Recycling of Plastics

Facts and Challenges

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Tempora mutantur

2016

“According to a recent study, for more than two thirds of the German Population plastics have a positive image.” [1)]

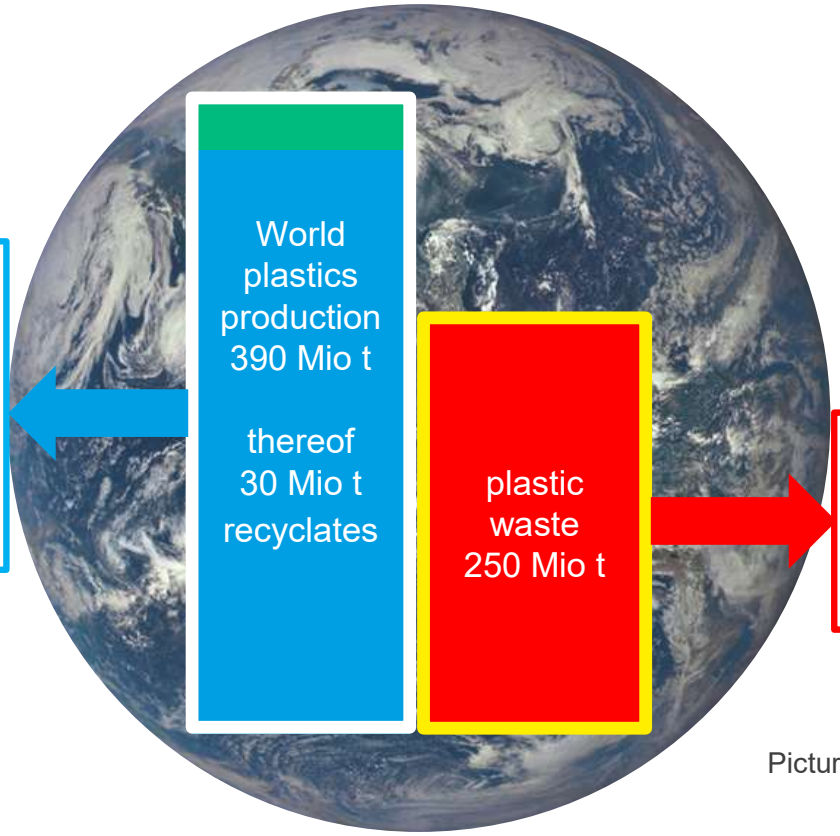
2019

“Plastics: image worse than ever.” [2)]

Where we are: plastics production and waste [3), 4)]

packaging*	40 %
building / construction**	20 %
automotive	10 %
electrical / electronics	6 %

*mainly PE, PP, PET, PS
**mainly PVC, PS-E, PUR



PET:
recycling rate up to 99 % due to well established collecting system

2/3 packaging (mainly PE, PP, PET, PS)

1/3 all other plastics

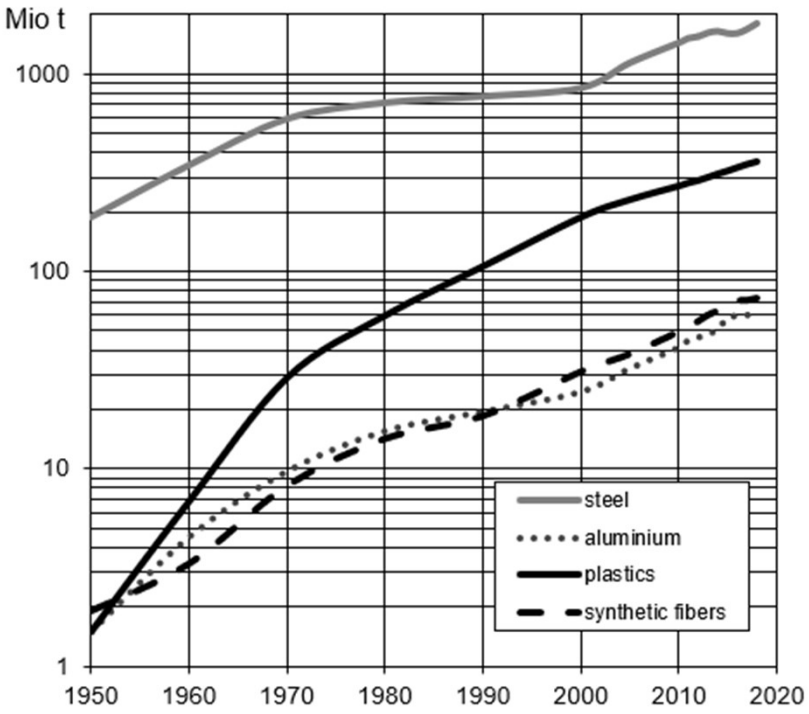
Picture: https://images.nasa.gov

total amount of „recycled“ plastics:	173 Mio t, thereof:
- **mechanical recycling:**	**50 Mio t**
- incineration with energy recovery:	51 Mio t
- landfilling:	72 Mio t

- 63 Mio t landfilled or incinerated illegally?
- 14 Mio t marine litter

From the beginning: plastics - a success story

Highest growth rate of all materials



World production of
steel, aluminium, plastics and synthetic fibers [5)]

Reasons for success:

technical and economical advantages over metal and other materials

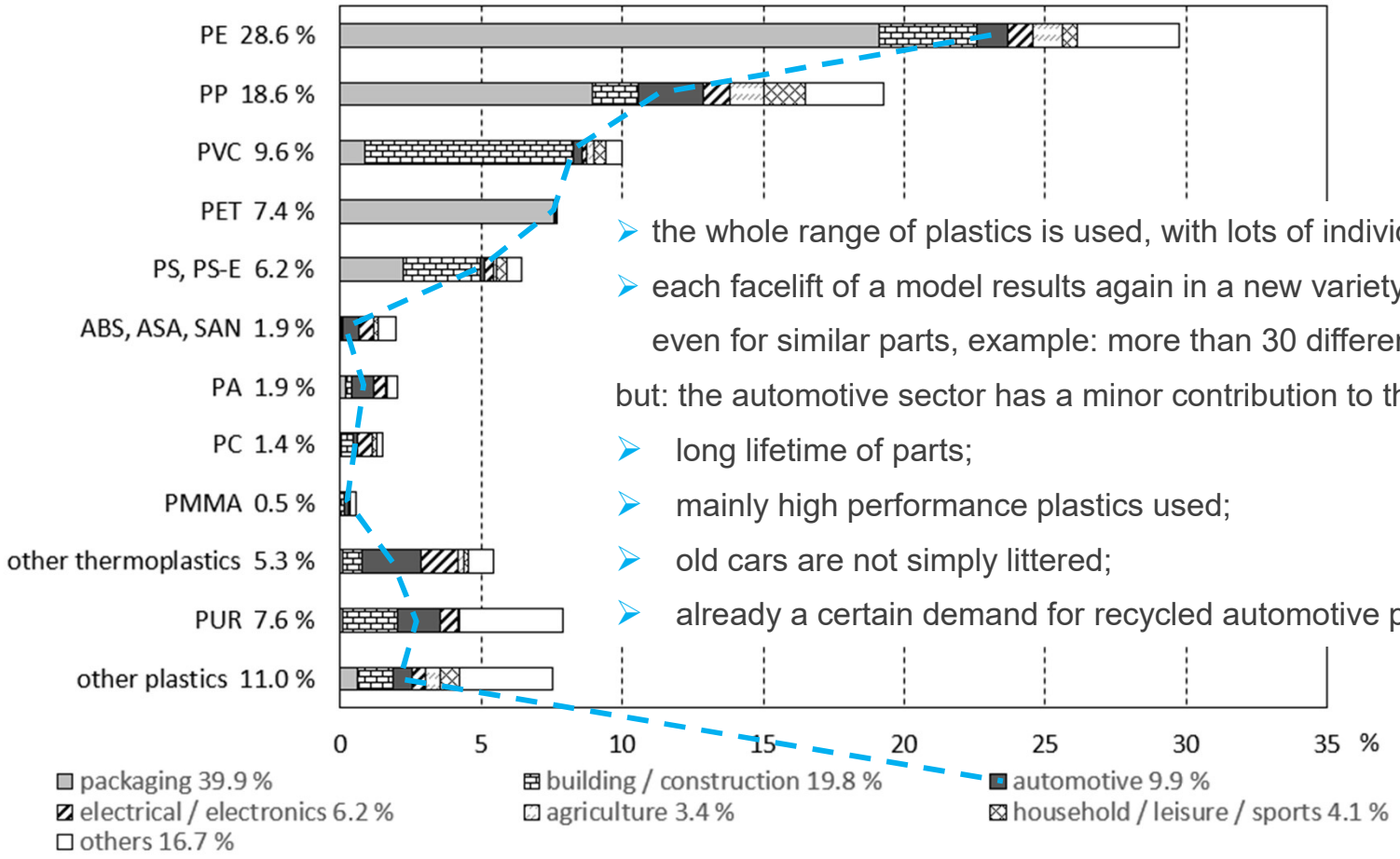
- **low density:** light-weight parts, lower energy and transport costs, fuel savings / increased range (particularly electric vehicles), reduced emissions of carbon dioxide and other pollutants;
- **low thermal conductivity:** lower demand for heating fuels, lower emissions;
- **hygiene:** protects foods from germs and extends the expiry date;
- **efficient processing:** low-priced mass production of articles even with complex geometry.

social components

- increasing population, life expectancy and living standards;
- growing demand for consumer and industrial goods;
- increasing desire for individual mobility;
- “throwaway society” and "to go“ culture.

How much do plastics used in automotives contribute?

Market share and applications of individual plastics [5)]



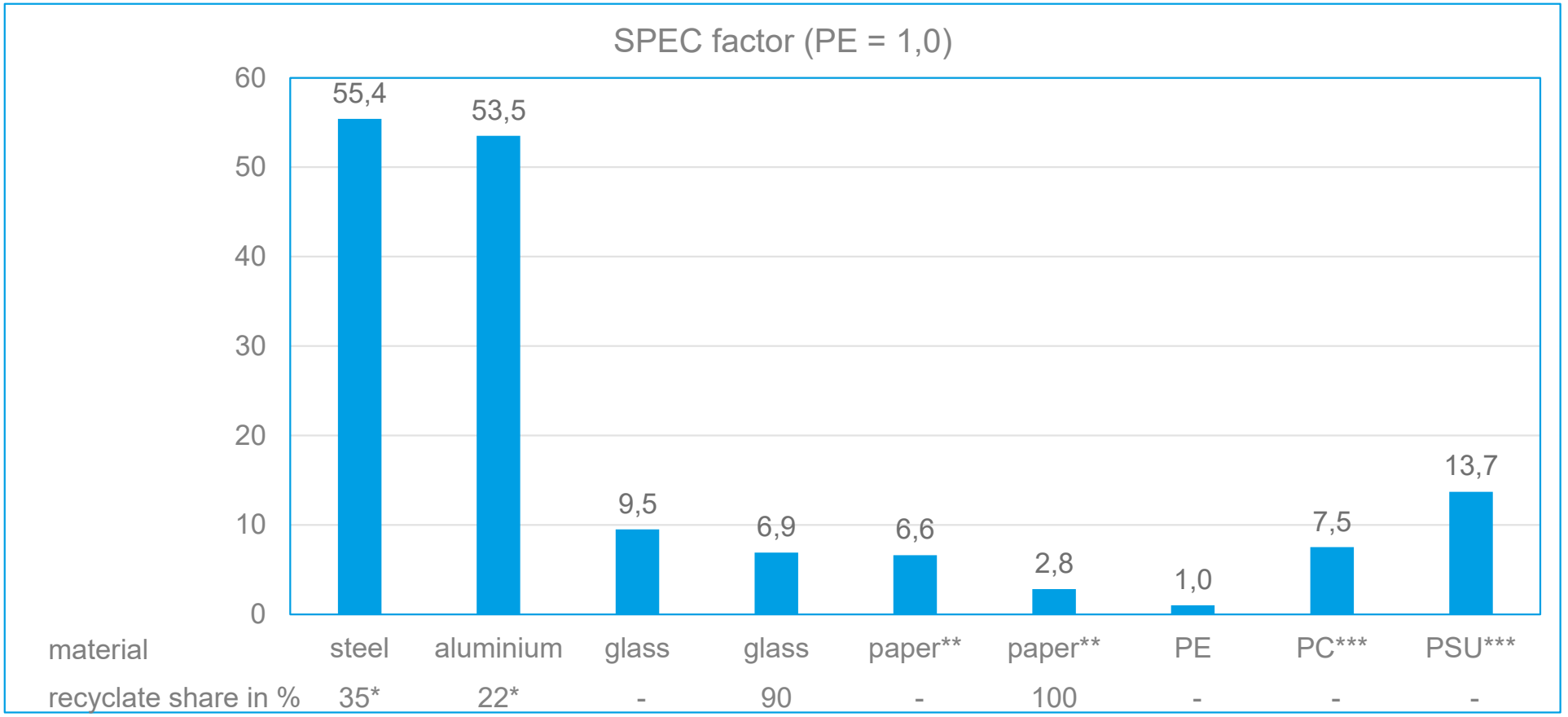
- the whole range of plastics is used, with lots of individual grades and modifications;
- each facelift of a model results again in a new variety of polymers, additives, colors... even for similar parts, example: more than 30 different beige colors for just one OEM!

but: the automotive sector has a minor contribution to the plastic waste only:

- long lifetime of parts;
- mainly high performance plastics used;
- old cars are not simply littered;
- already a certain demand for recycled automotive parts.

Are other materials an alternative to plastics?

Specific primary energy consumption (SPEC), volume related [5)]



* world average

** The enormous water consumption is not considered here.
Even if considering recycled paper, the replacement of plastic packaging back to paper is disadvantegous.

*** High performance plastics need to be compared with classical materials used for the same appplication.
Additional advantages such as lower weight, economic processing, breaking resistance and more have to be considered as well.

Are degradable or bio-based plastics the solution?

The “10 % fairy tale”

“Only about 10% of the world's cultivated areas is sufficient to meet the world's demand for plastics.”
Really?

True facts:

- limited available suitable cultivation area: competition with the production of food and feed;
- extreme demand for water, much more use of fertilizers, crop protection agents, fuels for agricultural machinery;
- significant deterioration of water quality and desertification.

Hence, the negative effects on climate and ecology would be increased.
So, especially in view of a growing world population, it is not possible to replace synthetic materials by bio-based materials.

Further disadvantages:

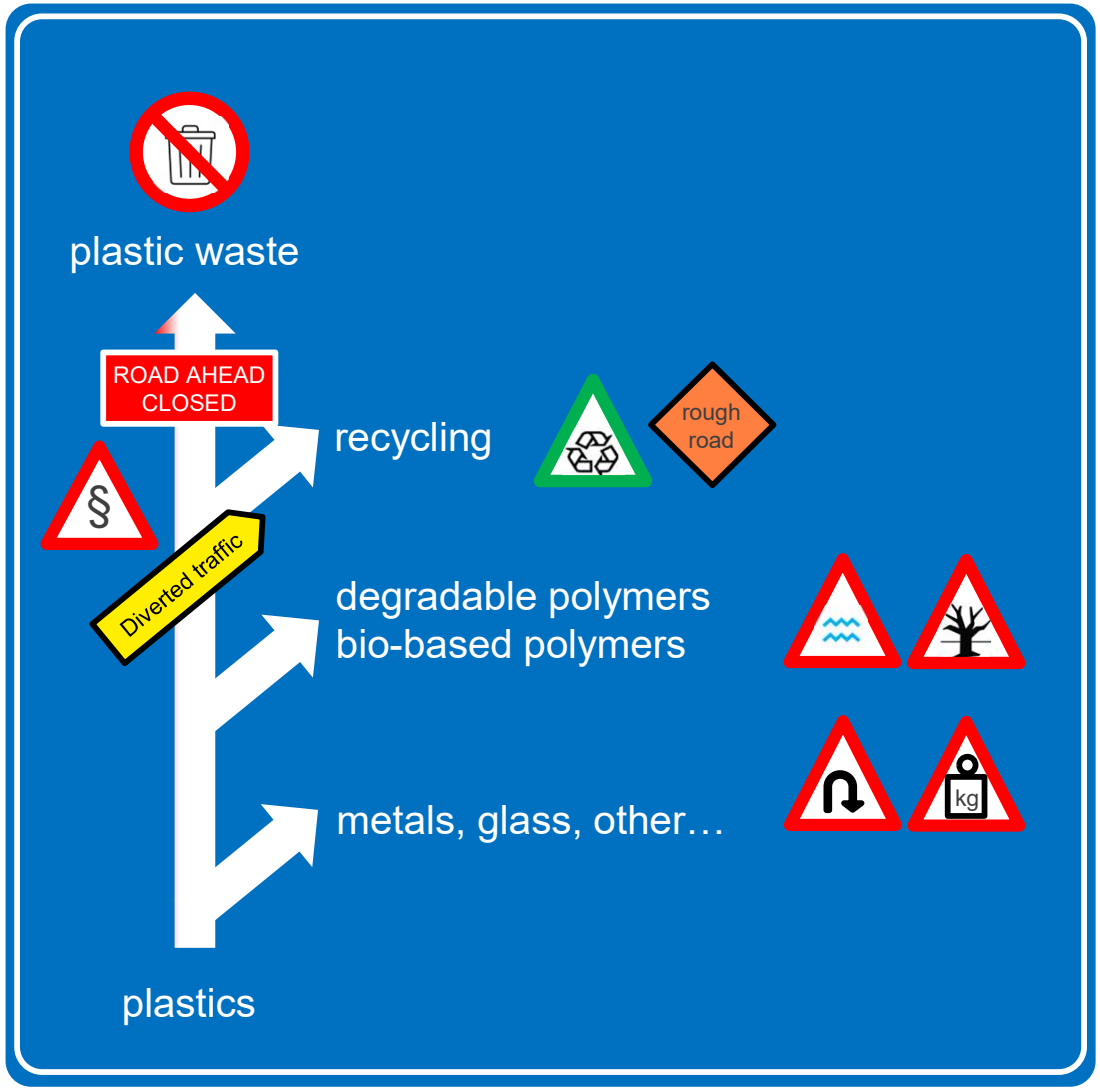
- plastics produced on biological basis are not automatically biodegradable;
- degradable plastics (whether on biological basis or not) cannot meet sophisticated technical demands;
- high-performance plastics based on renewable sources require a disproportionately high amount of water and energy;
- if used for disposable articles, degradable plastics encourages a more unmindful handling of plastics (deliberately littering).

By the way: waste of limited ressources?

- only up to 10 % of crude oil is used for the production of plastics.

Breaking new ground

E.U. Directive 2000/53/EC



Recycling of materials: a closer look inside

Plastics are completely different from other materials…

material group	internal structure
metals	atomic lattices consisting of one or several, but only a few kinds of atoms;
glass	amorphous, sub-cooled liquid, mainly consisting of silica (SiO_2), soda (Na_2CO_3) and lime ($CaCO_3$);
paper	cellulose fibers;
plastics	long chains of equal or different hydrocarbons; not / partially / fully cross-linked; combined with a multitude of additives.

… therefore recycling of plastics is different and more difficult!

Recycling of materials: an overview

Methods, advantages and disadvantages

material	recycling method	challenge	comments
steel	remelting	- tramp elements	- stable inorganic structure regained
aluminium	remelting	- tramp elements	- stable inorganic structure regained - reduced energy consumption
glass	remelting	- different chemical composition - pollution with pigments, metal and ceramic particles	- stable inorganic structure regained - reduced energy consumption
paper	water based solution process	- water consumption - accumulation of ink, adhesives, coatings - pollution with metal particles - reduced fiber length (tear resistance)	- mainly for cardboards and packaging - for high quality papers suitable to a certain extent only - questionable for foodstuff packaging
thermoplastics, thermoplastic elastomers	mechanical: grinding and remelting	- disassembling / collecting - separation, sorting, cleaning - structural damages (aging) through multiple thermal treatment	- reasonable costs for recycling - quotes up to 99 % are possible (PET) - r-PET, r-PE, r-PP, r-PA and others used in automotive applications already
elastomers, duromers mixed plastic waste	chemical: solvolysis, cracking	- different levels of complexity, depending on composition - halogens (depending on process) - energy consumption, compared to mechanical recycling	- energy consumption still lower than for recycling of glass or paper* - supplemental but effective method for mixed plastic waste and crosslinked plastics

established methods

* Such comparisons have to be made with materials that fulfill the same purpose, for example PET bottles vs glass bottles.

Recycling of plastics: mechanical process (1)

Unique composition

process

- visual and manual prescreening
- separation from metals, if required (magnets, electric fields)
- sorting by color, if required
- crushing down to approx. 10-30 mm
- washing with water and detergents
- remelting and pelletizing

examples

- non-automotive
  - water and softdrink bottles (PET), return rate up to 99 % due to „reward system“ (deposit)
  - crates (PE-HD): recycling rate up to 40 %, recycled crates in use for about 50 years already
  - window frames, floor coverings, roof coverings (PVC)
  - recovery from PS from polystyrene foam by melting under pressure
- automotive*
  - r-PE: tanks, wheel housings
  - r-PP: battery cases, front and backends
  - r-PET: console elements, technical parts, seats (upholstery)
  - r-PA: technical parts

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* Including approximately 3 % deficient products from primary production which are re-granulated and re-used. [6)]
This is sometimes called „in-house recycling“ but not considered as recycling according to ISO 14021.

Recycling of plastics: mechanical process (2)

Mixed (plastic) waste

process

- visual and manual prescreening and sorting of mixed waste (metals, paper, plastic…)
- crushing down to approx. 10 mm
- washing with water and detergents
- separation of plastics from metals by density (wet separator, air separator, cyclone, electrostatic separator)
- separation of different plastics (density is similar, with a few exceptions)
  - by infrared absorption (sequence of up to 10 infrared units)
  - by X-ray fluorescence analysis, laser spectroscopy (test phase, but not yet technically mature)
  - by solvents (different solubility in sophisticated solvents such as 2-butanone, tetrahydrofurane, xylene or mixes)
- sorting, remelting and pelletizing

current developments

- addition of IR sensitive markers (separation by IR not suitable for black colored plastic)
- digital watermarks, printed (such as matrix barcodes) or micro-topological variations of the mold (“HolyGrail 2.0”) [7)]
- solution process: new process with less flammable bio-degradable solvents in development (CreaSolv® Fraunhofer)

Recycling of plastics: mechanical process (3)

Challenges

technical

- separation of different plastics still not satisfactory
- solution process: flammability and toxicology of solvents
- detailed composition of each individual plastic not known if not suitably documented
- contamination with cleaning agents, mineral oil… which may have migrated into the plastic
- structural damage (aging) of the polymer chain due to multiple thermal treatment
- composites: short fibers cannot be separated and break in mechanical recycling processes
- in the long term, enrichment of recyclate in plastics, causing continuous and increasing deterioration of properties

automotive

- sophisticated mechanical and thermal requirements (safety parts)
- in contrast to metals, for each application individual tests and approval are required
- slightly heterogeneous composition even within the same polymer class (polymer, additives)
- detailed knowledge of chemical composition required (IMDS)
  - the complete product history has to be documented and updated through the whole lifetime
  - GADSL also contains substances allowed in direct contact with skin (e.g. zinc oxide, 2-phenoxy-ethanol…), insofar no general clearing for scrapped packaging of food or cosmetics.

logistical and commercial

- sophisticated collecting system required, adapted to application
- automotive parts: extreme expenditure for industrial-scale disassembling, sorting and storage

Chemical recycling of plastics

Principle

process

- breakdown to small molecules by solvolysis, pyrolysis or other

advantage

- monomers are recovered for the production of new polymeric materials or fuels
- high flexibility, suitable for mixed plastic waste
- the only suitable procedure for crosslinked plastics (elastomers, duromers) in order to recover raw materials

disadvantage

- high costs compared to mechanical recycling of an individual polymer
- some processes require separation of halogen-containing waste

challenge

- still not yet in industrial scale, but pilot plants are planned or are working already
- halogens (for example from PVC) can lead to corrosion

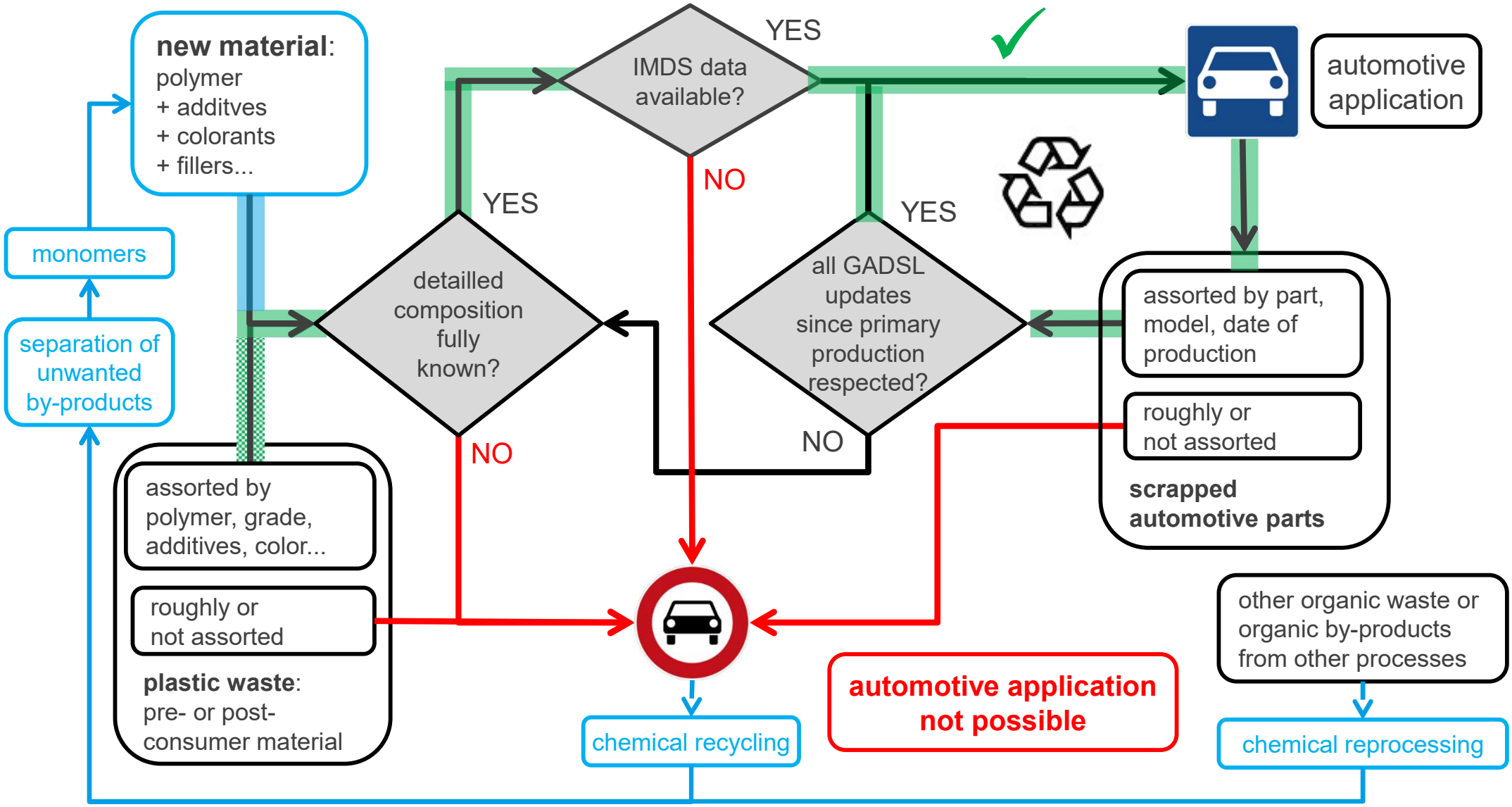
Chemical recycling of plastics

A quick overview

- solvolysis: splitting the polymer chain through chemical reaction
  - PA, PET and PUR react with water (hydrolysis), alcohol (alcoholysis), acids or bases in presence of catalysts
- depolymerization by heat or microwaves
  - PS to styrene monomer
- catalytic decomposition and destillation (about 400 °C)
  - PE, PP to fuels
- decomposition and hydrogenation (about 450 °C, 250 bar)
  - mixed plastic waste to fuels and oils
- pyrolysis (500 – 800 °C)
  - mixed plastic to pyrolysis oil and gases
  - less rate of yield compared to hydrogenation but also less complicated

IMDS and recycled plastics

A complete documentation through the whole lifetime is required



Consequences for automotive applications

For recyclates, IMDS material datasheets have to be submitted

Administrative requirements

- Recycling companies are material producers and hence have to provide corresponding IMDS material datasheets.
- In order to issue a correct MMDS, the complete product history has to be documented and updated through the whole lifetime.

Challenges

- pre- or post-consumer materials do not have a uniform composition
- plastic parts used for recycling must be free of undefined components or pollutions
- even the same automotive parts may be slightly different in composition due to different suppliers
- each facelift of a model results again in a new variety of polymers, additives, colors... even of similar parts
- industrial scale recycling requires disassembly plants and large storage capacities:
  scrapped parts need to be thoroughly assorted by part, color, model, date of production
- high performance plastics are contained in plastic waste only to a minor extent
- properties of recyclates may require to be enhanced by adding certain additives (“regenerates”)
- in the long term, enrichment of recyclate in plastics, causing continuous and increasing deterioration of properties

The road to a circular economy

To consider before production / use:

- consumption without waste is not possible;
- less is more: conservation of limited resources and the reduction of climate-changing effects can only be achieved by reducing the consumption of raw materials in general;
- think outside the box: even high-performance plastics can be produced from unwanted by-products or waste from other industries, which can reduce the amount of waste in general

Proper choice of materials and applications:

- plastics are indispensable, but certain applications are questionable
- metals, glass or other are no suitable replacement for plastics
- biobased polymers compete with foodstuff and cannot be the overall solution

Automotive re-use of material which has been scrapped:

- mechanical recycling requires sophisticated collection and separation as well as closed-loop documentation (IMDS)
- GADSL should generally allow all substances used in foodstuff or similar critical applications, then scrapped packagings of food or cosmetics in general would be suitable for mechanical recycling without bureaucracy
- chemical recycling represents a suitable supplement as new raw materials are produced.

Literature

Most graphs are taken from:

www.hanser-fachbuch.de
ISBN: 978-3-446-46291-5
E-Book-ISBN: 978-3-446-46525-1

Further literature:

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Pfandsystem fürs Badezimmer, Kunststoffe.de vom 28.04.2022

Thank you!

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