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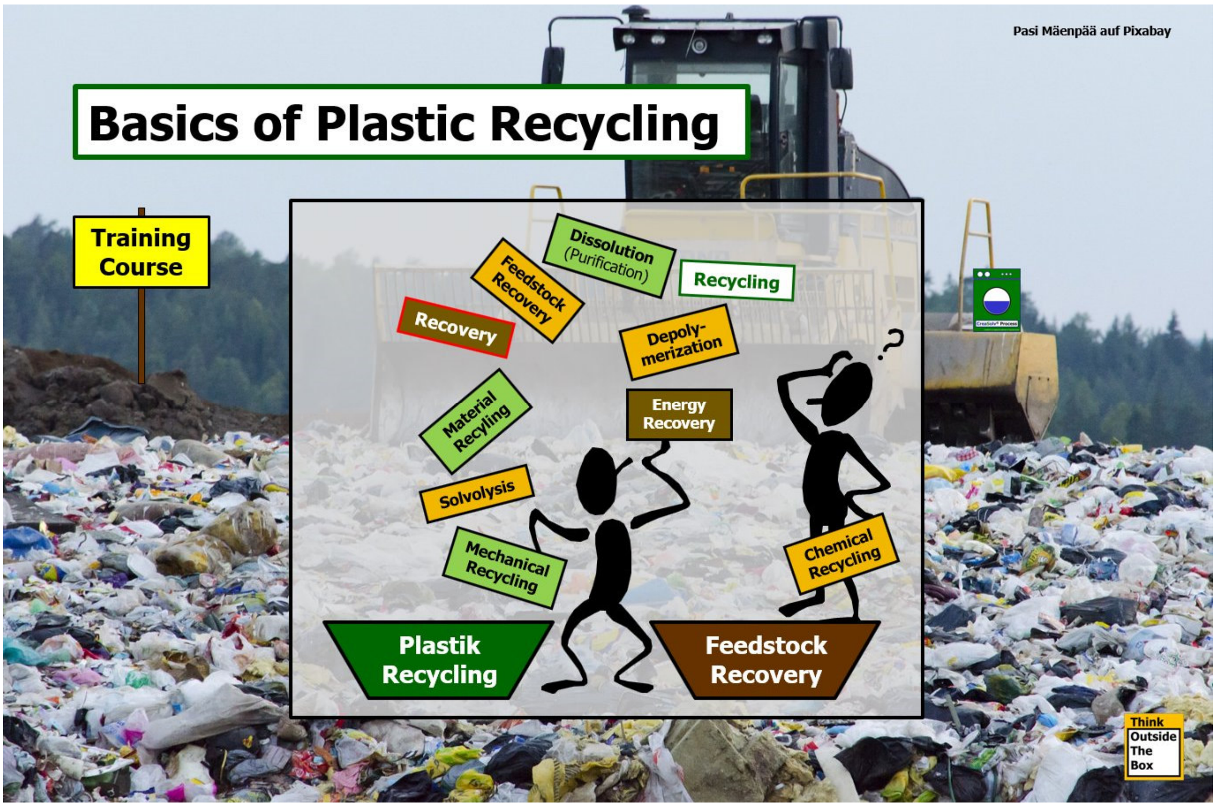
Basics of Plastic Recycling
Training Course



Over the last 2 years we have observed some confusion about available plastic recycling processes.

It seems that the Solvent-based Purification (Dissolution) technology has been overlooked or completely forgotten over the last decades and there exists uncertainty about the underlaying sciences.
Therefor we decided to offer a 2 minutes/day Training Course about the **Basics of Plastic Recycling** over a period of 15 days as Linkedin posts and started the project on 11th March 2020 for all those, which might be interested in this subject.

A post is limited to 1.300 sign, thus making it difficult to refer always to the literature used.
In this brochure with all courses we provide the literature sources for your review, verification and own follow-up.

What was intended as an experiment with the expectation that the audience would be very small (even on a network like Linkedin) for a rather "dry" science based and structured point of view, turned out to be a real positive surprise.
The large number of views from all regions around the Globe showed, that there was more interest in this subject than we thought.

The majority of the feedback was very positive.

Observations and Advice

Some comments to our posts showed very clearly that the subjects

- **Physical or chemical reaction?**
- **Dissolution or solvolysis?**
- **Recycling or recovery?**

are of critical importance when discussing plastic recycling technologies in order to compare their advantages and disadvantages.

As these were the initial triggers for the development of this training course, it was indeed a good confirmation for a **hidden need**.

We can only strongly recommend that you make yourself knowledgeable and confident enough to know the differences, so that you are prepared for discussions and are able to assess an information or a comment offered to you on these subjects.

Depending on your education, you may start with reference sites like **ThoughtCo** (https://www.thoughtco.com/about-us), one of the top-10 information sites. In 2018, they received a Communicator Award in the General Education category and a Davey Award in the Education category.

- ***Dissolving*** Sugar in Water: ***Chemical or Physical Change?***
  https://www.thoughtco.com/dissolving-sugar-water-chemical-physical-change-608347
- Is ***Dissolving*** Salt in Water a ***Chemical Change or Physical Change?***
  https://www.thoughtco.com/dissolving-salt-water-chemical-physical-change-608339
- ***What is a Chemical Reaction?***
  https://www.thoughtco.com/what-is-a-chemical-reaction-604042

Check more than one site or education program for pupils and students. If you see consistency in the information provided, you are on a good way.

Additionally, check **Wikipedia**, **Encyclopaedias** and **ScienceDirect**, a platform of peer-reviewed literature for R&D in order to cross-check and verify.

- **Solvolysis** 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.
  https://www.britannica.com/science/solvolysis
- **Solvolysis** 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).
  https://www.sciencedirect.com/topics/engineering/solvolysis

You have to develop your own point of view!

We can only help you to see a structure, a logical context or point you to critical areas, which may contain mis-interpretation or wrong information (intended or unintended).

With above preparation you will be well-equipped to judge information provided to you in our training course…
… and it will also help you to assess, what some experts may sometimes offer as information only certified by their years of experience.

So always be careful and look out for facts!

Basics of Plastic Recycling

Part 1

The Sciences: Physics and Chemistry

There exist two types of reactions which can be used to treat plastic waste.
They are differentiated by their out-put and what happens to the polymers.

Physical reactions don't produce new substances and the polymer chains in the treated plastic waste remain intact.

Chemical reactions always produce new substances and the polymer chains will be broken down into new smaller molecules / chemicals.

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

Physical or Chemical Reaction?

Basics for the Understanding of Plastic Recycling Processes

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 or other liquids**
- **Shredding paper (or plastic film)**
- **Dissolving sugar in water**
- **Melting a polymer** (e.g. extrusion)
- **Melting steel, glass and ice**
- **Dissolving a substance in a liquid**

Chemical Change

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

Examples

- **Burning wood, fuel or plastic**
- **Rusting of iron**
- **Polymerization & de-polymerization**
- **Pyrolysis of polymers**
- **Composting**

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Think Outside The Box

Part 2

Physical and Chemical Plastic Treatment Processes

20 years ago, physical treatment was called **Material Recycling**, capturing the concept of not changing the chemical structure of a polymer[1)]. This was soon replaced by **Mechanical Recycling** (diluting the concept!), focused on re-melting of plastic to granulates only.

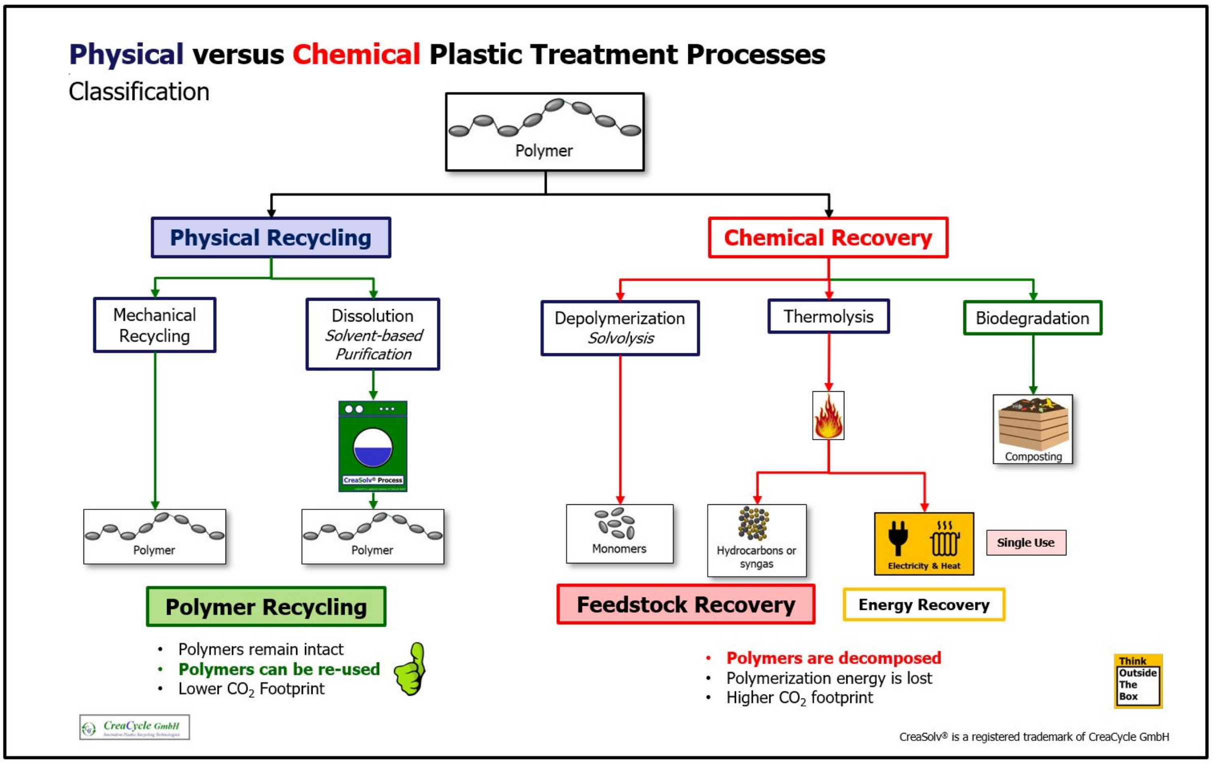
Solvent-based Purification (Dissolution) has been ignored or forgotten. It dissolves polymers and separates them from impurities (like washing).

Both above physical treatments need sorted waste streams and recycle polymers for re-use without changing their composition.

All chemical processes destruct polymers of plastic waste to smaller molecules, building blocks or monomers. This is considered as **Feedstock Recovery** based on the concept of regaining raw-materials (hydrocarbons). This requires a lot of (thermal) energy.

Pyrolysis and gasification can work with mixed plastic waste (but with consistent composition/quality) and produce liquids, naphta, fuel or synthesis gas (syngas).
De-polymerization also needs sorted waste streams and produces monomers.

Physical Recycling has a lower carbon footprint than **Chemical Recovery**.



Part 3

What is Solvent-based Purification (Dissolution)?

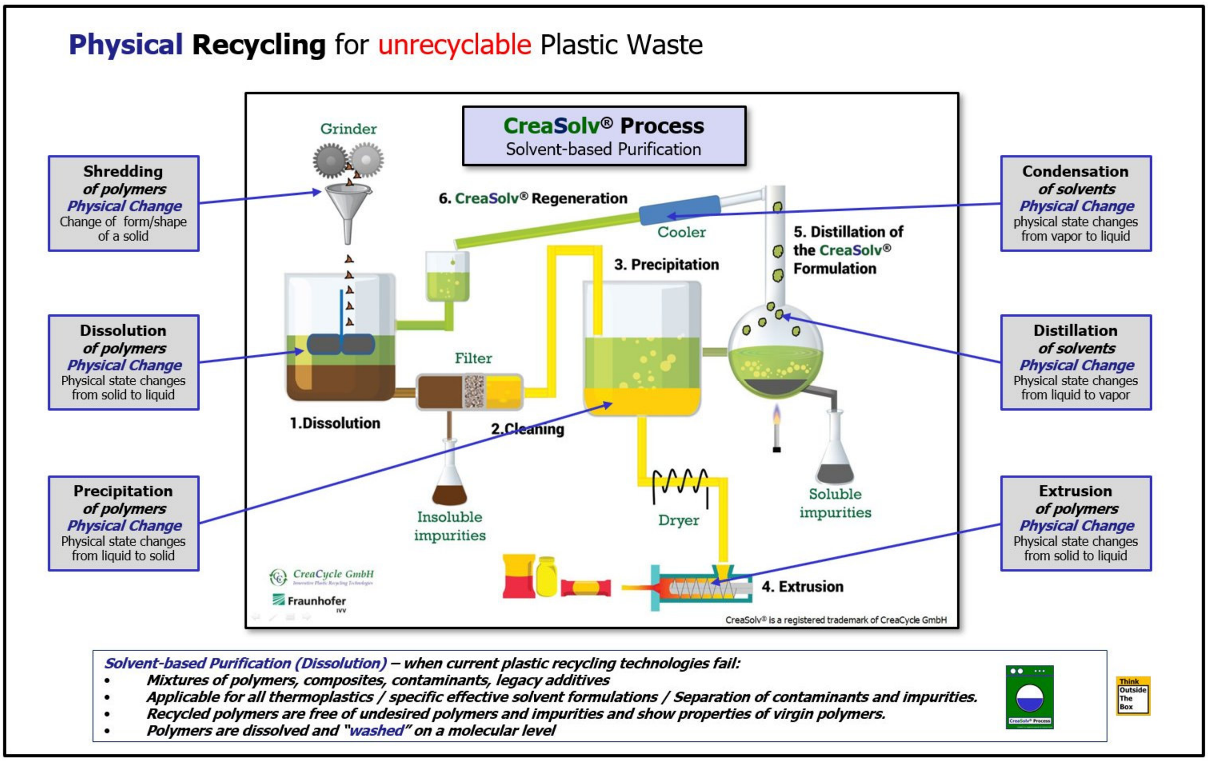
This technology is also known as solvent-based extraction[2)] (or solvent extraction[3)] or liquid-liquid extraction[4)]), and it is a common process in the production of industrial chemicals.

Solvent-based Purification of plastic waste will be explained at the example of the CreaSolv® Process[5)].
It works only with physical reactions or changes, so that only the physical state of the substance "polymer" changes from solid to liquid and back to solid. It also changes its shape during shredding, but the polymer chains remain intact.
The CreaSolv® Formulation (process liquid) changes its physical state when being recycled for re-use.

In short: The polymer is dissolved, filtered (cleaned) and precipitated. Impurities may not dissolve or stay in solution when the polymer precipitates. Finally, the polymer is separated, dried and extruded to granulates.

The CreaSolv® Process works like a washing machine on a molecular level and the result is a clean polymer that can be re-used in the original or a similar application.

The Solvent-based Purification (Dissolution) is a Physical Recycling Process for Plastic Waste.



Part 4

Solvent-Based Purification is no Chemical Recovery.

Several industry experts and NGOs incorrectly claim that Solvent-based Purification (Dissolution) is Chemical Recycling or a Solvolysis[6)].

The term **recycling** really suffers from **over-use**, obviously because it signalizes sustainability. Mixing up recycling and recovery leads to poor decisions and wrong recycling quota.

Recycling – reprocessing plastic waste for the original or similar purposes.
Recovery – any operation resulting in plastic waste serving a useful purpose (e.g. regaining raw-materials or energy)

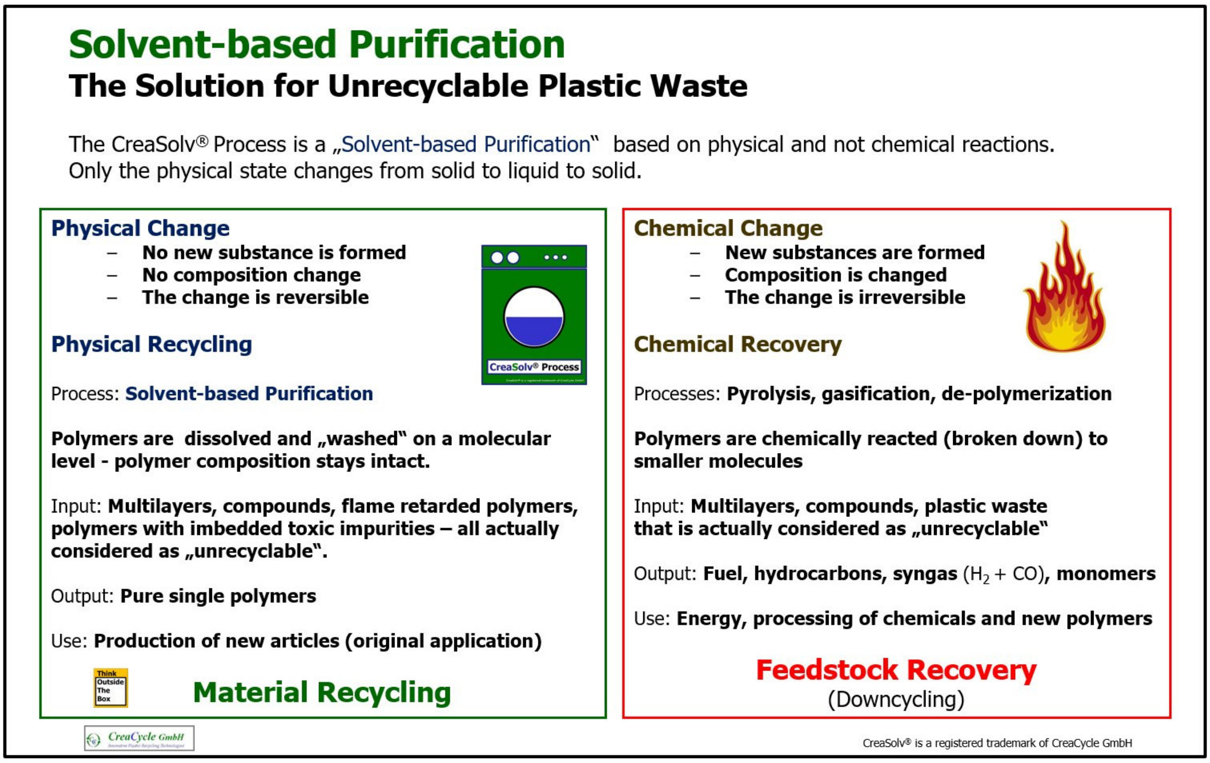
Solvent-based Purification produces clean polymers without changing the composition for re-use for the original or similar purposes.

Chemical recovery is based on chemical reactions like pyrolysis, gasification and de-polymerization.

Depolymerization can be achieved by **SOLVOLYSIS** (and other methods).

All chemical processes break down polymers into smaller molecules, building blocks or monomers. The output is called **feedstock** and the polymers don’t exist any longer. Feedstock (or raw-materials) can serve useful purposes.

Only when feedstock will be re-processed and polymerized back to polymers for the original or similar purpose it can be considered as **RECYCLING**.



Part 5

Recycling or Recovery? / EU Directives vs. Industry Standard

The EU Waste Framework Directive[7)] (WFD) defines **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 Waste Directive 75/442/EEC.
The same is valid for the Directives on end-of-life vehicles (ELV)[9)] and on waste electrical and electronic equipment (WEEE)[10)], but in the Directive on Packaging & Packaging waste[8)] the **final recycled product** is only the **material**.
The REACH[11)] regulation only speaks of **recovered substances** and "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 can be

- **recovered** by serving a useful purpose (plastic-to-fuel, energy, monomers or something else).
- Or **recycled** by reprocessing to plastic for the original or other purposes[27)].

EU Directives define essential requirements. Member States decide how to transpose them into national law. EU Regulations have binding legal force throughout every Member State.

Unlike laws, industry standards are not legally binding, their use is voluntary, except when being part of legislation[12)].
ISO 152270/2008[13)] defines certain **recovery** processes as **recycling**, when the Waste Directives don't.
This may lead to mis-interpretation or confusion.

Physical versus Chemical Plastic Recycling

EU Directives and Industry Standards

EU Directive on Packaging & Packaging Waste - 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
Recovery	Chemistry	**Polymerization** of monomers or processed feedstock	*feedstock monomers*	polymer	yes	chemical reycling

- ***Only Physical Recycling preserves the polymer for re-use in the original application.***
- ***Chemical Recovery should only be considered as Recycling, when the recovered Feedstock is processed & polymerized back to new polymers.***
- ***ISO Norm 152270/2008 defines certain „recovery processes" as recycling processes .***
- ***EU Waste Directives define terms like recovery and recycling, but not specific technologies. Recycling may be different in different Directives.***

Chemical Recycling = Feedstock Recovery + Polymerization

EU Directive 94/62/EC on Packaging and Packaging Waste

- *"**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 .*
- *"**Recovery**" shall mean any of the applicable operations provided for in Annex II.B to Directive 75/442/EEC (e.g. use as fuel or other means to generate energy, etc).*

***ISO 15270/2008 –** Guideline for recovery and recycling of plastic waste*

- *"**mechanical recycling**" - processing of plastics waste into secondary raw material or products without significantly changing the chemical structure of the material*
- *"**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.*
- ***recycling** - processing of plastics waste materials for the original purpose or for other purposes, **excluding** energy recovery*
- ***recovery** - processing of plastics waste material for the original purpose or for other purposes, **including** energy recovery*

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Think Outside The Box

Feedstock recycling (or chemical recycling) *means a process changing the chemical structure of plastic waste, converting it into shorter molecules, ready to be used for new chemical reactions.*
For instance, processes such as gasification and pyrolysis break down plastic waste to produce synthesis gas (syngas) as well as other liquid and semi-liquid products. ***In addition****, new* ***depolymerisation processes*** *are under development to convert some types of plastics back into monomers for the production of virgin plastics. Source:* ***PlasticsEurope:***
https://www.plasticseurope.org/en/focus-areas/circular-economy/zero-plastics-landfill/recycling-and-energy-recovery

Part 6

Definitions of Recycling, Recovery and Reuse

After 10 Minutes Course you have now reached the capability to become an adviser to the EU Commission, ready to help executing the New Green Deal with a special focus on plastic waste.

You start with the definitions of the draft EU Directive on Packaging Waste as documented by Prof. Arnold Tucker in his article "Plastics Waste – Feedstock Recycling, Chemical Recycling and Incineration" from 2002[1)].

1. Reuse
2. **Material Recycling** (plastic to plastic)
3. **Chemical Recycling** (plastic to plastic)
4. **Feedstock Recycling** (plastic to feedstock)
5. Energy Recovery

With a strong intent to enforce/stimulate more recycling of plastic waste, you will upgrade them only slightly and you will easily arrive at meaningful definitions as shown in the table below.

They swing now in harmony with the **recycling** and **recovery** definitions of the EU Directive and show an understanding of underlaying sciences and outputs of different plastic waste treatment processes, which can be combined, aiming at reducing the consumption of fossil resources and energy.

With this concept you are now ready for **Mapping the Future**.

Re-use, Recycling and Recovery of Plastic Waste

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 reactions**, 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 reactions**, 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 again**.

4. **Feedstock recovery** implies the processing of **plastic waste** with **chemical reactions**, 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 useful 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**.

Part 7

Physical & Chemical Recycling and Feedstock Recovery

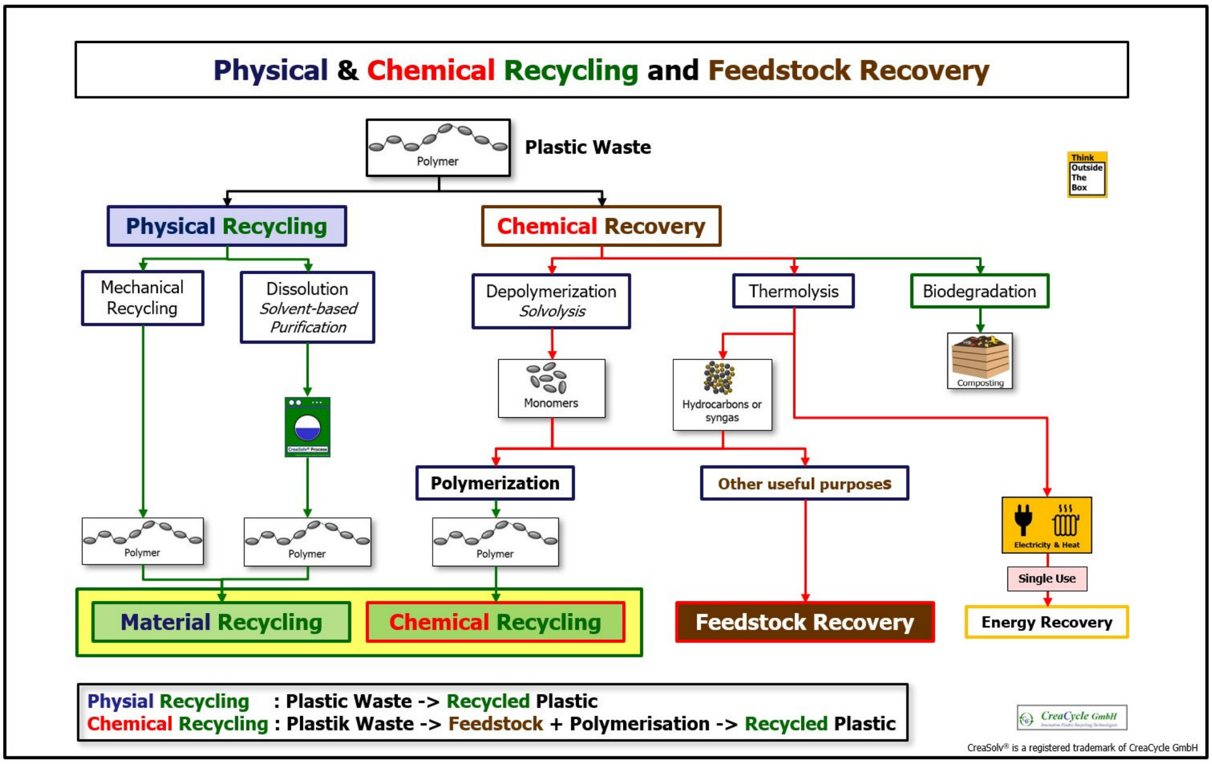
With DEFINITIONS, as formulated in Course 6 we are now ready to draw a map with all available plastic waste treatment processes, so that we can visualize "What is RECYCLING of Plastic Waste and what is not".

Physical processes allow recycling of thermoplastics[14)] (moldable plastic polymers) without breaking them down into smaller molecules.
They are the base of **Material Recycling** and fulfil the original concept of not changing the chemical structure of a polymer, so that it can be re-used in the original or similar applications[27)].

Chemical processes will always break down polymers and allow **Feedstock Recovery**.
This feedstock can be utilized for **other useful purposes** including the processing of other chemicals or new polymers.

Chemical Recycling is achieved by applying again chemical processes to feedstock (raw-materials) in order to process and **polymerize it back to polymers** used in the original or similar applications. The German Environment Agency does not consider it as recycling for packaging waste[27)].

This map points out, where the focus has to be set in the **Future Design of Plastic Articles** and the **End-of-Life Treatment of Plastic Waste**, if we really want to increase the Recycling Rates.



Part 8

Material Recycling – Mechanical Recycling vs. Solvent-based Purification

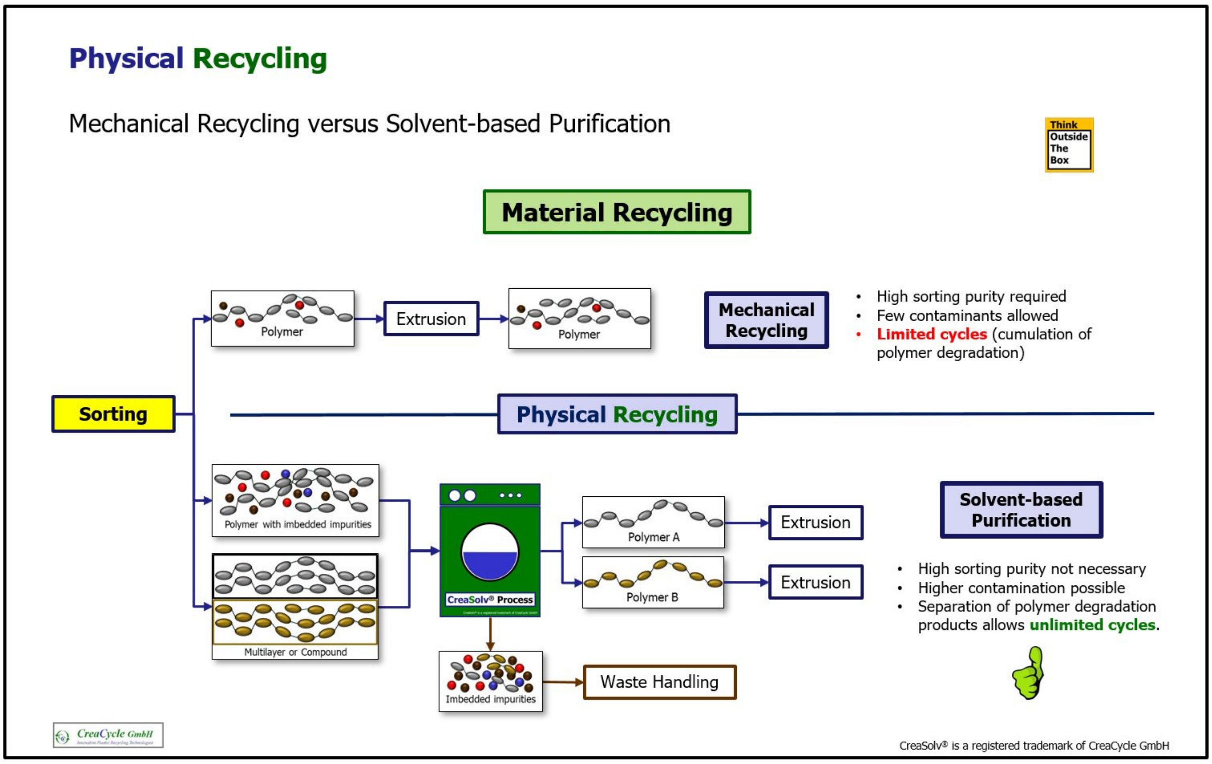
Mechanical Recycling – needs a high sorting purity of plastic waste streams and cannot separate imbedded additives, dangerous impurities, legacy chemicals or compounds with different polymers. It is very effective on mono streams (e.g. PET bottles) and has a low carbon footprint.

Both, extruding a new virgin plastic part and mechanical recycling cause polymer degradation, which limits the number of times it can be recycled. The degradation cumulates with each recycling.

Solvent-based Purification (Dissolution) - needs a lower sorting purity and separates imbedded additives and hazardous impurities. It can recycle plastic composites from electr(on)ical components, automotive parts or multi-layer packaging.

The process works like a **washing machine** on a molecular level and removes degraded polymer chains as well, thus allowing nearly perpetual recycling. It offers a wide field of recycling applications, especially for some plastic waste streams, which are today considered as "not recyclable". The carbon footprint is also low.

In November 2018 Unilever built a CreaSolv® Pilot plant for sachet recycling in Indonesia[15)] and proved that the CreaSolv® Recycling technology is a technically viable solution to recycle multi-layer sachets.



Part 9

Combining Material Recycling with Feedstock Recovery

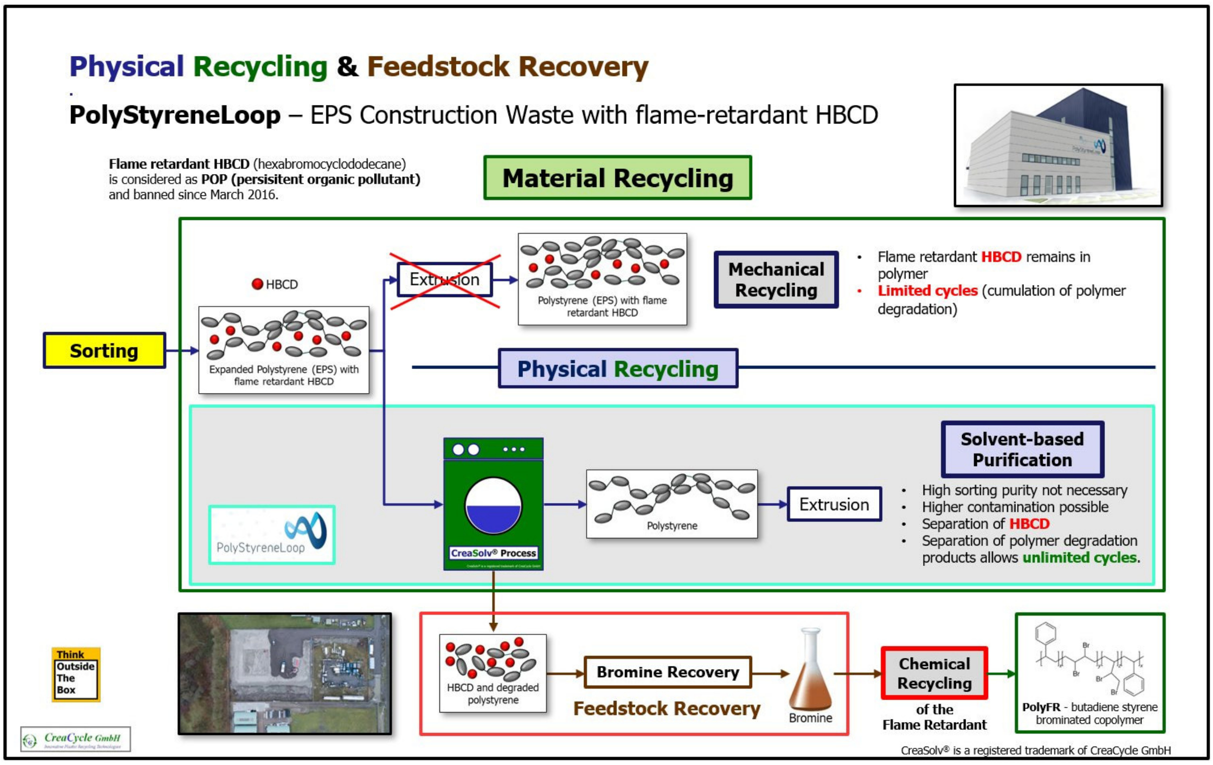
Polystyrene foam (EPS) is an efficient insulation material in buildings. The flame retardant hexabromocyclododecane (HBCD), which has been used since the 1960s, is today considered a persistant organic pollutant (POP) and millions of tons of EPS waste in our houses can no longer be mechanically recycled.

PolyStyreneLoop – a Cooperative with more than 70 members from the whole EPS value chain is actually developing a solution based on the CreaSolv® Process (Solvent-based Purification or Dissolution) that turns EPS and XPS waste into new polystyrene. During the process, impurities, such as cement or other construction residues, as well as the imbedded flame retardant HBCD are safely removed and **polystyrene is material-recycled**.

The HBCD is destroyed, while the valuable **bromine is feedstock-recovered** and can be chemically recycled to a safer PolyFR flame retardant.

The **Dissolution** is already included as BAT (Best Available Technique) in the Basel Convention Technical Guidelines for recycling of polystyrene with HBCD since 2017![16)]
A **Life Cycle Analysis** (LCA) is available.[17)]

A demonstration plant (3.3 Kt capacity) is being built in Terneuzen, NL with a planned startup in 2. Q 2021. Link www.polystyreneloop.eu



Part 10

Environmental Impact & Process Cost

In 2018 the Netherlands Institute for Sustainable Packaging (KIDV) compared 4 different chemical recycling technologies "solvolysis, depolymerization (+re-polymerization), pyrolysis and gasification" to help industry in their decisions when scaling up chemical recycling for packaging material in the Netherlands.[18)]
TNO and CE Delft provided the data for process cost & environmental impact.

The CreaSolv® Process for EPS recycling (PSLoop project) was chosen as example for a solvolysis.
Of course, during this course you learned that it is a Solvent-based Purification (Dissolution) and not a solvolysis (depolymerization).

> *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), but the still incorrectly classify it as chemical recycling.*[26)]

But this mix-up doesn't change the results! The data speak for themselves.

Solvent-based Purification (**material recycling**) combines a low carbon footprint with attractive economics.

Why is it so difficult to find mass & eco balances (LCAs) for chemical recycling technologies to be able to compare all plastic waste treatment processes?
The German Federal Environmental Agency (UBA) plans a comparison study, because they also have no data.

How can the EU decide on a Path Forward for the "Green Deal" without sufficient data?

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"

Part 11

Plastic Waste Recycling / Value Chain / Environmental Impact

There are 3 routes to recycle thermoplastic plastic waste.

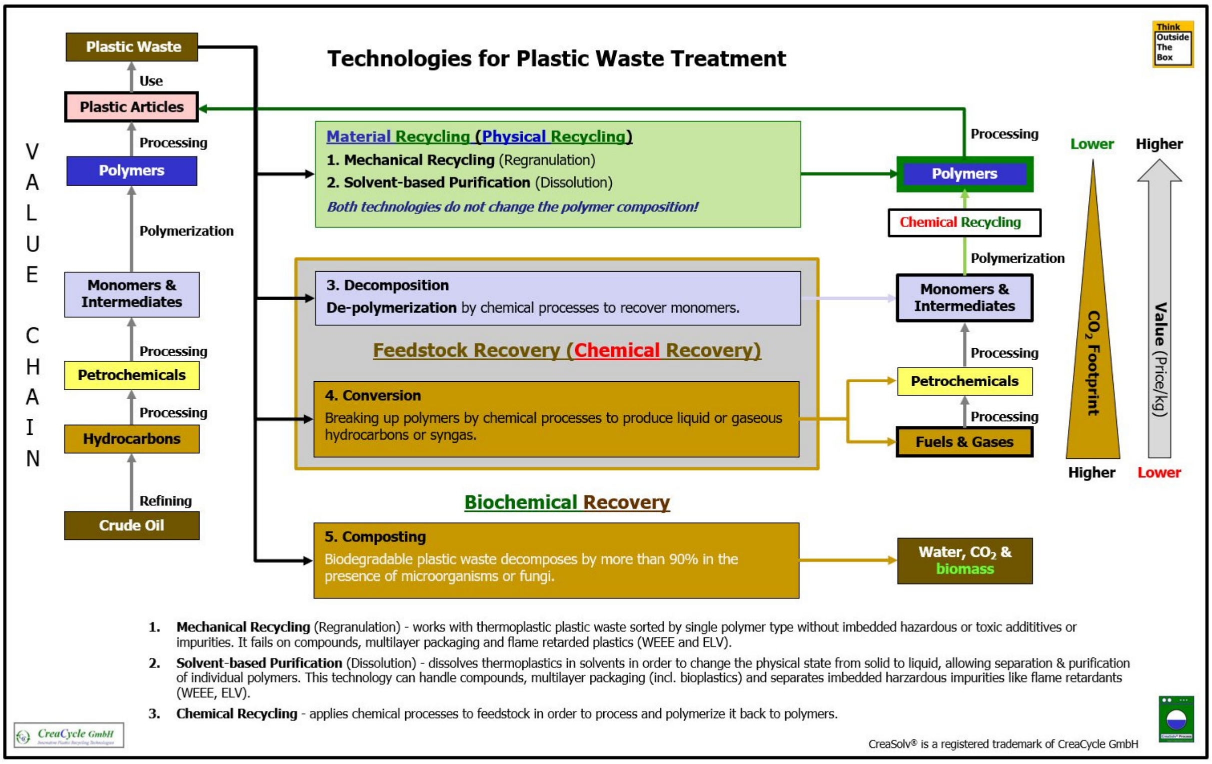
Mechanical Recycling – needs high purity waste and cannot separate imbedded additives (POPs, legacy contaminants) or different polymers. The number of times it can be recycled is limited. The CO_2 footprint is low.

Solvent-based Purification - accepts a lower waste purity and can separate imbedded hazardous impurities (legacy contaminants). It can recycle plastic composites from electr(on)ical components, automotive parts or multi-layer packaging and it removes degraded polymer chains and offers nearly endless recycling. The CO_2 footprint is low.

Chemical Recycling applies chemical processing to feedstock and polymerization back to polymers. The lower the feedstock is positioned on the value chain; the more energy is required to bring it back up to polymers. The CO_2 footprint is higher.

Depolymerization (Solvolysis) cannot separate imbedded additives or dangerous impurities.

Pyrolysis and **gasification** can handle mixed waste and dangerous impurities (e.g. halogenated substances) but the cleaning of the gases is very difficult.



The situation on compostable bioplastics is unclear. The German Environmental Agency (UBA) actually recommends the disposal of bioplastic waste via the residual waste. Then bioplastics can at least be incinerated with energy recovery.[19)]

Part 12

Recycling & Recovery in Circular Value Chains

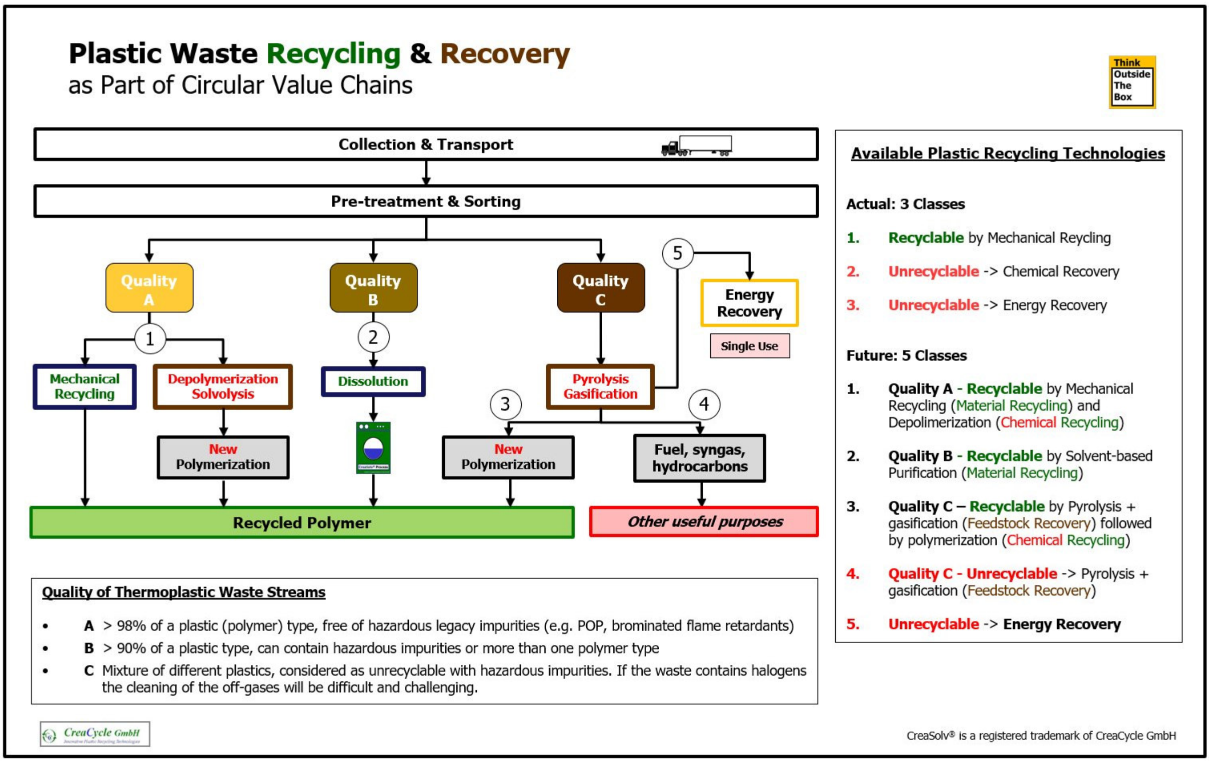
2018 the Technical University of Lyngby Denmark published their study "Quality Assessment and Circularity Potential of Recovery Systems for Household Plastic Waste"[20) and concluded that at best **55% of the generated plastic was suitable for recycling due to contamination**. Source-separation, a high number of target fractions, and efficient MRF (Material Recovery Facility) treatment were found to be critical. The circularity potential illustrated that less than 42% of the plastic loop can be closed with current technology and raw material demands.

The actual model, discussed and offered by the plastic industry only knows 3 technologies: Mechanical Recycling, Chemical Recovery (called Recycling) and Energy Recovery.[21)]

But if we look at all available processes and their capabilities as discussed in this course we could work with 5 classes based on 3 waste stream qualities.

- Pure mono polymer waste (**1)** without imbedded hazardous impurities for Polymer Recycling via Mechanical Recycling or Depolymerization.
- Mono polymer waste (**2**) with imbedded hazardous impurities for the Solvent-based Purification.
- Mixed plastic waste (**3-5**) for Chemical Recycling, Feedstock or Energy Recovery.

With this approach, more plastic waste could be recycled back into polymer.



Part 13

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)[22)] or the European Waste Hierarchy.

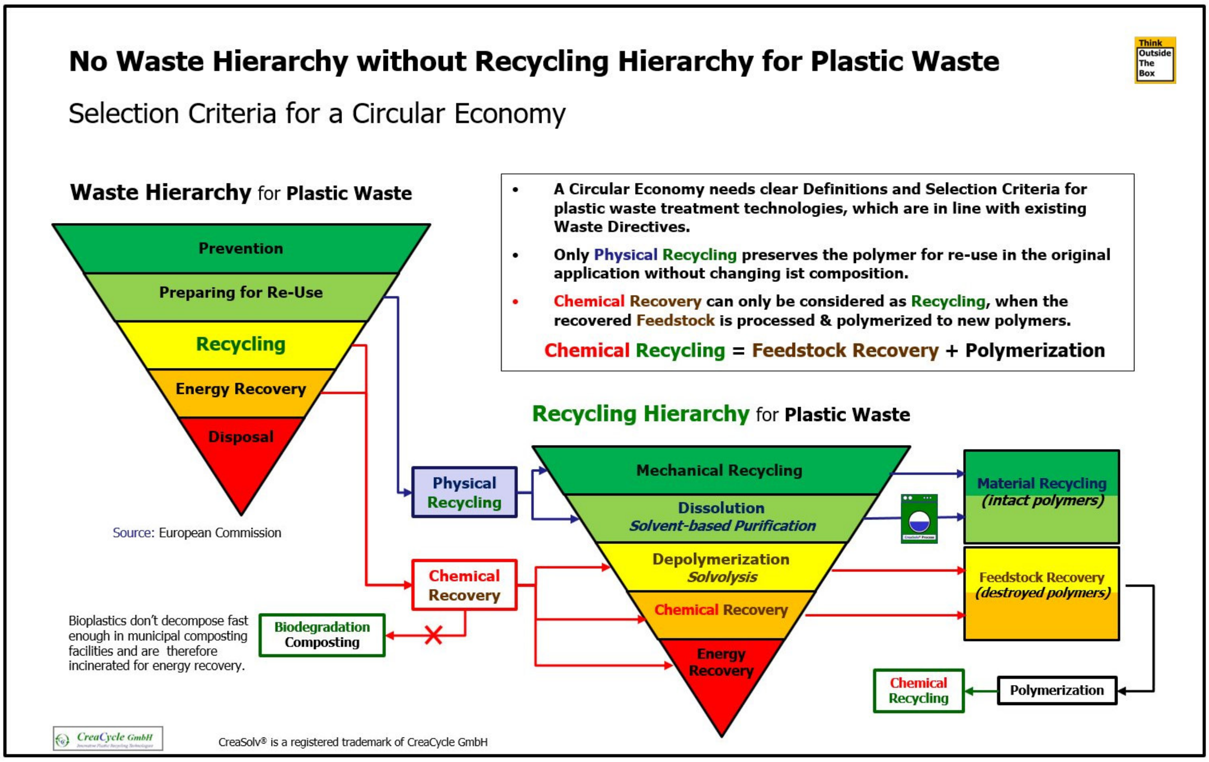
All existing plastic recycling technologies need to be defined, so that a differentiation is possible.

Industry standards like ISO 15270/2008 need to be upgraded so that they match the EU Directives (recovery & recycling).

Strengths and weaknesses of different recycling technologies need to be understood, so that they can be ranked in line with the Waste Hierarchy because only some plastic waste recycling technologies are able to keep the polymer on its value chain position.

It is only logical to apply a prioritization of certain recycling technologies versus others (based on Life Cycle Analyses and mass balances) if the desire is to **Re-use** a polymer instead of down-cycling it or burning it instead of fossil energy.

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



Due to problems during composting German municipalities refuse as a general rule the disposal of bioplastics with the biowaste[23)].
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[19,24)].

Part 14

Plastic Waste and the "Tragedy of the Commons"

The **Tragedy of the Commons**[25)] is a situation in a shared-resource system where individual users only act to their own self-interest, behave contrary to the common good of all users by depleting, spoiling or poisoning the shared resource.
"Commons" means any shared and unregulated resource such as atmosphere, oceans, rivers, fish stocks, beaches, soil, roads and highways, or even an office refrigerator.

After decades of ignorance we realize that we polluted the globe with plastic and in contrary to the Corona virus there was no enforcement to change our way of living. The environment and all creatures (including us) will have to pay the non-monetary price for it.
And the price for our individual health is unaffordable.

At present many large companies, organizations and authorities sponsor new recycling technologies but seem to focus on Chemical Recovery mainly.

If our societies will not **include end-of-life-treatment cost in the price for plastic or an article made with it**, in order to pay for waste recycling & recovery, we will fail in bringing back polymers into their original applications and closing the loops for a Circular Economy.

Link to Article: https://www.creacycle.de/en/press-news/187-2020-02-12-plastic-waste-pollution-the-visible-tragedy-of-the-commons.html

Part 15

How to achieve a Circular Economy?

Only with a clear structure, correct & meaningful definitions and a **Strategy for more Plastic Recycling** we will be able to take control over the plastic waste pollution instead of being victims of it.

Material Recycling (physical processes) and **Feedstock Recovery** (chemical processes) should be concerted with a **preference for RECYCLING** in order to increase recycling quota.

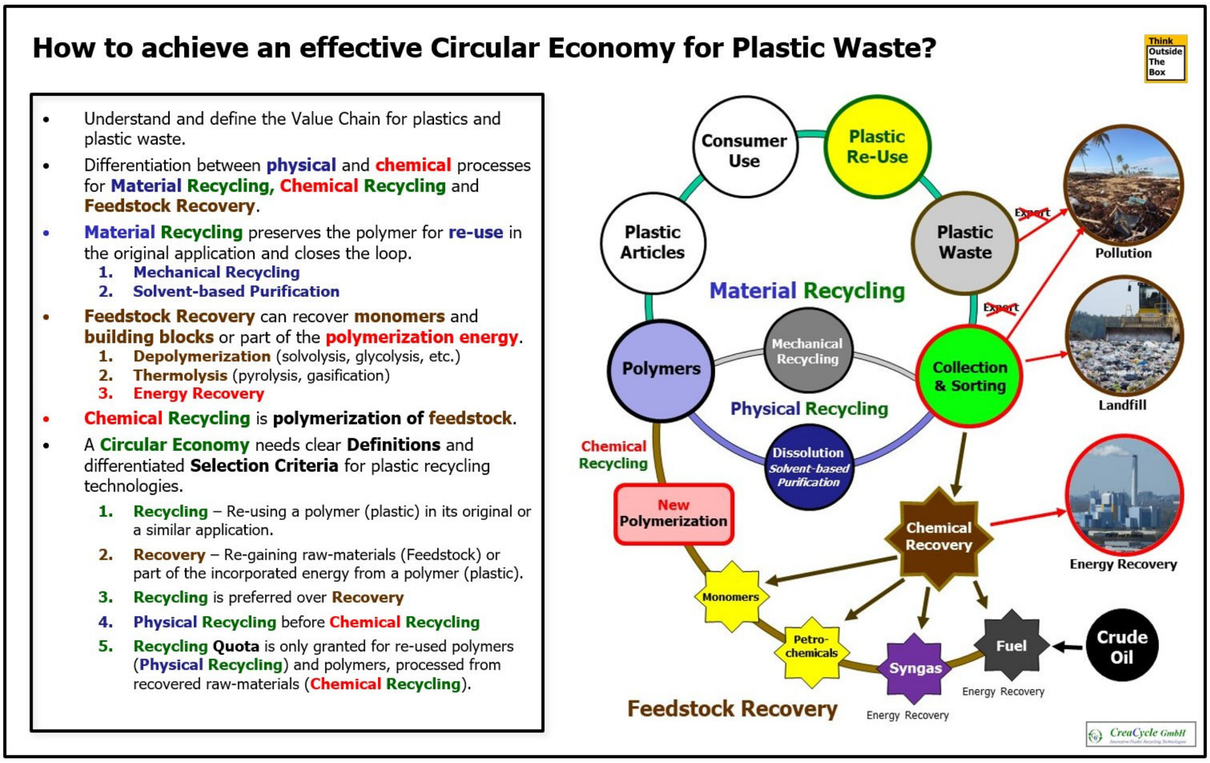
Feedstock should be preferably be polymerized to new polymers to increase **Chemical Recycling**.

Recycling quota should only be given for "recycled polymers" from Material Recycling and Chemical Recycling.

Industry needs to **develop plastic articles which can be recycled by above technologies**.

No export of plastic waste to developing countries.

End-of-Life Treatment Cost need to be added to or included in the price of plastic articles in order to fund plastic waste recycling.



Closing Comments

We hope that this training course was helpful and informative and able to demonstrate that

- there exist 2 (two) sciences: **Physics** and **Chemistry** for **plastic waste treatment**, but depending on which one is chosen, a polymer will change its composition or not.
- **recovery** and **recycling** may have different meanings when being mentioned in a directive, in an industry standard or in a discussion about plastic treatment for circular economy.
- there are **more plastic recycling processes** available than mechanical recycling and chemical recovery.
- there is a **need for clear definitions**.
- we need a **plastic recycling hierarchy** to drive more recycling versus recovery
- **End-of-Life treatment cost need** to be part of the price for plastic and/or plastic articles, so that investment in recycling plants and their operation cost can be paid for and **plastic waste gets a value**.
- we need data (e.g. eco and mass balances) to be able to compare plastic waste treatment processes.

For more information you may check

- **Chemical Recycling – Recovery or Recycling of Plastic Waste?** – *G. Altnau*
  https://www.creacycle.de/en/press-news/190-2020-03-01-chemical-recycling-recovery-or-recycling-of-plastic-waste.html
- **What is High-Quality Plastic Recycling?** – *G. Altnau*
  https://www.creacycle.de/en/press-news/176-2019-08-20-what-is-high-quality-plastic-recycling.html
- **Chemical vs. Mechanical Recycling of Plastic waste** – *ChemViews Magazine*
  https://www.chemistryviews.org/details/ezine/11222262/Chemical_Versus_Mechanical_Recycling_of_Plastic_Waste.html

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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