CreaCycle GmbH
Innovative Plastic Recycling Technologies

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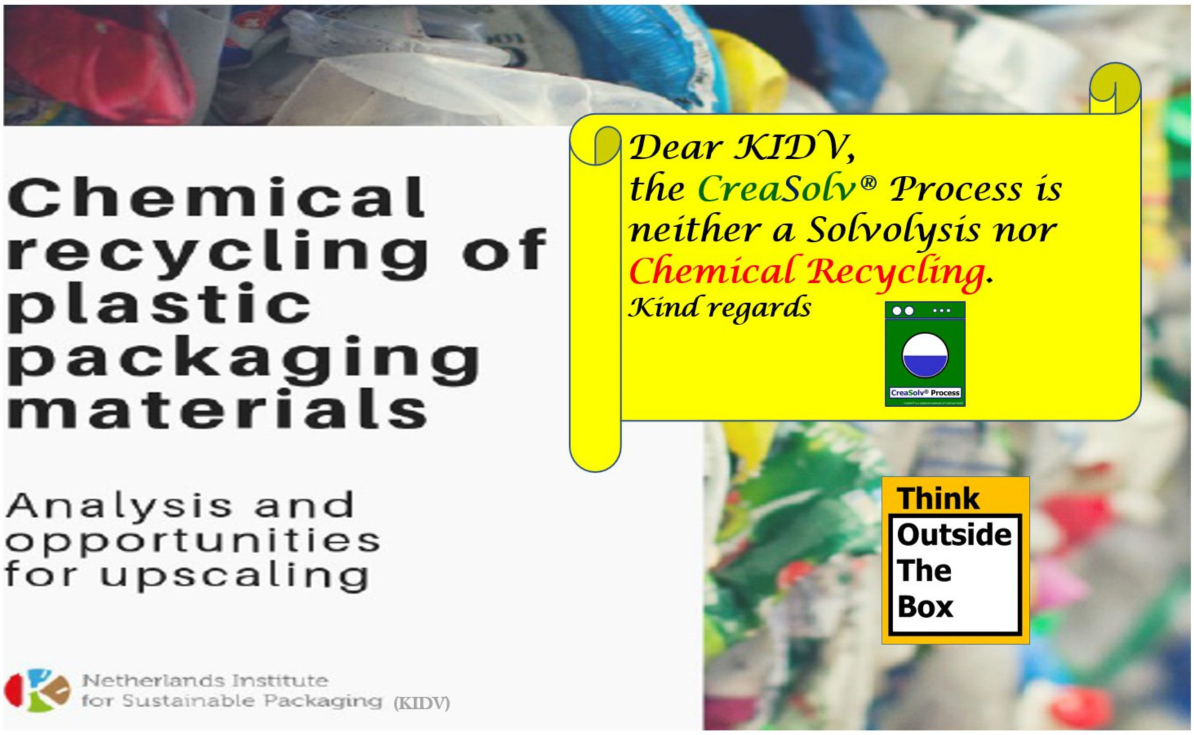
The CreaSolv® Process is neither a Solvolysis nor Chemical Recycling



Plastic packaging has been identified as a main contributor to the present plastic waste pollution of the environment and so it is normal that stakeholders of this value chain have an interest in closing the loop for a circular economy "in an economic sense" (Should it pay for itself?). In order to achieve this, chemical recycling techniques were identified as having the potential to improve and increase the recycling of plastic packaging materials and raise the quality of the recyclates to that of virgin plastics or raw materials[1)].

On 25 October 2018 the Netherlands Institute for Sustainable Packaging (KIDV) published the report "Chemical recycling of plastic packaging materials: analysis and opportunities for upscaling" in order to compare four different chemical recycling technologies (solvolysis, depolymerization, pyrolysis and gasification) and help industry in their decisions when scaling up chemical recycling for packaging material in the Netherlands.

The CreaSolv® Process for the recycling of EPS (expanded polystyrene) with brominated flame retardants (HBCD – Hexabromocyclododecane) from the construction sector was chosen as example for the solvolysis as chemical recycling technology.

In the Dutch National Waste Management Plan 3 (LAP3), that entered into force in December 2017 and will run until 2023, a distinction is made between a number of forms of recycling. Chemical recycling has been defined as the lowest form of recycling (c3). This adds to the challenge to improve the image of chemical recycling as well, so that it can be presented as desired "Game-changer" by all industries depending on plastic packaging. This also explains the actual engagement and activities of Global polymer producers, fast-moving-consumer goods (FMCG) companies and packaging producers and this is not limited to The Netherlands.

Waste Hierarchy from the National Waste Management Plan (LAP3) – The Netherlands

[51] Source: https://lap3.nl/beleidskader/deel-algemeen/b9-recycling-binnen/

- LAP3 will run from 2017 to 2023.
- A distinction is made between different forms of recycling, based on possible applications of the recyclate.
- Chemical recycling is defined as the lowest form of recycling (c3) due to the often high costs and the high energy requirements.

Source: KIDV report 25 October 2018

- c2 and c3 are considered as „down-cycling".
- Mechanical recycling (physical process) falls into category c1 or c2.
- The **CreaSolv® Process**, based on „Solvent-based Purification" (physical process) falls into category c1 or c2.

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Source Waste Hierarchy*: Netherlands Institute for Sustainable Packaging (KIDV) published the report "Chemical recycling of plastic packaging materials: analysis and opportunities for upscaling" published 25 October 2018.*

Chemical Recycling is considered as the lowest form of recycling due to the often-high costs, the high energy requirements and the fact that the output cannot always be used as raw-material (page 50). Volumes that are recycled into their original materials count as recycling and contribute to the realization of VANG targets[4)] (**V**an **A**fval **N**aar **G**rondstof – From waste to resource).

This makes of course sense because Chemical Recycling is based on chemical reactions. This means that the composition of the Polymer is changed. The polymer chains are broken up into smaller molecules and in order to get back to the polymer, monomers have to be processed and polymerized again before they can be used in their original applications.

Mixing up Science and Lack of clear Definitions

The KIDV report is very comprehensive, contains very valuable information and allows a very good comparison between de-polymerization, pyrolysis and gasification of plastic waste.

On the other side it also is an example how mixing up science and chemical terminology, combined with unclear definitions, can lead to mis-interpretation and wrong conclusions or recommendations.

We have seen this in other reports as well[2,3)] and this shows how important it is to have a clear definition and a common understanding when discussing about a specific subject and/or comparing different technologies.

In the KIDV report chemical recycling is defined (page 10) as:

- *The output is used by the manufacturing industry*
- *The chemical process produces raw-materials for similar applications*
- *The output is turned into raw-materials or fuel, etc.*

The target is set as: Recycling plastic packaging materials which are currently not being recycled using mechanical techniques (page 11).

Actually, everyone splits plastic recycling into 3 technologies:

1. mechanical recycling
2. chemical recycling
3. energy recovery.

ISO 15270/2008 Plastics - Guidelines for the recovery and recycling of plastics waste[5)] definitions:

1. mechanical recycling - processing of plastics waste into secondary raw material or products without significantly changing the chemical structure of the material

2. chemical recycling - conversion to monomer or production of new raw materials by changing the chemical structure of plastics waste through cracking, gasification or depolymerization, excluding energy recovery and incineration
   Feedstock recycling and chemical recycling are synonyms.

3. energy recovery - production of useful energy through direct and controlled combustion
   Solid-waste incinerators producing hot water, steam and/or electricity are a common form of energy recovery.

Without doubt one can conclude from above that Chemical Recycling of plastic waste always goes in line with the destruction of the chemical composition/structure of the polymer(s).

Solvent-based purification of plastic waste (Dissolution) is not well known and it is typically described as chemical recycling, what may be based on the opinion that this cleaning technology has been used in the chemical industry for decades, but it was and still is a false and misleading classification.

Solvent-based Purification is based on physical and not on chemical reactions or changes and only the physical state of the polymer changes from solid to liquid and then back to solid. The polymer chains remain unchanged in contrary to Chemical Recycling and can be **re-used** in the original or similar applications.

Physical or Chemical Reaction?

Basics

A chemical reaction produces new substances, while a physical reaction does not.

A material may change shapes of forms while undergoing a physical change, but no chemical reactions occure and no new compounds are produced.

Physical Change

- ***No new substance is formed***
- ***No composition change***
- ***The change is reversible***

Examples

- ***Boiling water, melting ice***
- ***Shredding paper (or plastic film)***
- ***Dissolving sugar in water***
- ***Melting a polymer** (e.g. extrusion)*
- ***Dissolving a substance in a liquid***

Chemical Change

- ***New substances are formed***
- ***Composition is changed***
- ***The change is irreversible***

Examples

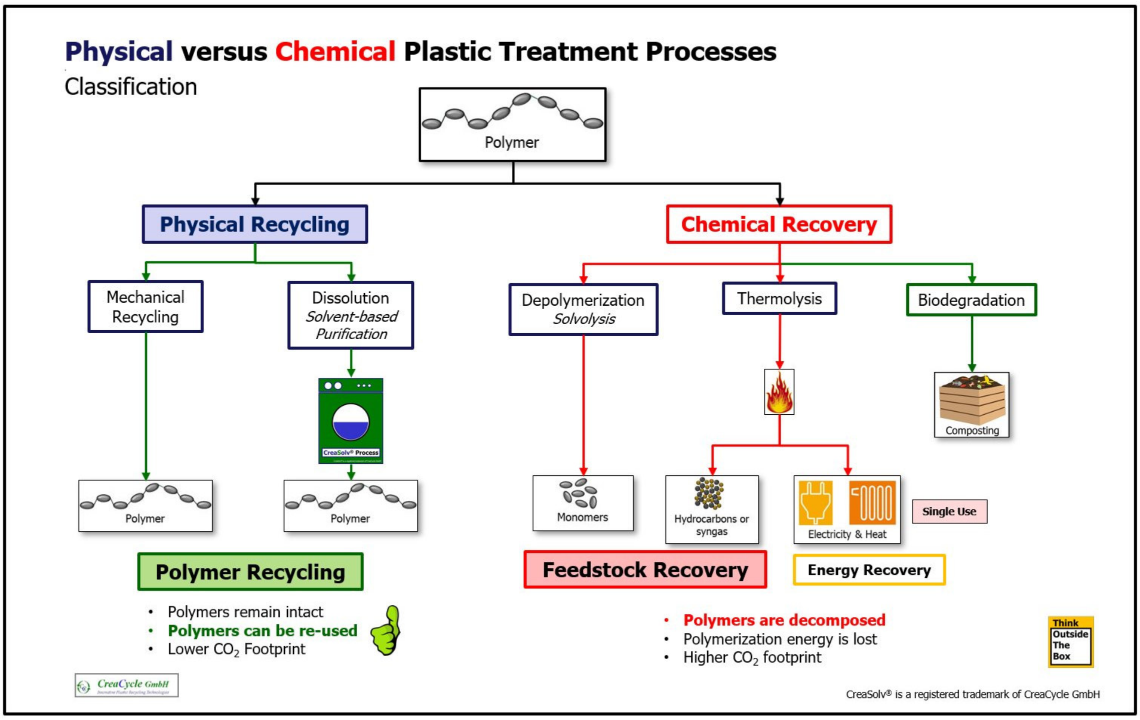
- ***Burning wood***
- ***Rusting of iron***
- ***Polymerization & de-polymerization***
- ***Pyrrolysis of polymers***

Please check:
Bozeman Science - "Chemical and physical changes":
https://www.youtube.com/watch?v=ziQtpXVDpn0&feature=youtu.be

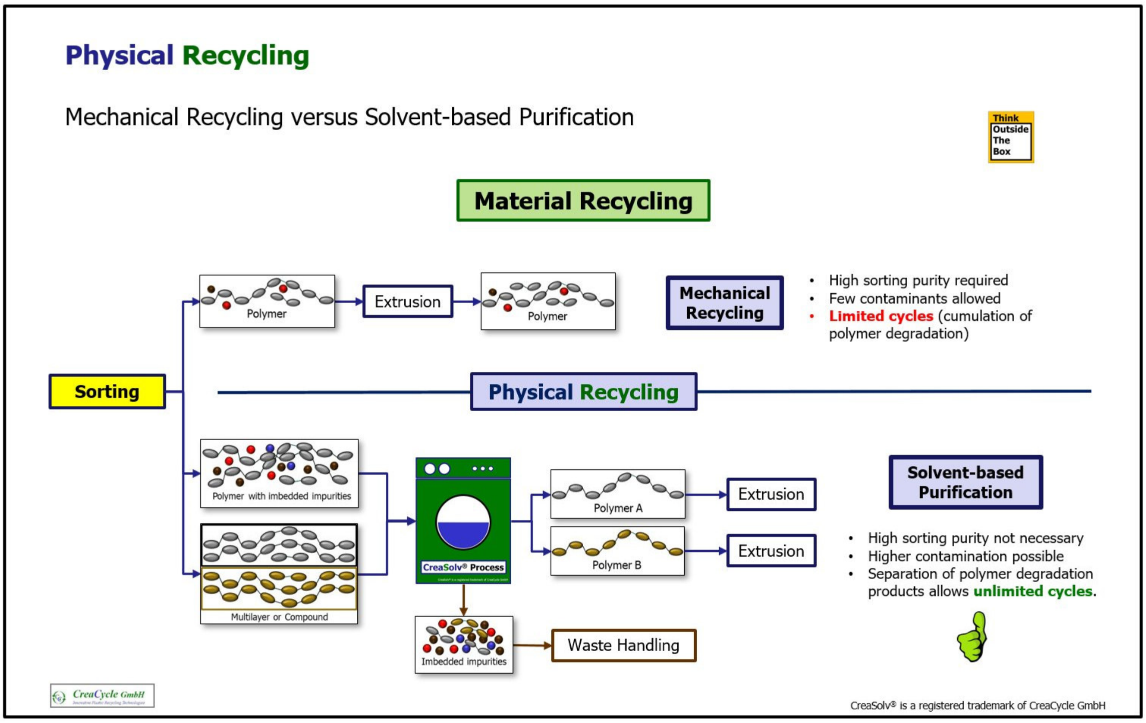
Chemistry for Kids – "Chemical and physical changes":
https://www.youtube.com/watch?v=x49BtB5dOwg&feature=youtu.be

The Solvent-based Purification meets the criteria of mechanical recycling (ISO 15270/2008 Plastics) but not the ones of chemical recycling, what leads to the conclusion that the actual description and classification of plastic recycling processes is no longer up-to-date and leads to confusion.

Mechanical recycling and solvent-based purification belong both to the category **Physical Recycling** and both enable the "re-use" of the polymer without down-cycling it to raw-materials (e.g. fuel, syngas, hydrocarbons) or building blocks of polymers, which have to be polymerized again to bring them back into the cycle.



When mechanical recycling needs a high sorting purity of waste streams and fails on imbedded additives and impurities (including hazardous and toxic ones) or multilayer packaging, the CreaSolv® Process based on a Solvent-based Purification works like a washing machine on a molecular level.

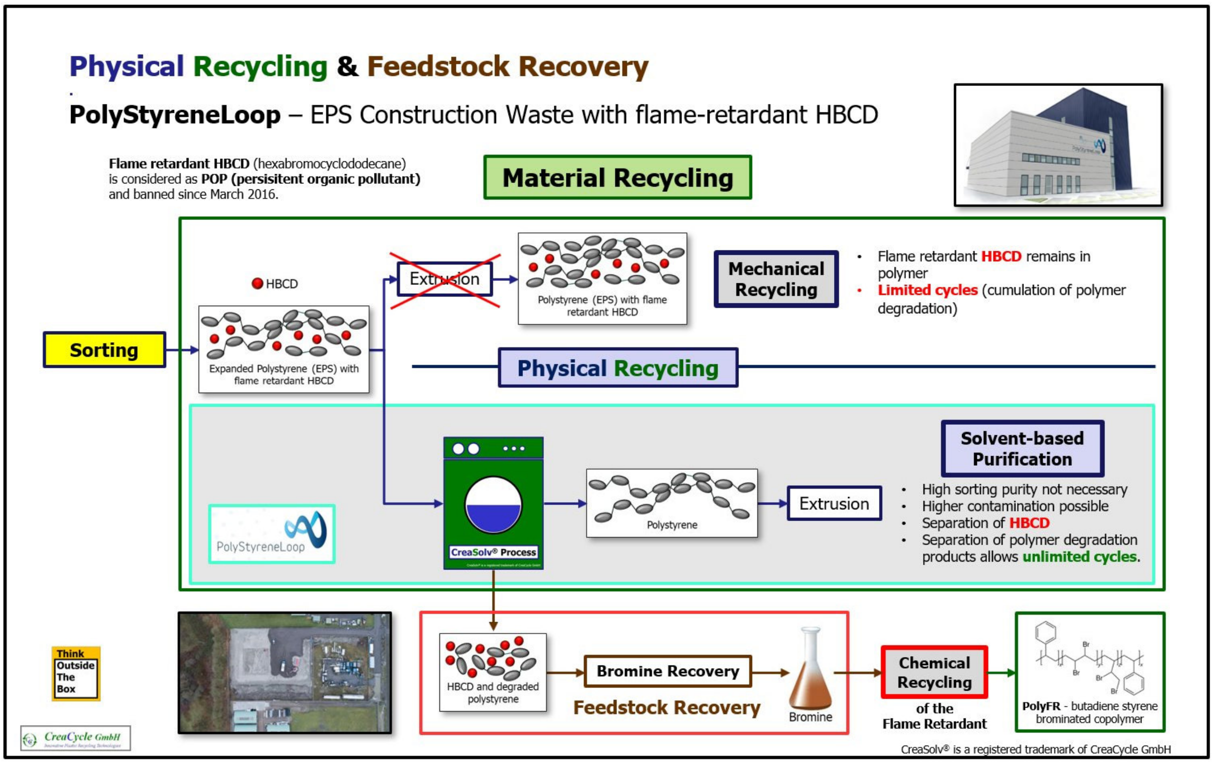


The degradation issue of polymers (and its accumulation) is a typical deficiency of mechanical recycling.
When a virgin polymer is produced and casted or formed to an article (typically in an extruder), the thermal stress in the extruder causes polymer degradation.
When this article becomes plastic waste and is mechanically recycled (= re-extruded) the polymer is extruded for a 2^{nd} time and the thermal stress produces more degraded polymer chains, which accumulate in the polymer with each additional recycling cycle until the physical properties decline too much, thus forcing it into 2^{nd} grade quality.

In the CreaSolv® Process also the degraded polymer chain parts are removed and so it can be re-used without limitation.

The PolyStyreneLoop Cooperative[6)] is set up to demonstrate the feasibility of a large-scale demo plant as a closed-loop solution for the recycling of polystyrene (PS) insulation foam waste and the recovery of bromine and the planned demonstration plant in Terneuzen, Netherlands, will work with the CreaSolv® Technology.

The PSLoop Cooperative is an organization under Dutch law and has actually more than 70 members from the whole polystyrene foam value chain including PS foam manufacturers, raw material and additives suppliers, foam converters, and recyclers.



PSLoop has chosen the CreaSolv® Process because Physical Recycling leaves the polystyrene polymer intact and the dissolution allows to separate the flame-retardant HBCD, that is considered a POP (persistent organic pollutant) thus requiring incineration if no recycling technology is available.
The separated HBCD undergoes a chemical recycling process for bromine recovery.
The PSLoop project will demonstrate how physical and chemical recycling can be combined in order to demonstrate that the combination of different technologies can deal with plastic waste streams that have been considered as unrecyclable.

The CreaSolv® Process is not a Solvolysis!

The fact that the polymer is dissolved doesn't classify the CreaSolv® Process to be a solvolysis - but this seems to be a common mis-interpretation.

- **Solvolysis**[7)] is a chemical reaction in which the solvent is one of the reagents and is present in great excess of that required for the reaction.

- **Solvolysis**[8)] is the generic term for processes involving reactions with corresponding solvents, e.g. hydrolysis (e.g. depolymerization of polyethylene terephthalate to terephtalic acid and ethylene glycol by the addition of water) (Patel et al., 1993; Hedlund-Åström, 2005), methanolysis (by the addition of methanol) and glycolysis (by the addition of ethylene glycol) (Pickering and Beg, 2010).

With regard to plastic recycling a solvolysis is the same as a de-polymerization and is therefore a chemical recycling process that down-cycles the polymer.

The CreaSolv® Process leaves the polymer intact and is therefore neither chemical recycling based on chemical reactions nor a solvolysis.

According to the KIDV report (page 34) "Solvolysis is a physical process in which a solvent is used to dissolve polymers and separate them from other materials".
The dissolution of a polymer (as the basic principle of a solvent-based purification) is correctly described as a physical process, but the combination with the chemical term "solvolysis" (a chemical depolymerization reaction that breaks down the polymer chain) is wrong, creates confusion and creates the wrong belief that the CreaSolv® Process is a chemical recycling technology.

Update - End of March 2020 CE Delft updated their report "Chemische Recycling in het afvalbeleid" and clarified the terminology "oplossen" (dissolution or solvent-based purification).[11)]

But this doesn't change the results in this comparison study in regard to the environmental impact and the process cost.

Solvent-based Purification, Depolymerization and Feedstock Recovery

Plastic Recycling Processes

Environmental Impact and Process Cost

	Physical Recycling	Chemical Recovery				
	Solvent-based Purification Dissolution	*Depolymerization Solvolysis*	*Pyrolysis*		*Gasification*	
	CreaSolv® Process		of recycling losses	of mixed plastics	of recycling losses	of mixed plastics
Environmental impact compared to incineration in a waste-to-energy facility (CO^2 eq./ton input)	-3,2	-3,1		0,2		-3,0
Compared to mechanical recycling into plastic recyclate for thick-walled applications			-1,8		-2,3	
Doing nothing, i.e. storing the trays		-1,5				
Compared to the mechanical recycling of PET with no additionaly processing steps		0,8				
			Rapid low-temp. Pyrolysis (scale 30 kt/y)		*Hightemp. Gasification (scale 100 kt/y)*	
CAPEX (M€)	26,1	18,7		25,4		81,9
Process costs (OPEX M€/year)	12,1	11,2		8		40,8
Feedstock price (€/ton feedstock)	50,00 €	100,00 €		-50,00 €		-50,00 €
Input material	**EPS (PS)**	**PET**		**mixed plastics**		**mixed plastics**
Process efficiency (mass %)	95%	95%		90%	*addition of O_2+H_2 ->*	143%
Output price (€/ton product)	1.720,00 €	960,00 €	*naphta*	600,00 €	*methanol*	250,00 €
			diesel	500,00 €		
			gas	800,00 €		
Output material	**PS**	**BHET polym. -> rPET**		**hydrocarbons**		**hydrocarbons**
Production costs (€/ton feedstock)	672,00 €	605,00 €		310,00 €		449,00 €
EBITDA (€/ton feedstock)	**962,00 €**	**307,00 €**		**100,00 €**		**-89,00 €**

KIDV report (pages) 34 - 37 | 37 - 40 | 41 - 44 | 44 - 48

EPS = expanded polystyrene
PS = polystyrene
PET = Polyethyleneterephtalat, rPET = recycled PET
BHET monomer = Bis(hydroxyethyl)terephtalat / needs to be polymerized to rPET

The CreaSolv® Process cost were calculated for the PolystyreneLoop Project.

Think Outside The Box

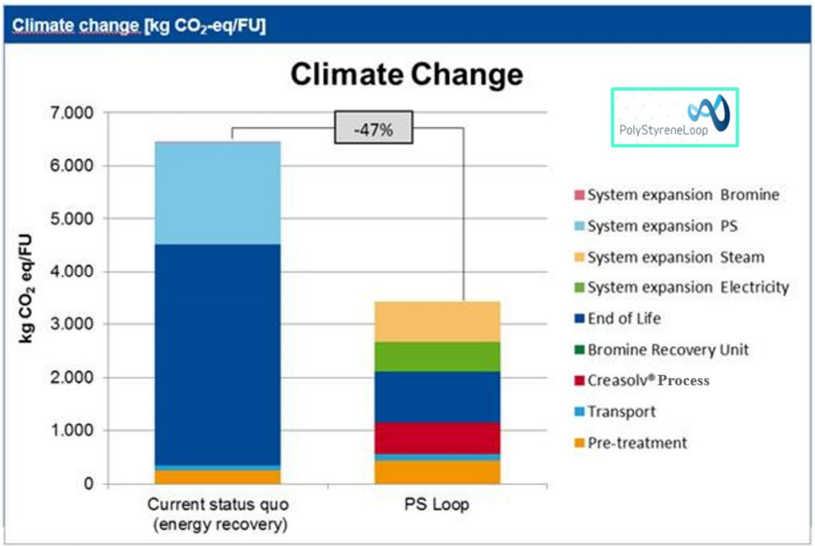
Source: Netherlands Institute for Sustainable Packaging (KIDV) "Chemical recycling of plastic packaging materials: analysis and opportunities for upscaling"

When using the appropriate terminology of the four plastic waste recycling technologies and differentiating between physical and chemical recycling processes at the same time, one is in a better position to compare the differences, benefits and deficiencies of available processes to get to a Circular Economy, as analyzed by TNO on behalf of the KIDV in October 2018.
Some of the results become more obvious and are better understandable.
This article is not meant to discuss the cost comparison or the CreaSolv® Process cost model (based on a capacity of 20 Kt/y) as presented by KIDV.
PSLoop is building a CreaSolv® Demonstration plant for EPS waste containing HBCD from construction with a capacity of 3 Kt/y in order to prove the technical and economic feasibility. Once this plant is running we will be in a better position to make a reality check.

The CO_2 savings calculated by TNO with 3.2 CO_2 equivalent/ton input are very much in line with the results in the Life Cycle Analysis (LCA) for the PSLoop project prepared by the TÜV Rheinland[10)].
But it needs to be noted that the approximately 50% lower carbon footprint in the LCA is calculated by including all end-of-life treatment cost for demolition, sorting, transportation, bromine recovery, etc.
The CreaSolv® Process *(separation of HBCD and cleaning/washing of the polystyrene)* ***alone only contributes approximately 1/14 to the PSLoop project's low CO_2 footprint!***

CreaSolv® Process

PolyStyreneLoop – EPS Construction Waste with flame-retardant HBCD (POP)



Source: TÜV Rheinland "Life Cycle Assessment for End of Life Treatment of Expandable Polystyrene (EPS) frm ETICS – April 2017

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Physical vs. Chemical Recycling

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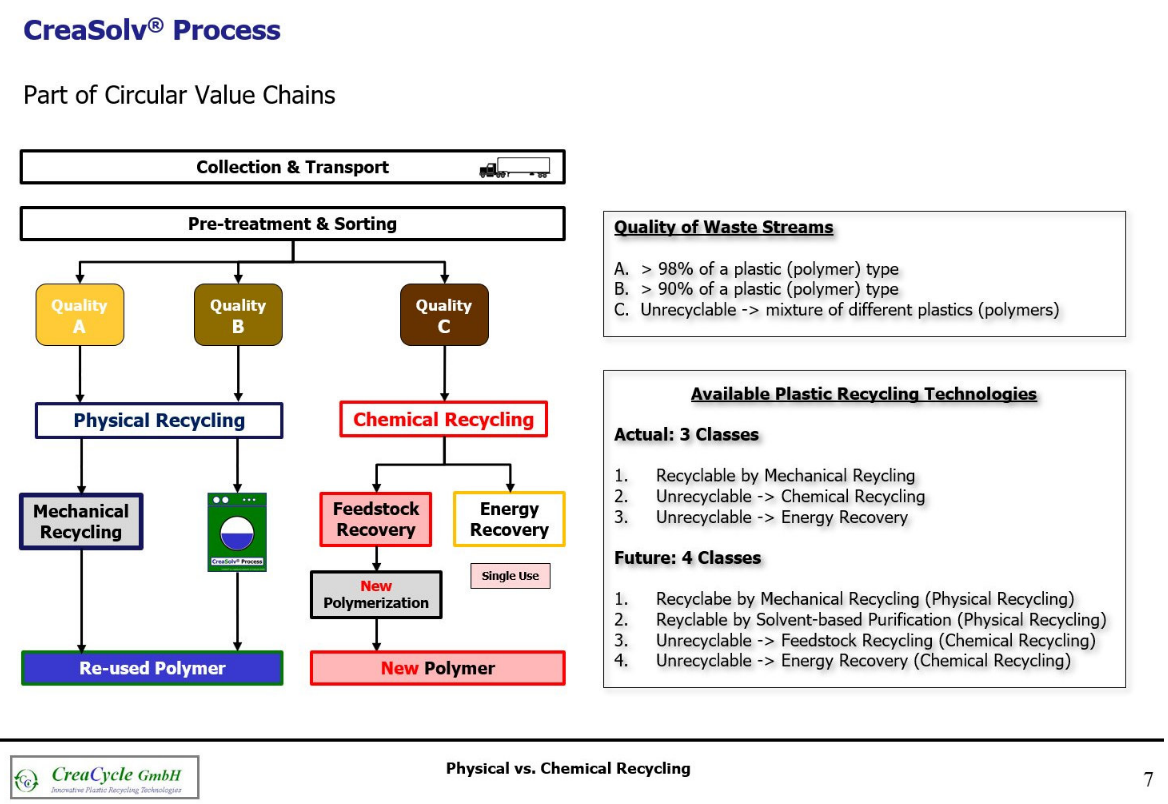
The TNO cost calculation needs to be adapted to actual selling prices of polystyrene of € 1.200 – 1.300/t, but even at such a level the margin is still attractive. Because prices declined for thermoplastics in general and for their feedstock materials the cost comparison also shows that physical recycling processes like the solvent-based purification are less sensitive to price fluctuations than chemical recycling processes.

A Solvent-based Purification like the CreaSolv® Process is based on physical changes and preserves the polymer on its value chain position and keeps the polymerization energy in the molecule. This reduces the needed process energy, the required process cost and the CO_2 footprint. The selling price for a polymer is higher than for its monomers and raw-materials. This has a positive impact on the EBITA.

Chemical recycling will always require a new polymerization after breaking down the polymer chains in order to close the loop for a circular economy. This goes in line with higher energy requirements and a higher CO_2 foot print depending on how far the down-cycling goes.

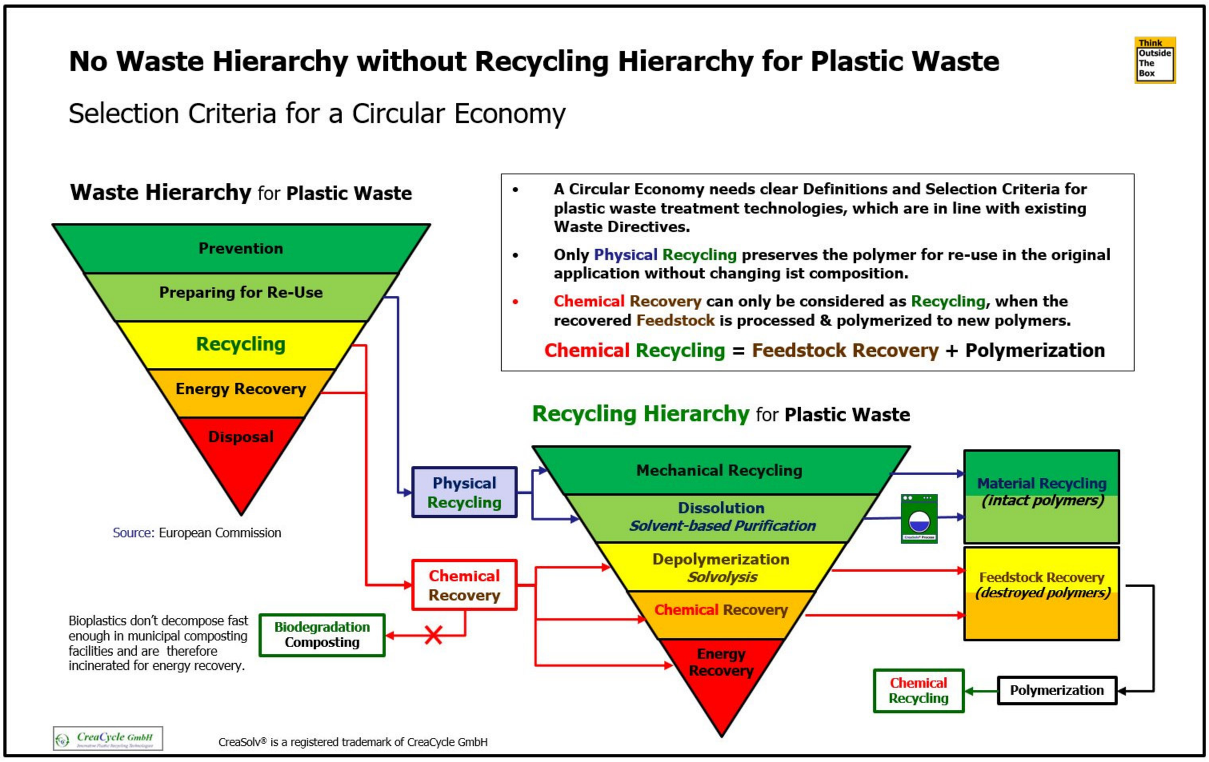
With this understanding in mind one should develop a plastic recycling scheme that works with 4 classes instead of 3 as it is actually the case.



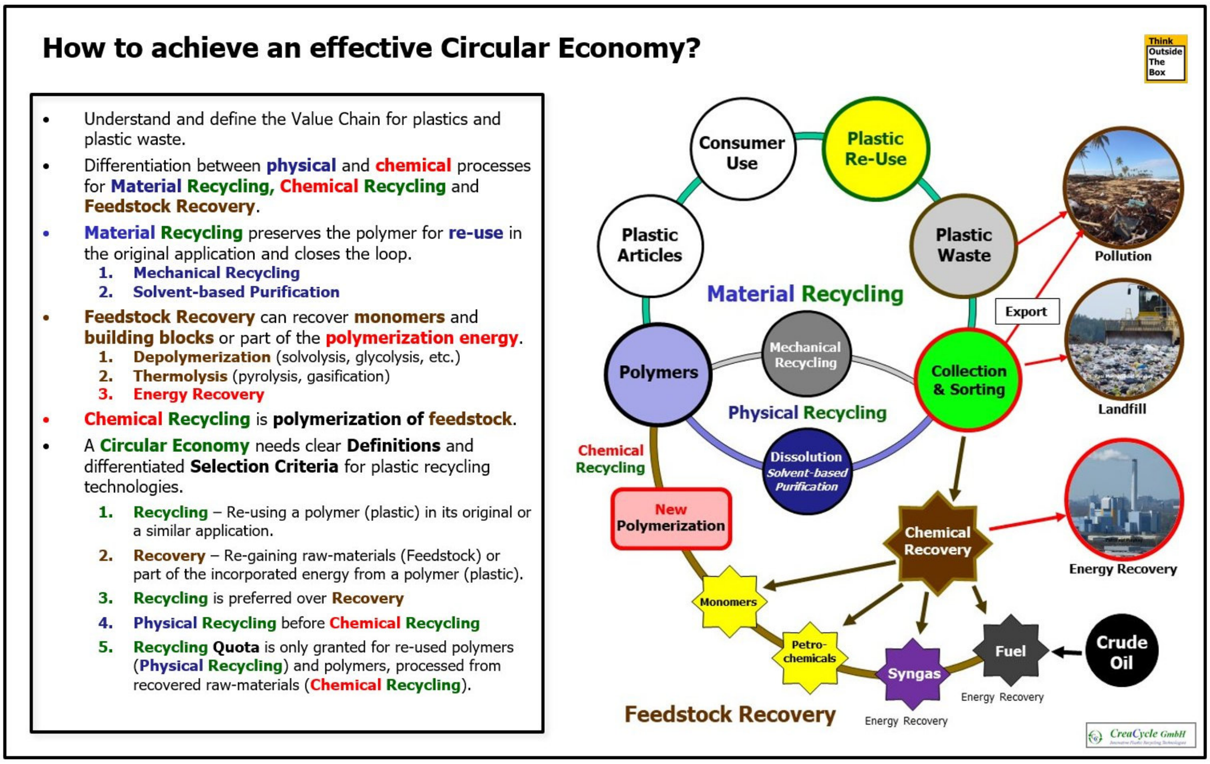
Physical Recycling with mechanical recycling and solvent-based purification will allow to recycle more plastic waste by keeping the polymers intact and it will enable to recycle plastic waste streams that are today still considered as unrecyclable.
Especially the solvent-based purification will open waste streams like multilayer packaging, WEE & ELV compounds and other plastics with imbedded impurities and extract the polymers without destroying them.

Recycling Hierarchy for Plastic Waste

With different plastic waste recycling technologies there is a need for a Recycling Hierarchy similar to the Dutch National Waste Management Plan 3 (LAP3) or the European Waste Hierarchy.
Existing recycling technologies need to be defined that a differentiation is possible.
Norms and guidelines like ISO 15270/2008 Plastics need to be upgraded. The pros and cons of different recycling technologies need to be understood so that they can be ranked in line with the Waste Hierarchy because only specific plastic waste recycling technologies will be able to keep the polymer on its value chain position.
It is only logical to request a prioritization of certain recycling technologies versus others if the desire is to "Re-use" a polymer instead of down-cycling it or burn it instead of fossil energy.



Only with a clear structure, correct & meaningful definitions and a strategy we will be able to take control of the plastic waste pollution instead of being victims of it.



Conclusion

KIDV and the experts working on the report have probably been mistaken by choosing the CreaSolv® Process for the recycling of EPS (expanded polystyrene) with brominated flame retardants (HBCD – Hexabromocyclododecane) from the construction sector as an example for a solvolysis.

But the positive thing is, that they have proven that similar to mechanical recycling the CreaSolv® Process – a solvent-based purification (dissolution) - has a much better CO_2 footprint and economics than chemical recycling processes.

Based on the fact that the polymer chains remain intact, the CreaSolv® Process has to be considered as Physical Recycling. Additionally, the CreaSolv® Process does definitely not meet the criteria for "chemical recycling" as defined by ISO 15270, but the ones for "mechanical recycling". Both mechanical recycling and solvent-based purification (dissolution) work with physical processes.

The probably unintended wrong description and classification of the CreaSolv® Process hopefully enables a broader audience to increase their awareness about physical processes and how they can be an addition and a help to treat plastic waste in a way that is not possible with chemical recycling.

KIDV - the Netherlands Institute for Sustainable Packaging is of course focused on packaging and looking for "solutions" for plastic packaging waste streams. Including the CreaSolv® Process in their study was definitely not a bad idea, because it can help to recycle single-use multi-layer packaging that is today considered as unrecyclable.

In 2018 Unilever opened a CreaSolv® Sachet recycling pilot plant in Indonesia and on 12 November 2019 they stated on their Homepage: "*We have proven through large scale industrial trials that the CreaSolv® Recycling technology is a technically viable solution to recycle sachets*" [9)].

For the future we need improved recycling schemes, clear definitions and recommendations, so that we apply the right plastic recycling technologies with the correct prioritization.
Physical recycling should be preferred versus chemical recycling, so that larger quantities of polymers will be re-used in their original applications in line with a necessary redesign of plastic composites.

How can the plastic industry satisfy the actual strong desire from consumers for re-designing plastic articles to be better recyclable, when they are not aware that they have a choice between physical and chemical recycling? And this is especially important for the packaging industry that is considered as the main contributor to the pollution with plastic waste.

In order to protect resources and our environment, high-quality recycling technologies for plastic waste are required, which allow the reuse of polymers without breaking up the polymer chains.
CreaCycle GmbH and the Fraunhofer Institute for Process Engineering and Packaging (IVV) in Freising, Germany combined their competencies in a cooperation aimed at "Plastic/Raw-Material Recycling with a Solvent-based Purification Technology" (selective extraction) and developed the CreaSolv® Process that is based on physical changes and leaves the polymer composition intact.
Proprietary CreaSolv® Formulations from CreaCycle with the lowest risk potential possible for user and environment dissolve selectively a target polymer. This reduces besides the hazard also the cost for the equipment. After the separation of imbedded impurities or undesired polymers the recycled polymer can be reused in its original application.

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Literature

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