through
   a. Depolymerization (Solvolysis)
   b. Pyrolysis (Cracking)
   c. Gasification

   in such a way that the resulting chemicals will be used **for another purpose** than producing the original polymer or plastic.
5. **Energy recovery** implies the input into a device where the **energy content of plastic waste is used**.

Figure 6. *Recovery hierarchy for plastic waste*

… *Recognition and inclusion of Solvent-based Recycling as Material Recycling.*

Dissolution meets the recycling definition of the Waste Framework Directive and is based on physical processes that - like mechanical recycling - do not change the chemical structure of polymers. That is why the authors call for EU member states to approve solvent-based purification/dissolution for the calculation of recycling quotas.

Such recognition is necessary to secure future investments in the development and commercialization of dissolution technologies in order to achieve the ambitious recycling targets of the EU Green Deal.

April 2021

CreaCycle GmbH and the Fraunhofer Institute for Process Engineering and Packaging (IVV) have combined their competences in a cooperation with the aim of „plastic/material recycling with a solvent-based process" (selective extraction) and together developed the CreaSolv® Process, which is based on physical processes and does not change polymeric structures. CreaCycle develops and supplies special CreaSolv® Formulations with the lowest possible risk potential for users and the environment.

Fraunhofer IVV is a leading R&D provider in the food and food packaging sector with specific expertise in the field of plastics/materials recycling. The department „Process Development Polymer Recycling" has developed and patented the CreaSolv® Process, which enables the recovery of pure polymers of high quality from plastic and packaging waste. The range of services includes the optimization of existing recycling processes, the analysis of products for hazardous ingredients, and support in replacing fossil raw materials with renewable ones.

EPC Engineering & Technologies GmbH is a family-owned German technology company with more than 145 years of engineering tradition. The main business areas of the company are process technology licensing, engineering services as well as the construction of turnkey plants. EPC's core competencies include polymers & fibers (both recycling and production plants), fine chemicals & pharmaceutical technologies, chemical plants, sustainable energy, foodstuff and biotechnologies, as well as construction and infrastructure projects. EPC Engineering & Technologies has been involved in the development of the CreaSolv® Process and is the exclusive licensor for this technology and the engineering partner of PolyStyreneLoop

PolyStyreneLoop B.V. is a Dutch cooperative with more than 70 members across the EPS/XPS value chain and is currently building a CreaSolv® Demonstration plant with an annual capacity of 3.300 tons in Terneuzen, the Netherlands, for the recycling of expanded polystyrene (EPS/XPS) construction waste contaminated with the flame retardant additive HBCD (hexabromocyclododecane), which is now banned as a POP. Commissioning is scheduled for the 2nd quarter of 2021.

LÖMI GmbH has been developing high-quality and innovative process engineering plants since 1991, especially for handling solvents. In 2018, LÖMI set up the first CreaSolv® Pilot plant for the recycling of pouches (sachets) in Indonesia for Unilever. In 2020, its own CreaSolv® Pilot plant was installed in Germany to support the commercialization of their clients.

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