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Chemical Recycling
Recovery or Recycling of Plastic Waste?

The best for the environment is an integrated solution for the existing different plastic waste streams that works with **all** available recycling and recovery technologies. The selection of processes should be based on the combination of Life Cycle Assessment (LCA) with a good overview of the carbon footprint for the complete process and should include the collection up to the process as well as the output as polymer, feedstock, electricity or replacement for fossil fuel.

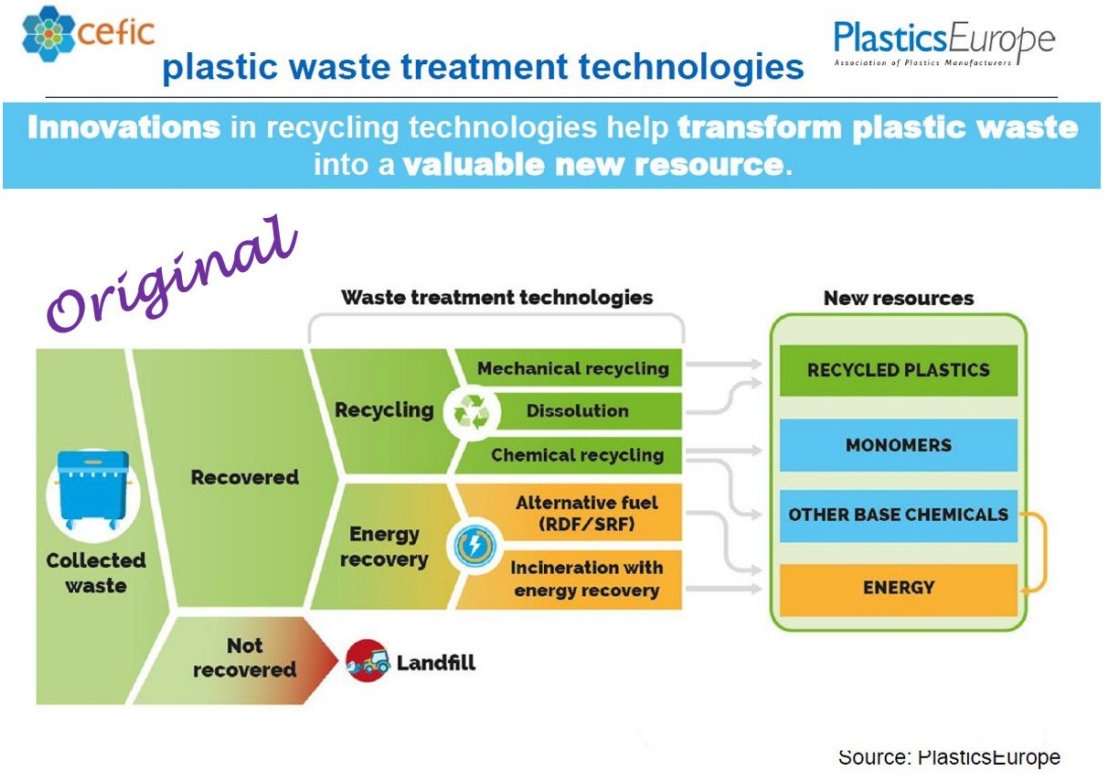
Since 2018 we have been provided by some associations, experts and environmental groups with incorrect information about the Solvent-based purification (Dissolution) in general and for the CreaSolv® Process especially, describing this plastic recycling technology as chemical recycling and/or solvolysis.

- Netherlands Institute for Sustainable Packaging (KIDV) - "Chemical recycling of plastic packaging materials: analysis and opportunities for upscaling" [1] -October 2018
- CE Delft – "Chemical recycling and its CO_2 reduction potential" [2] - February 2019
- Confederation of Netherlands Industry and Employers (VNO-NCW) supported by Rebel - "Actieplan Doorbraakproject Chemische Recycling" [3] - April 2019
- Zero Waste Europe - Eldorado of Chemical Recycling [4] - August 2019
- Greenpeace - "False Solutions Report: Throwing away the future" [5] - October 2019
- Deutsche Gesellschaft für Abfallwirtschaft (German Association for Waste Management) „Chemisches Recycling – ein Lösungsweg für das Recycling von Mischkunststoffen" [6] - December 2019
- AMI Consulting - White Paper "Chemical Recycling and the Plastics Industry" [7] January 2020
- CE Delft – "Exploration chemical recycling – Extended summary" [8] - January 2020

Solvent-based Purification (dissolution) 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. Therefore, it can be no surprise that the dissolution meets the criteria of mechanical recycling (ISO 15270/2008 Plastics) but not the ones of chemical recycling.

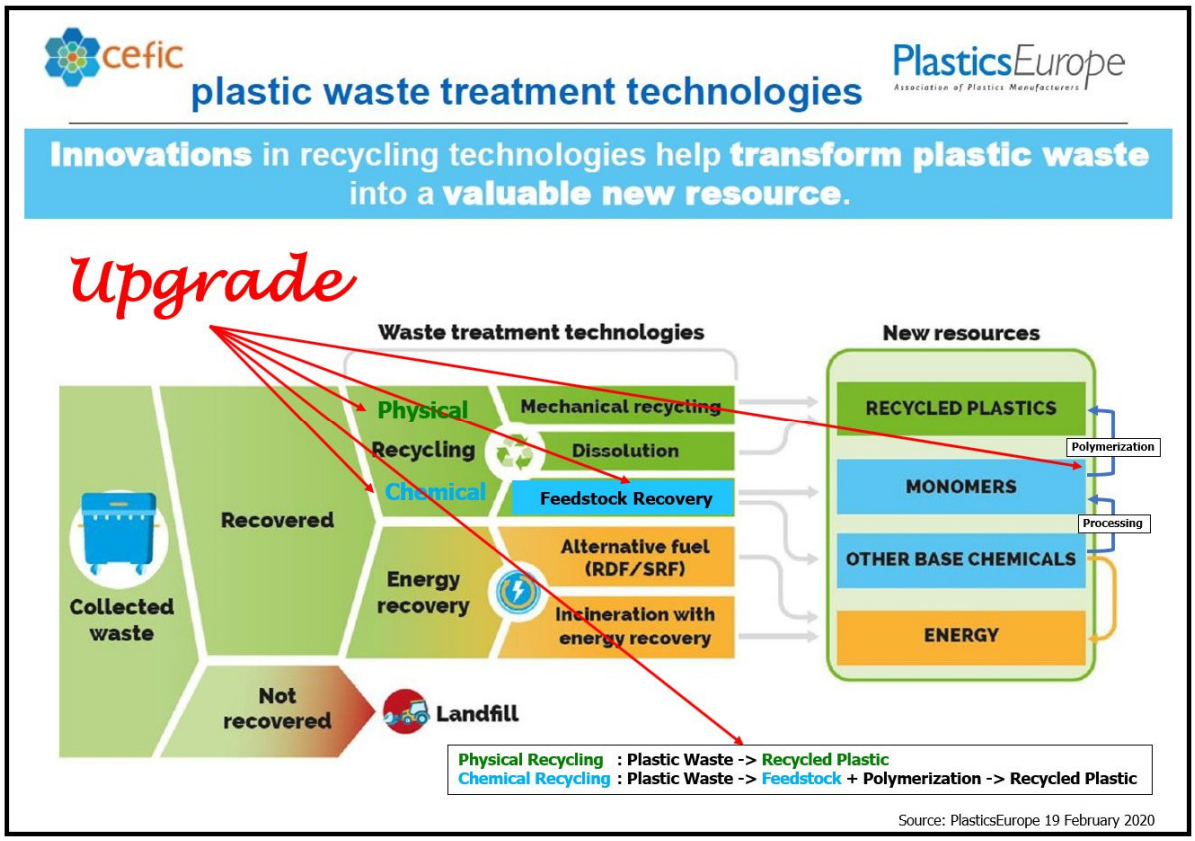
> *Update - End of March 2020 CE Delft updated their report "Chemische Recycling in het afvalbeleid" and clarified the terminology "oplossen" (dissolution or solvent-based purification).*[20)]

After all this consistent wrong information with the potential to prevent that the dissolution is recognized and appreciated as an additional (new) physical recycling process besides mechanical recycling (which both leave the polymer chains intact), it was a positive experience to see CEFIC & PlasticsEurope's recent overview of plastic waste treatment technologies presented at the meeting of the European Coalition of Chemical Recycling on 19th February 2020[9)].



The Dissolution is shown as a separate technology that produces recycled plastics (same as Mechanical recycling) besides Chemical recycling that produces monomers and other base chemicals instead.

This description is in line with reality but the design of the graphic, the choice of colors and the development/change of the meaning of some technical terms in regard to plastic recycling during the last 20 years may make it difficult to get a clear understanding and to differentiate all technologies based on their advantages and deficiencies. Therefore, we propose the following upgrades to the graphic.



Maybe we have to go back into the past and start again without all the modifications made over time, thus enabling us to be able to build a Circular Economy.

Directives and ISO Norm

In his article "Plastics Waste - Feedstock Recycling, Chemical Recycling and Incineration" from 2002 Prof. Arnold Tucker described that the **draft EU Directive on Packaging waste** contained definitions of various forms of recycling and reuse[10]:

(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** implies the application of the material used, without changing the chemical structure, for a new application;*

*(3) **Chemical recycling** implies a change of the chemical structure of the material, 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 implies input into a device where the energy content of the input material is used.

The above simple and straight definitions make a lot of sense, sound familiar and captured everything, but when we compare it with what is used today, we may have difficulties when searching for the synergy and correlation, especially in light of the actual desire for a Circular Economy or the Waste Directive.

Interestingly and in contrary to above, EU Directives do not define specific recycling processes or technologies.
EU Directives define "recycling" and "recovery" based on the final product resulting from a certain waste treatment.

Directive 94/62/EC on Packaging and Packaging Waste[11)]

- *"**Recovery**" shall mean any of the applicable operations provided for in Annex II.B to Directive 75/442/EEC[12)]*
- *"**Recycling**" shall mean the reprocessing in a production process of the waste materials for the original purpose or for other purposes including organic recycling but excluding energy recovery*

Directive 2008.98.EC – Waste Directive[13)]

- *"**Recovery**" means any operation the principal result of which is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfil a particular function, or waste being prepared to fulfil that function, in the plant or in the wider economy. Annex II sets out a non-exhaustive list of recovery options.*
- ***"Recycling"** means any recovery operation by which waste **materials** are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but it does not include energy recovery and the reprocessing into materials that are to be used as fuels or back-filling operations.*

ISO 15270/2008 Plastics - Guidelines for the recovery and recycling of plastics waste[14)] 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.*

Looking at waste directives, ISO norm and the actual discussion about future plastic recycling technologies, a bit of sorting is required to bring some logic into all the pieces of information.

EU Directives define essential requirements and Member States decide how to transpose them into national law.

Unlike laws, standards (e.g. ISO) are not legally binding, their use is voluntary, except when being part of legislation[20)].

Recycling versus Recovery

The EU Waste Directive differentiates between "recycling" and "recovery".

The main difference is the final product which is either a "product, material or substance" (recycling) or a "waste serving a useful purpose" (recovery) according to Annex II.B to Directive 75/442/EEC (e.g. use as fuel or other means to generate energy, etc).
The same is valid for the Directives on Packaging & Packaging Waste, End-of Life Vehicles (ELV) and Waste Electrical & Electronic Equipment (WEEE).

However, under REACH this distinction is not made. REACH only speaks of "recovered substances".

According to the ECHA Guidance for monomers and polymers[19] (version 2.0, April 2012) "a **polymer** is a substance consisting of molecules characterized by the sequence of one or more types of monomer unit."

In line with existing EU Directives, plastic waste (one or more types of different polymers) can be

- **recycled** by reprocessing to plastic for the original or other purposes (plastic-to-plastic)
- or **recovered** by serving a useful purpose (plastic-to-fuel, energy, monomers or something else).

Mechanical Recycling versus Feedstock Recycling

Mechanical recycling and feedstock recycling seem to be the key technologies, industry and PlasticsEurope[15] actually rely on for the recycling and recovery of plastic waste in regard to the different waste directives:

- Mechanical Recycling – reprocessing to plastic for the original or other purposes without changing the chemical structure (plastic-to-plastic).
  This technology is commercial and meets the "**recycling**" criteria of directives.

- Feedstock Recycling – plastic serving a useful purpose by changing the chemical structure (e.g. monomers, fuel or syngas) without the necessity to reprocess and polymerize it to plastic.
  Feedstock recycling is considered or presented as the same as chemical recycling
  These technologies are in pilot stage and are actually not considered as recycling according to the directives. They meet the criteria for "**recovery"**.

The ISO norm 15270/2008 describes the same point of view.

Where is the "Red Threat" to Plastic Recycling?

It is obvious that there exists a correlation between

- **WHAT** (What is recycled or recovered?) -> The **Output** (Directives)
- and **HOW** (How is something recycled or recovered?) -> The **Process**.

But this correlation is difficult to see when combining the definitions from directives, ISO norm and industry. Let's try to bring some order into it and look for synergies.

1. **WHAT is recycled** (output)**?**
   a. ***Material*** -> Waste plastic is processed to recycled plastic (no change of chemical structure!) -> **recycling**
   b. ***Feedstock*** -> Waste plastic is chemically reacted (depolymerization/cracking) by changing the chemical structure into new substances (chemicals), which
      i. **will not** be polymerized to produce plastic -> **recovery**
      ii. or **will** be processed and polymerized to produce plastic -> **recycling**

2. **HOW is something recycled** (process)**?**
   a. ***Chemical Recycling*** -> Waste plastic is chemically reacted (depolymerization/cracking) by changing the chemical structure and forming new substances.
      The underlying science is **Chemistry**.
   b. ***Mechanical Recycling*** -> Waste plastic is processed without changing the chemical structure.
      The underlying science is **Physics**.

3. **Mix-up / Exchange of terms /Loss of Differentiation**
   a. ***Material Recycling*** disappeared and was replaced by ***Mechanical Recycling***, thus excluding other technologies like **Dissolution** (Solvent-based Purification), which do not change the chemical structure of the polymer.
   In Germany the term "Material Recycling" is still used (werkstoffliches Recycling).
   It is unclear what the underlaying science is, that allows processing *without changing the chemical structure of the material plastic.*
   b. ***Chemical Recycling*** and ***Feedstock Recycling*** are considered as synonyms.
   According to ISO 15270/2008 and the description of industry both technologies only fulfil the criteria of "**recovery**" and therefore Chemical Recovery and Feedstock Recovery are the more appropriate descriptions. Recycling is the incorrect term in this context.

All this needs clarification so that a motivation scheme can be developed that stimulates plastic recycling with a low carbon footprint based on comparable data like Life Cycle Analyses (LCA) in order to create a Circular Economy and stop pollution of the environment.

The inflation of the term "Recycling" carries the risk that the focus is on recovery technologies with a higher carbon footprint instead placing the first priority on improving recycling actual recycling capabilities with lower carbon footprint.

We have to stop the use of the term RECYCLING for technologies, which recover feedstock in order to avoid confusion.

Physical or Chemical Reaction?

It is unfortunate and a serious stumbling block that a dissolution is considered and described as a chemical reaction and is classified as Chemical Recycling by some industry associations, consultants and environmental groups.

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

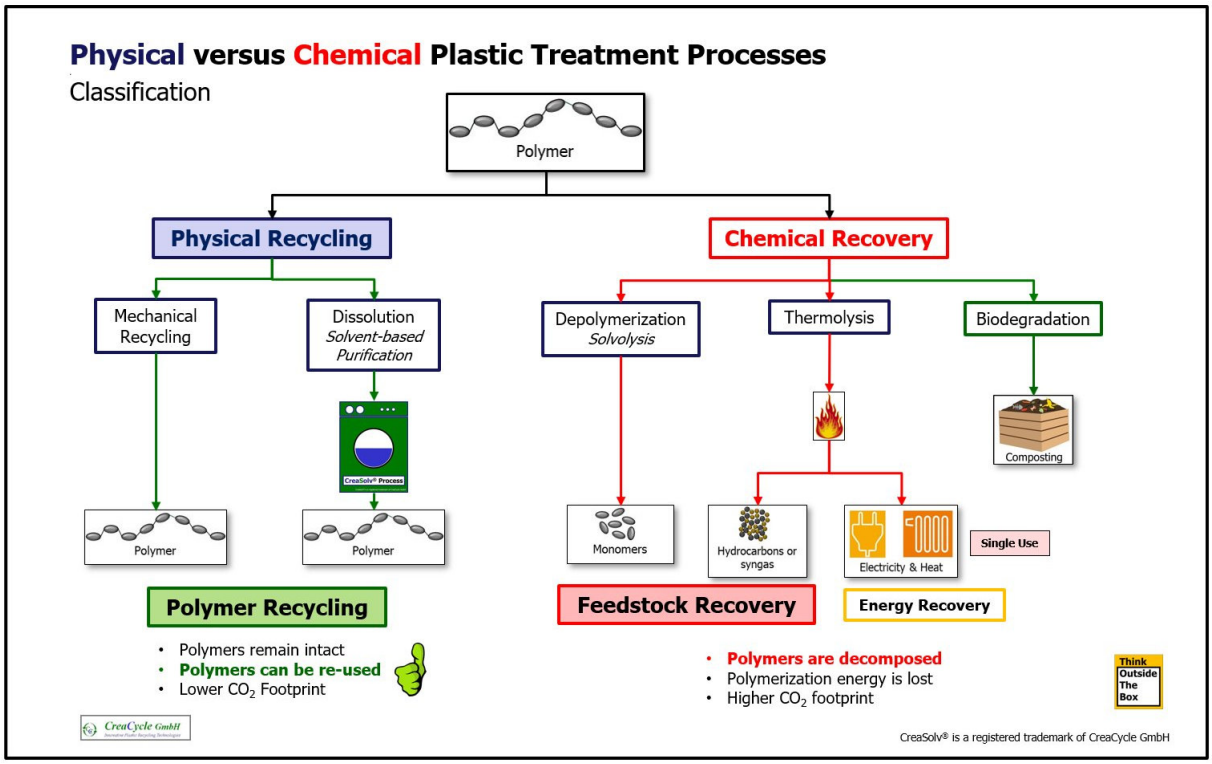
Without doubt one can conclude from ISO 15270/2008 Plastics that Chemical Recycling of plastic waste always goes in line with the destruction of the chemical composition/structure of the polymer(s).

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

Chemical Recycling is an "Oxymoron" because it is an undounted fact that chemical reactions change the composition of polymers and fulfil the definition for "recovery" of the Waste Directive. The same is true for Feedstock Recycling.

> ***Oxymoron*** *– combines two opposite qualities or ideas and therefore seems impossible.*

Only a combination of "Feedstock Recovery" with a new Polymerization could be considered as "Chemical Reycling".



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 Solvent-based Purification (Dissolution) works like a washing machine on a molecular level. The dissolution fulfils the criteria for "recycling".

Proposal for upgraded Definitions of available Plastic Recycling Technologies

After having discussed, compared and sorted all different definitions and terms around plastic recycling processes we will now try to bring them into a logical order so that they fit to the EU Waste Directive. We will do this according to the following rules:

- ***Recycling is not the same as recovery!*** (very important and in line with EU Directives)

- The term "Recycling" will only be used for processes which use the material "plastic waste" to produce plastic again.
- The differentiation between processes with and without composition change of the material treated will be science-based (physics versus chemistry).
- All available technologies will be included

Definitions

(1) **Physical recycling** - Processing the material "plastic waste" with physical changes without significantly changing the chemical structure of polymers for a new or a similar application through
   a. mechanical recycling
   b. **dissolution** (solvent-based purification),

   Physical recycling and Material recycling are synonyms.

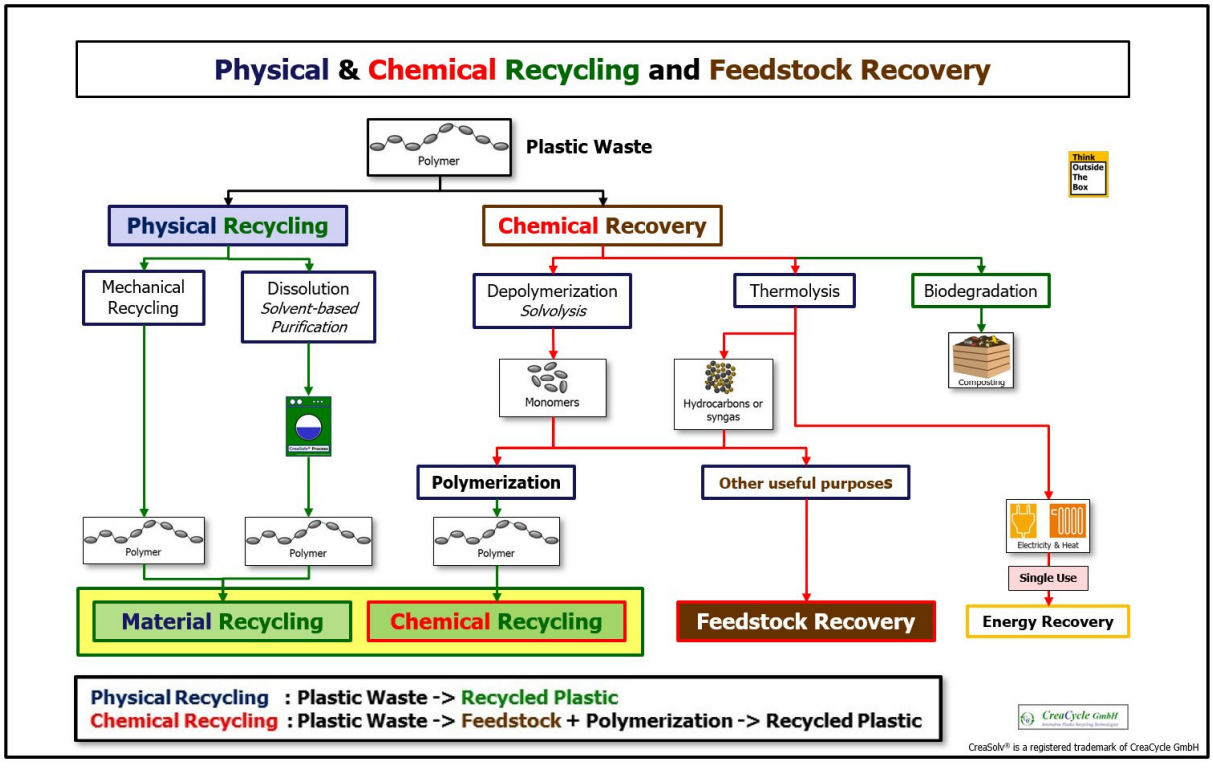
(2) **Chemical recycling** – Processing the material "plastic waste" by chemical reactions and changing the chemical structure through
   a. cracking,
   b. gasification
   c. depolymerization,

   in such a way that the resulting substances (chemicals) will be used to process and polymerize the original material "plastic".

(3) **Feedstock recovery** – Processing the material "plastic waste" by chemical reactions and changing the chemical structure through
   a. cracking,
   b. gasification
   c. depolymerization,

   in such a way that the resulting substances (chemicals) will be used for another useful purpose than producing the original material "plastic";

The above technology definitions match the definitions of existing EU directives and allow a differentiation between plastic recycling and recovery.



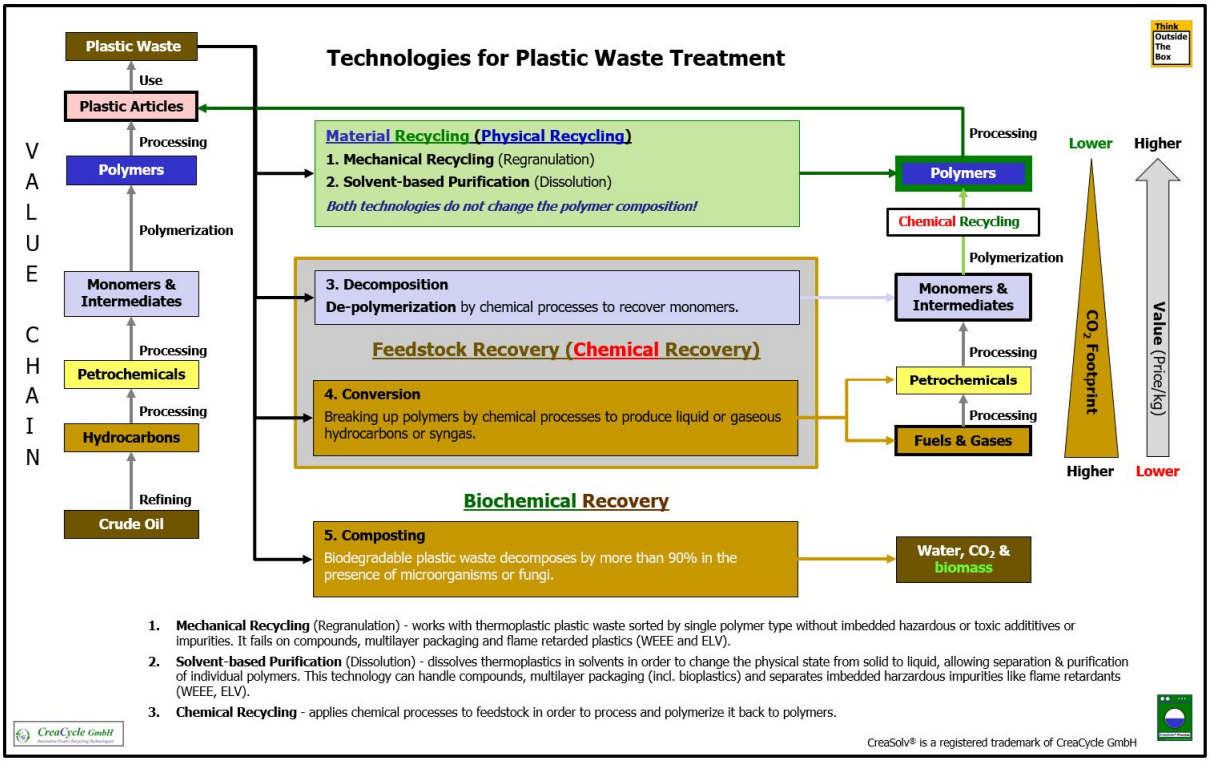
Chemical Recycling can only meet the "recycling" definition of EU Directives when plastic waste is re-processed in any operation for the original or similar purposes.

Because chemical reactions always produce new substances by changing the chemical structure of the polymers Chemical Recycling can only be achieved by combining it with a new polymerization.

Chemical Recycling = Feedstock Recovery + Polymerization

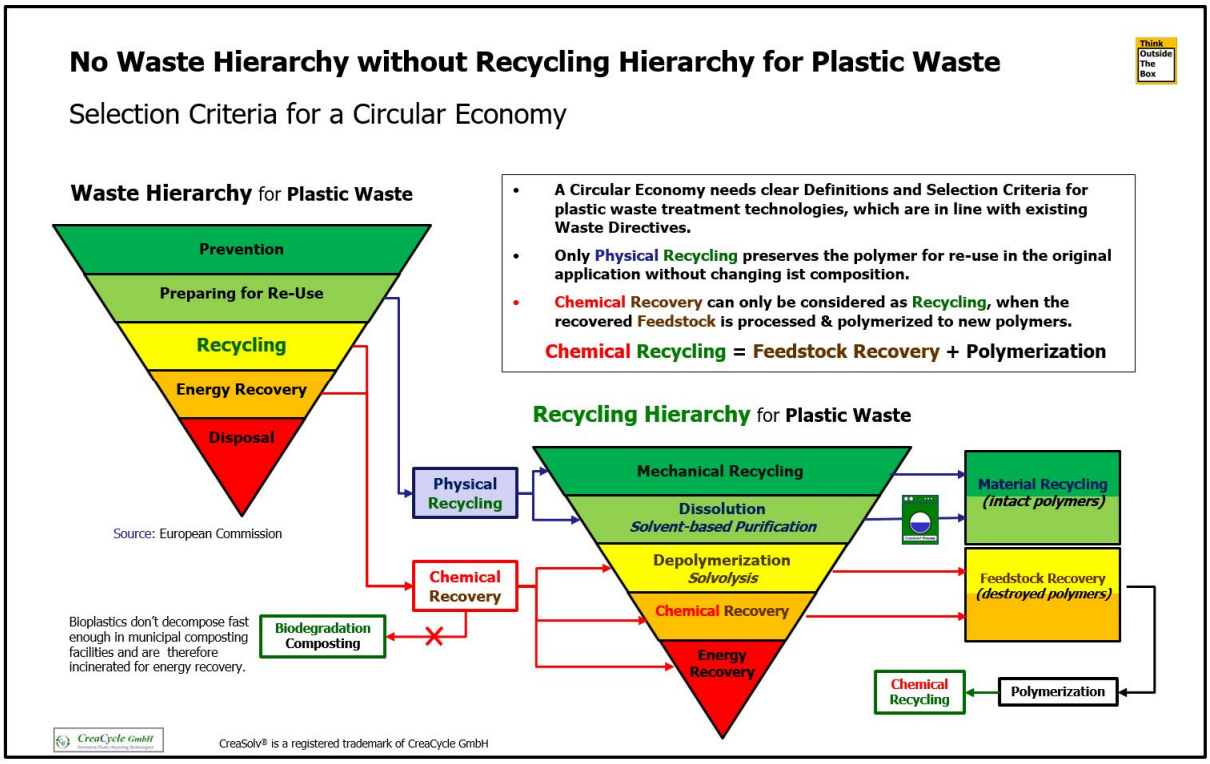
EU Waste Directive - Plastic Waste Recycling & Recovery						
Waste Directive	***Science***	***Process***	***Input***	***Output***	***Composition change***	***Technology***
Recycling	**Physics**	melting	polymer	polymer	no	mechanical recycling
Recycling	**Physics**	dissolution	polymer	polymer	no	solvent-based purification
Recovery	**Chemistry**	de-polymerization	polymer	***monomers***	yes	feedstock recovery
Recovery	**Chemistry**	pyrolysis	polymer	***feedstock***	yes	feedstock recovery
Recovery	**Chemistry**	gasification	polymer	***feedstock***	yes	feedstock recovery
Recycling	**Chemistry**	**Polymerization** of monomers or processed feedstock	polymer	polymer	yes	chemical reycling

It is probably a logical expectation that breaking polymers and re-polymerizing them again will require more energy than physical recycling without changing the chemical structure of polymers, and so it is very important to compare the economics and the carbon footprint or other environmental aspects when deciding on future waste treatment technologies.



We will definitely need both of them Physical Recycling and Feedstock Recovery, and not to forget the combination of Feedstock Recovery & Polymerization (Chemical Recycling).

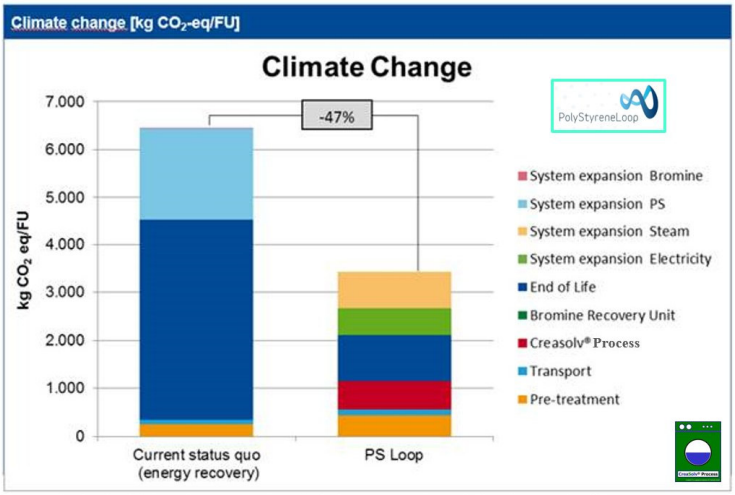
In order to assist industry in the choice of plastic waste treatment processes or in the design of plastic articles for better recyclability it would be very helpful if the Waste Hierarchy is combined with a Recycling Hierarchy for plastic waste.



Additionally, the Recycling Hierarchy needs to be connected to overall carbon footprints including collection, sorting, cleaning, recycling or recovery and the final end-product. The PolyStyreneLoop Project based on the CreaSolv® Process is a good example of a LCA for a Solvent-based Purification (Dissolution)[17,18].

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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Conclusion

The EU Waste Directive and those for Packaging, ELV and WEEE include definitions for "recycling" and "recovery". In the context with the global plastic waste issue and the desire for a Circular Economy industry, experts and ISO 15270/2008 provide us with definitions for recycling technologies which seem not to be complete or not fully aligned with the existing definitions as used in directives.
The term "recycling" is often used for activities which qualify for recovery. This carries the risk for confusion.
"Chemical Recycling" based on the definitions of industry and ISO norm is an "Oxymoron" because chemical reactions change the composition of polymers and fulfil the definition for "recovery" of the Waste Directive. The same is true for Feedstock Recycling.
Only a combination of "Feedstock Recovery" plus Polymerization could be considered as "Recycling"

There is a need for updating and upgrading of some of the definitions and terms used to avoid confusion or mis-perception.
The plastic waste problem is too severe and we need to take the right decisions now.
We need all available plastic treatment technologies – and this counts especially for the "Dissolution" – in order to solve the plastic waste problem, but the underlying principle going forward needs to incorporate economic and environmental aspects as well by increasing recycling activities versus recovery operations and by driving for the lowest carbon footprint possible.

In order to get there, we have to bring our sciences in order and make intelligent and science-based choices.
If we remain unclear in the differentiation between recycling and recovery activities we may continue reporting excellent and increasing recycling quota but there will be no-one out to believe in them. We may start another decade of promising plans and questionable investments.

In this context the German "Heating Value Clause" (in operation until July 2017) that placed energy recovery of waste with high calorific value on the same level with "recycling and preparation for re-use" and was not in accord with the waste hierarchy of the Waste Directive 2008/98/EC should be remembered as a severe warning signal and example.
It was in 2012 when 5 German Environmental NGOs (DNR, NABU, BUND, DUH and bfub) sent a joint letter[16)] to the Environment Commissioner of the European Commission asking for correction.
It needed 5 years for a change!
And only during the last 2-3 years we began to accept that our oceans are polluted with plastics, that is in reality the case for more than 20 years.

We should learn from our mistakes, avoid oxymorons and strive for clarity and improvement.

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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