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What is High-Quality Plastic Recycling?

There exists common agreement that higher-quality plastic recycling is needed to deal with the increasing plastic waste pollution, so that recycled plastics can compete with virgin material in the original applications. Many new projects even aim for recycling of food-grade plastics.

But how to get there when a Danish study[1)] recently concluded that industrialized countries with existing waste collection systems lack the necessary sorting, source-separation and material recovery effectiveness & capability as well as sophisticated new plastic recycling processes to cope with the actual requirements for a Circular Economy. It was concluded that we lack recycling technologies for more than 60% of our household plastic waste at present.

According to the actual "Plastik Atlas 2019"[2)] from the Heinrich Boell Foundation and BUND (Friends of the Earth Germany) the official recycling quota of Germany – the World Champion for Plastic Recycling – is relatively high with 45% for the year 2016; but this detracts from the fact that this only describes the delivered plastic waste volume (counted!) to a "recycling company" and not the correct recycled output. Only 15,6% of post-consumer plastic waste is processed to recyclates and thereof only 7,8% are comparable to virgin plastic. The latter represents 2.8% of the plastic products manufactured in Germany. The official recycling quota of 45% includes also the plastic waste exports and these may end up in incineration or illegal land-fills… or may be sent back to the World Champion by the misled receiver[3)].

In 2018 (Jan – Nov) Germany was the 3rd largest plastic waste exporter behind USA and Japan.

If above is the performance of the best, what does this tell about the actual true situation, the hurdles ahead or the capabilities of developing countries to cope with increasing plastic waste volumes of their own and those of exporting "recyclers" of industrialized countries?

What Recycling Technologies do we actually have for Plastic Waste?

In order to address above question, it is important to understand how industry is looking at this and how they differentiate between Mechanical Recycling, Feedstock Recycling and Energy Recovery. Below (burger dot 1 to 3) are the actual technologies used according to Plastics Europe (Association of Plastic Manufacturers) for a Circular Economy[4)]. The descriptions were taken from their homepage and certain comments and explanations were added.

1. **Mechanical Recycling** (or Material Recycling)

…is applicable for thermoplastics which can be cleaned and sorted by single polymer. The process can be applied to post- consumer and industrial plastic waste and is currently the almost sole form of polymer recycling in Europe. The sorting and cleaning process ***does not change the chemical structure of the polymer chains*** (this is why it is also called "material recycling"), but when the polymer is extruded again to form an article at high temperature, degradation could take place and adds to the one of the original (first) production. This is why this recycling loop cannot be repeated endless and sooner or later the physical properties of the recyclates may not be sufficient any longer for the original application.

Only sorting fails of course for multilayer packaging systems (combination of different polymer types), galvanized polymers or plastic compounds (combination of plastic with other materials like metals, carbon or glass fibers etc.), to name only a few.

A further hurdle can be additives which are intentionally imbedded in polymers in order to achieve desired properties e.g. to make them safer (flame retardants) or softeners (plasticizers) to name only a few examples. Exposed to heat or warm conditions such additives can thermally degrade and form dangerous impurities when re-melting the polymer for recycling purposes or they may actually have become legacy chemicals and are now considered as POPs (Persistent Organic Pollutants) or substances of high concern (SVHC), thus making mechanical recycling and re-use impossible unless these additives can be removed and destructed.

2. **Feedstock Recycling** (or Chemical Recycling)

… ***changes the chemical structure of the polymer chains***. Processes like gasification and pyrolysis break down the polymer chains at high temperatures to produce synthesis gas (syngas) as well as other liquid and semi-liquid products (fuel). It is applied to laminated and composite plastics, low quality mixed plastic streams and contaminated plastics …. and all wastes streams which are considered by a waste owner as "non-recyclable".

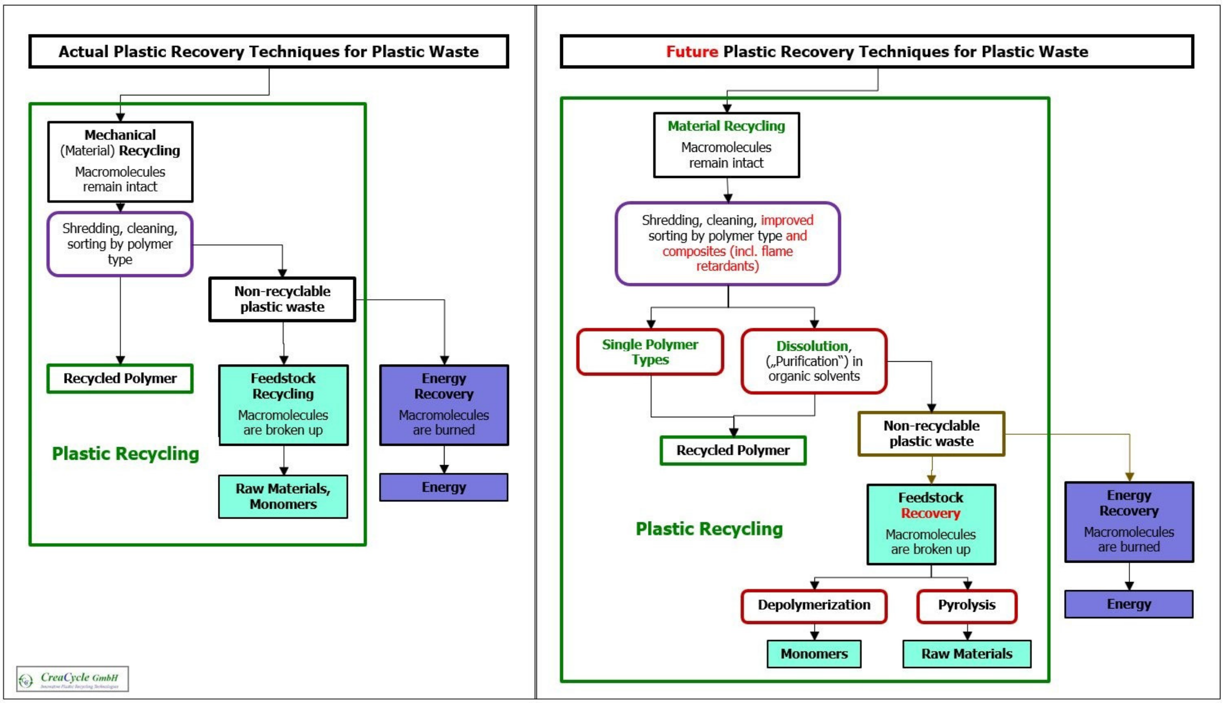
The most common example for feedstock recycling is the use of plastic waste in blast furnaces to replace coke, coal or natural gas as reducing agent.

There is a mentioning about new depolymerization processes, being under development.

3. Energy Recovery

… is another use for plastic waste that cannot be recycled. Plastic waste is incinerated in heat and power plants.

The actual Global plastic waste issue has shown that relying on the status quo will not bring us any further when coping with this major problem, especially when the consumption of plastic increases steadily and the articles (e.g. multilayer packaging or metal and fiber composites) become more complex, thus making recycling more difficult.



If we really want to increase our "micro" recycling quotas for plastic waste that goes back into the original applications, we need to improve and increase our actual sorting capabilities.

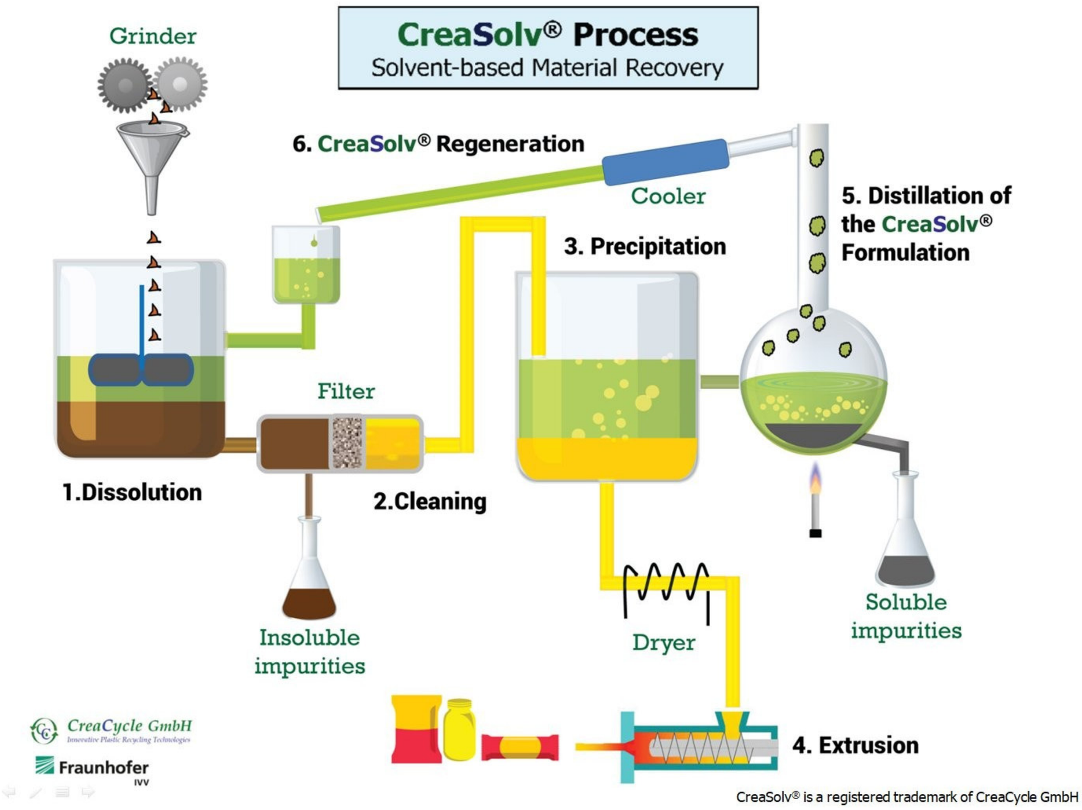
Based on this we have to add "new" recycling or recovery technologies like the "Dissolution".

In practice a combination of plastic recycling and energy recovery often takes place and additional recycling technologies will increase low recycling quota by opening up new waste streams which are actually considered as non-recyclable, what is actually the vast majority.

4. Dissolution (Purification)

is a technology known for decades and used in the chemical industry as cleaning process, but it is not a chemical process! It is a ***physical process*** because the substance (polymer) only changes its physical state from solid to liquid **without changing the chemical structure of the polymer chains**[5)]. A physical process can be reversable in contrary to a chemical reaction, because the latter produces new substances with a different composition (chemical recycling).

This physical behavior is the base for the CreaSolv® Process that was developed 2002.



The process concept is relatively simple and can be compared with a washing machine on a molecular level (polymer chains in comparison to textiles) that can remove imbedded unwanted impurities or additives (e.g. flame retardants or softeners which are actually considered as POPs - Persistent Organic Pollutants) or other materials in plastic composites (e.g. metals, fibers, etc). For more information please check: CreaCycle GmbH – CreaSolv® Process - https://www.creacycle.de/en/the-process.html

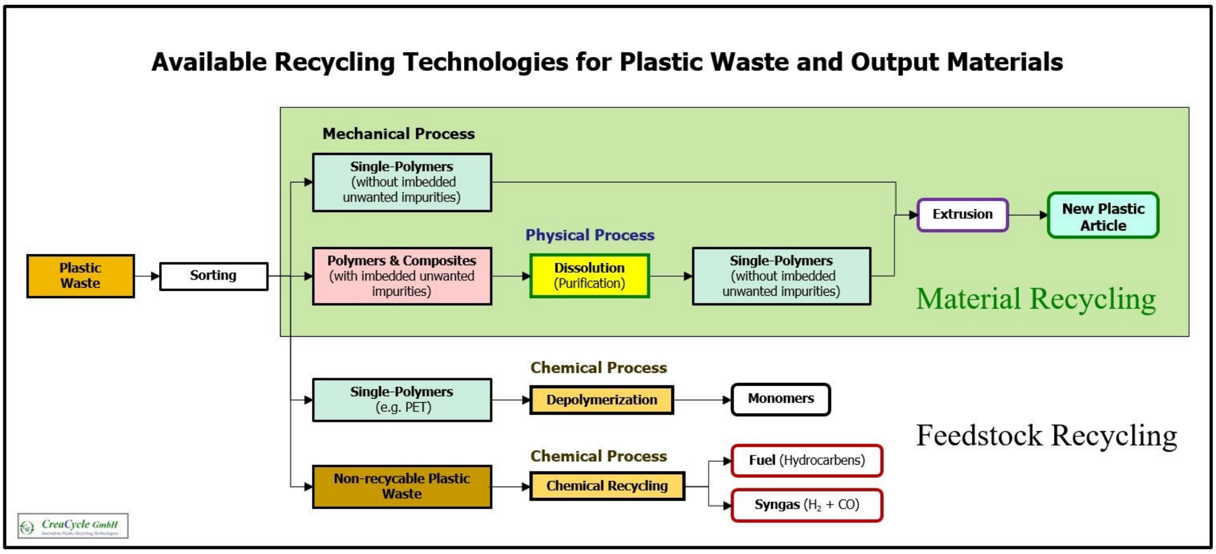
The output is in general a clean polymer, free of additives or impurities that can be re-used in the original application. This is why the "Dissolution" (or sometimes called Purification) falls into the category of "Material Recycling" like mechanical recycling. Because the dissolution will also wash out polymer degradation products to produce a purified polymer, the same polymer can be recycled multiple times without limitation.

5. Depolymerization

Certain polymers like polyester (PET) can be depolymerized. Glycolysis of PET is one of the most widely studied processes for PET depolymerization6). The polymer undergoes a chemical reaction back to the monomers which can be polymerized again to polymers to be used in the original application. At present several groups work on this subject and new processes, but I remember well when starting my chemical carrier with DuPont in the Luxembourg Mylar® plant (PET film production) in Luxembourg in 1981, that the first thing that impressed me, was the inhouse PET film recycling (out of specification material) via glycolysis. DuPont was the only company doing it and they started with this approach long before I joined and they considered it as a meaningful thing and a competitive edge.

Based on this experience I would assume that depolymerization will be another technology that will/should become more important for future plastic recycling options. Therefore, it may be recommendable to consider depolymerization as an individual recycling technology.

Interestingly Closed Loop Partners lists Purification (Dissolution) as a separate recycling technology that does not change the polymer on a molecular level in their report "Accelerating Circular Supply Chains for Plastics" [21] and according to their analysis in the US and Canada, current recycling infrastructure recovers less than 10% of post-consumer plastics.



Now that we have five different technologies for future "High Quality" plastic recycling, it will be useful to bring them into the right order like the Waste Hierarchy[7] to allow an evaluation in regard to protect the environment alongside resource and energy consumption from most favorable to least favorable options. If for example sorted based on quality (purity) of the recycled polymer, the carbon foot print and the ability to remove unwanted or legacy chemicals, the list may look like below:

1. Mechanical Recycling
2. Dissolution/Purification (Physical Process)
3. Depolymerization (Chemical Recycling)
4. Feedstock Recycling (Chemical Recycling)
5. Energy Recovery
6. *Composting*

- **Mechanical Recycling and Dissolution (Purification) do not change the chemical structure of the polymer chain** and both can be considered as "Material Recycling". The Dissolution is more divers and effective in dealing with imbedded impurities and other polymer types or composite materials.

- The Dissolution (based on the CreaSolv® Process as part of the PolyStyreneLoop Project[8]) has already been recognized as BAT (Best Available Technology) to separate the brominated flame retardant HBCD (Hexabromocyclododecane - actually considered as POP) as alternative to the mandatory incineration by UNEP Basel Convention Technical Guidelines[9] and Unilever is actually piloting this process for multilayer Sachet Recycling (polyolefines) in Indonesia[20].

- **Depolymerization and Feedstock Recycling (Chemical Recycling) change the polymer composition with a chemical process and are considered as**

"Downcycling". The output cannot be directly re-used in the original application (it steps down the "value chain"), except it is re-polymerized or re-processed, but has then a lower carbon footprint. If the plastic waste contains halogenated and/or other hazardous impurities, this may enforce incineration if they are not separated before and to low ppm levels.

- **The CO2 footprint increases from 1. to 5**.

- In general Material Recycling technologies have the best eco-balances because a major part of the energy used to produce the polymers is retained. Mechanical recycling is slightly better than the Dissolution. Feedstock Recycling (Chemical Recycling) and Energy Recovery typically show worse eco-balances. Both technologies are able to use a large part of the energy content of the plastic waste.

- **The monetary value (price) of the output products declines from 1. to 5**.

- For completeness ***Composting of bioplastic*** should be included in this overview, especially since this is actually widely presented as favored solution for packaging. Bio-based products are manufactured partially or completely from renewable raw materials and can be biodegradable or not biodegradable. According to DIN EN 13432 biodegradable means, that a material is capable of being decomposed by more than 90% to water, carbon dioxide (CO_2) and biomass within a defined period of time at defined temperature, oxygen and humidity conditions in the presence of micro-organisms or fungi[11)]. For bio-based plastics we need of course cultivation areas, which are becoming increasingly scarce with a growing world population and its increasing food requirements and biodegradable bioplastics decompose to water and the greenhouse gas CO_2, that contributes to global warming. Besides biomass composting generates the same as plastic waste incineration, but without energy recovery. Recent studies have also shown that bioplastic degrades very slowly and even biodegradable plastics remain in the environment for months or years[12)].

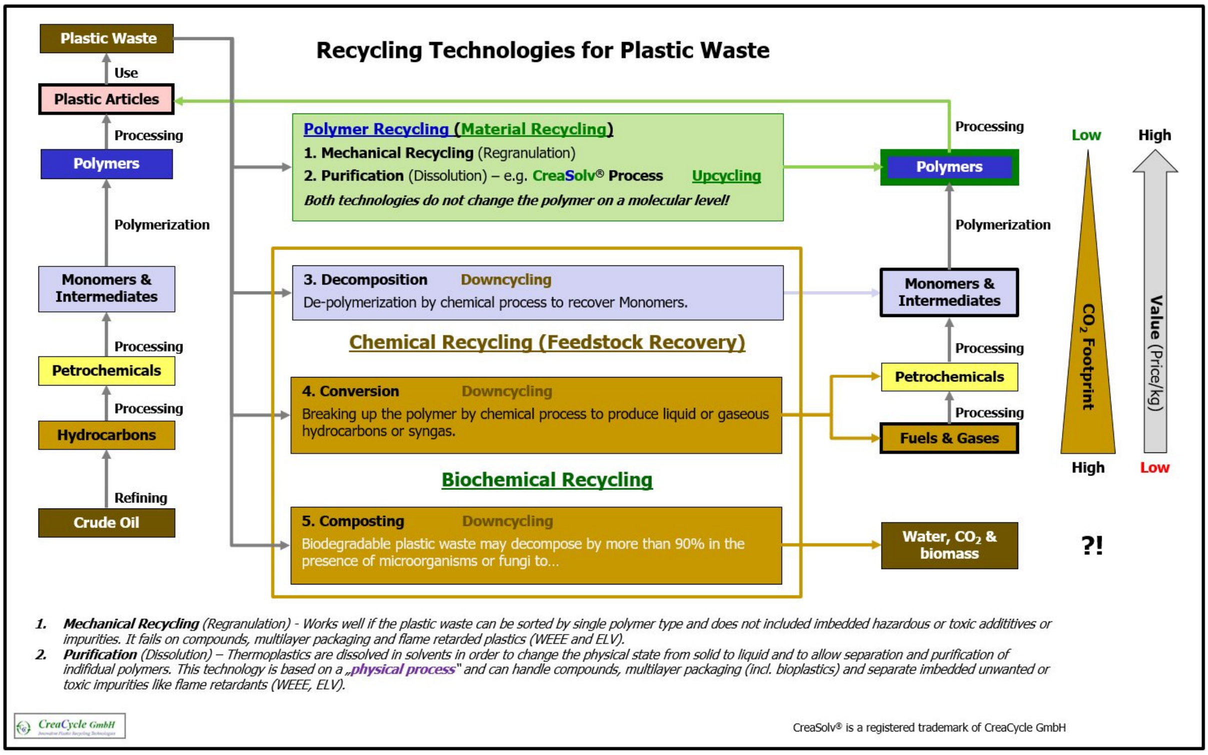
Due to problems during composting German municipalities refuse as a general rule the disposal of bioplastics with the biowaste[13)]. Bioplastic waste does not decompose (biodegrade) fast enough and is considered as impurity that needs to be costly removed. Not to forget that bioplastics may be used in multilayer packaging together with oil-based plastics.

Even the German Environmental Protection Agency describes it as a "**Bluff Package**" and recommends – together with Environmental Action Germany (DUH) – the incineration of bioplastic waste, because this allows at least an energetic recovery[14,15)].

Furthermore, a recent study of the University in Bonn suggests that shifting to bioplastics will lead to loss of forest and increased greenhouse gas emissions[16)].

Composting falls definitely into the category of "down-cycling" (breaks the polymer chain) and seems to be a problem for actual disposal and composting processes.

Of course, bioplastics can be recycled via Purification/Dissolution as any other plastic with the CreaSolv® Process[17)].



Conclusion & Outlook

When entire cities and corporations are presently aiming for "Zero Waste" goals and combine this with an aspiration or rule to exclude landfilling and incineration, then this may sound right, but may also be more difficult than they think[10)].

Definitely it will need more "true" plastic recycling in the meaning of "Material Recycling" back into the original applications, instead of making up numbers and exporting hazardous plastic waste to developing countries. It will also need the will to invest in the commercialization of new (or forgotten and ignored) plastic recycling technologies.

Looking at the actual available alternative plastic waste recovery technologies, the Dissolution (Purification) technologies like the CreaSolv® Process seem to be the only ones which offer a more effective separation capability to cope with imbedded impurities and multicomponent composites by enabling a much broader diversification in regard to different polymers, be it oil or bio-based.

Such "up-cycling" processes can meet the criteria for "High-Quality Plastic Recycling" and a Life Cycle Assessment (LCA) shows a 47% lower carbon footprint for the CreaSolv® Process (including transportation of the waste) versus incineration[19)], developed for the PolyStyreneLoop project that intends to build a demonstration plant with an annual capacity of 3.000 tons at the end of 2020 in order to prepare for growing volumes of expanded polystyrene (EPS) insulation boards from deconstruction containing the brominated flame retardant HBCD (today considered as a POP). In Indonesia Unilever is piloting multilayer Sachet Recycling and is confronted with the task to build a new collection network for the input waste stream, similar to PolyStyrene Loop for EPS in Europe. The first steps are done towards commercialization and we will find out whether such technologies can help to recycle more plastic waste and support a Circular Economy.

But there is also a price pay for end-of-life treatment for our fast-growing volumes of plastic waste and ignoring the fact that someone needs to pay for collecting, sorting and recycling will only force all of us to pay for with the quality of our environment and our health. This is a truth that will not go away with time, it will only become more obvious and frightening.

We have to come to grips with our self-made Plastic Waste Pollution and stop this "Tragedy of the Commons"[18)] instead of ending up as victims of our consumerism and ignorance.

CreaSolv® is a registered trademark of CreaCycle GmbH

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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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