The role of plastic recyclates upgrade into safe products in the challenge of supporting circularity and the application of larger volumes of recyclates

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Waste handling panorama in EUROPE

The access to proper solid waste handling and the later landfill ban in central and northern Europe have fostered an unique perspective in the EU. The recycling rates of plastics and energy recovery have been a more sustainable alternative to the uncontrolled littering and landfilling in other locations of the world (Figure 1). Furthermore, the controlled landfill will continue to decrease and alternatives to incineration must be found. In many instances, the end of life by incineration is economically and environmentally costly but also opens opportunities for valorization of these streams. Therefore the further development of recycling technologies (chemical, solvent based and mechanical recycling) as complementary processes to optimize the environmental and cost panorama is required.

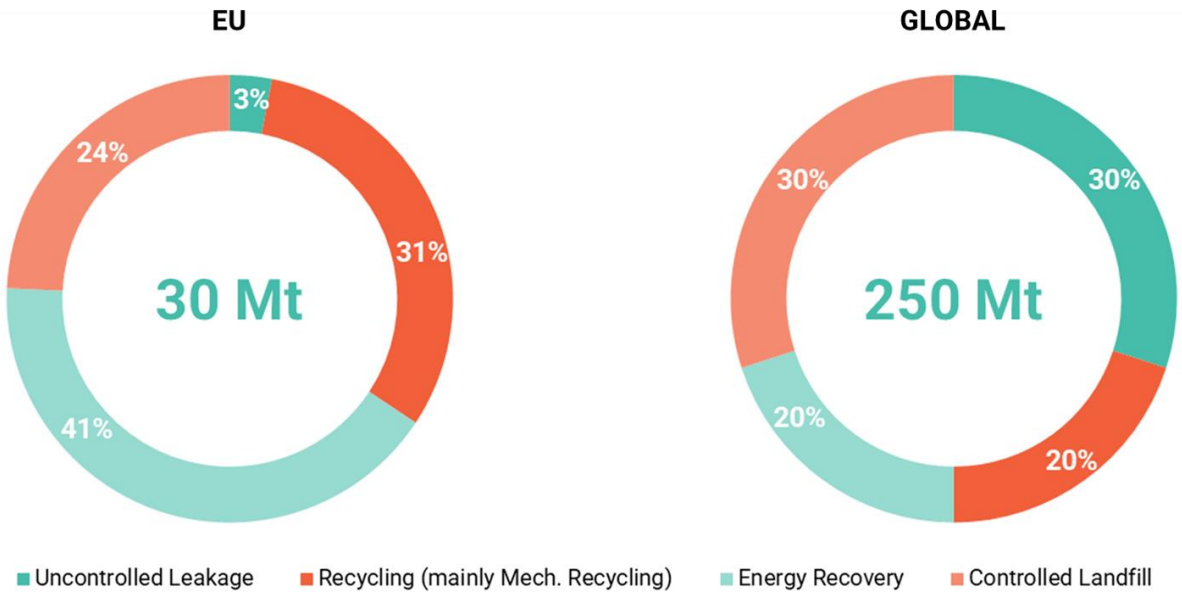

Figure 1 Plastics waste handling panorama in EU and Globally in 2018 [1]

This project has received funding from European Union's Horizon 2020 research and innovation programme under grant agreement N°820895

In the EU, the demand of plastics is about 50 Mt (2018), of which almost a 40% corresponds to Packaging, 20% to Building & Construction, 10% to Automotive and 6% to Electrical & Electronic market segments. Compared to the demand, only about 4 Mt of plastics (8% of the plastics demand) were produced in European recycling facilities. Considering the restrictions on the food contact approval for most of the packaging market, main opportunities for application of recyclates have been found in Building & Construction (46%), Non-food packaging (24%), Agriculture (13%) and in low levels in market segments such as Automotive (3%) and Electrical & Electronic (2%) [2].

In the European Plastics Strategy from 2018 [3], the EU has set the target to increase to 10 Mt of recycled plastics into products from the 4Mt in 2018 by 2025. To achieve that ambitious target, the value chain and technology development must cooperate to overcome major challenges when it comes to volumes, quality and safety with a focus on larger market segments such as Building & Infrastructure and packaging. In particular, it is of importance to focus in major market segments with low uptake of recyclates such as Electric & Electronic and Automotive (here the upcoming revised ELV directive may challenge the car industry with an overall recycling content target for plastics in cars).

Multiple factors have hampered the use of recycled plastics into products. Two main technological related issues are quality and safety while from the side of the market, the user perception of recycled plastics is often described as “cheap” or “poor quality”. Also, the value chain is not in place to deliver the volumes with a consistent quality and converters and brand owners together with recyclers are under development to bridge this gap. When it comes to safety, a significant limitation to maximize the recycled volumes is the content of legacy hazardous substances (LHSs) such as brominated flame retardants (BFRs) and Persistent Organic Pollutants (POPs) [1] [4] [5]. Due to the content of LHSs, the end of life of a large proportion of these materials, with an associated costs for the recycler, is incineration and in a minor proportion landfilling (with restrictions on the type and content of the contaminant) in the absence of sustainable and cost-effective purification and recycling processes. According to the life cycle analysis performed in NONTOX about a 50% of the polymers collected for recycling in the WEEE and about 95% of the ELV streams require or may require purification by specific treatments to meet the requirements for health and environment protection set by the current and upcoming regulations in EU [6].

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Certainly the introduction of economic incentives as well as more restrictive regulations are expected measures to be implemented to facilitate circularity.

The challenge of NONTOX

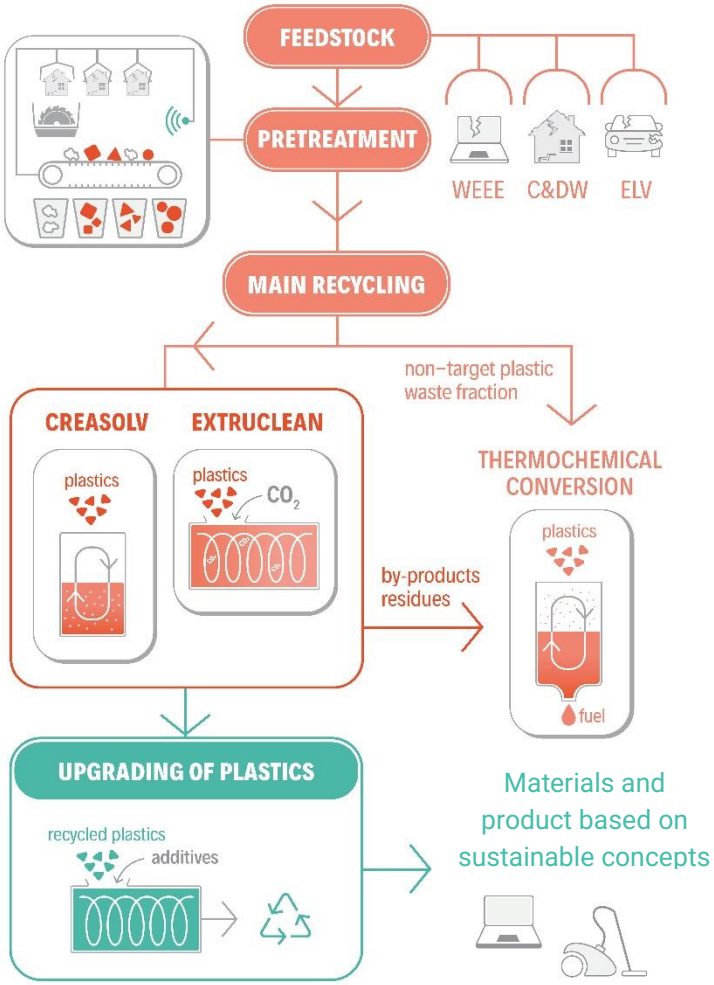

Figure 2 The NONTOX concept

The NONTOX project (Figure 2) with a value chain perspective, supports the achievement of the 10Mt EU target by developing sustainable technology for sorting, purification, material design and upgrade the valorization of residues, while improving the understanding of the impact of these technologies from an environmental and economical perspectives in the life cycle of the materials and products [5].

Waste streams handling perspectives in NONTOX

WEEE, ELV and C&DW are the plastic waste streams in the scope of NONTOX (Figure 3). When it comes to safety, the following types of LHSs are of major concern: BFRs are the most relevant hazards in WEEE [4], in ELV plastics (excl textiles) BFRs play a minor role, however PCBs and plasticizers are significant [5] and with respect to C&DW, plasticizers and the BFRs are the main LHSs [4].

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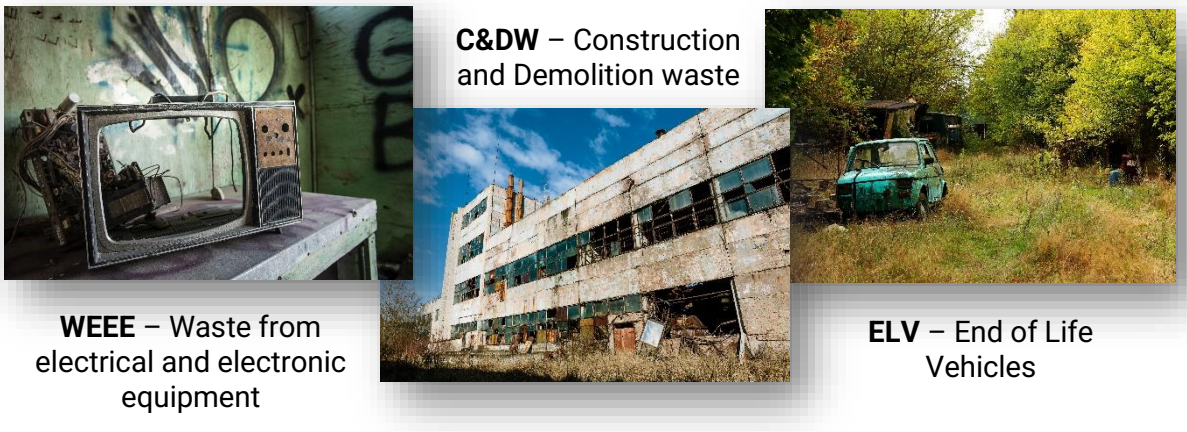

Figure 3 Polymer waste stream in the scope of NONTOX

For the purposes of material handling, two types of streams can be distinguished: single and mixed plastic streams. Mixed plastics streams refer to streams with less than 90% of a specific polymer type.

The strategy of NONTOX has been developed starting from density sorting which is the basic process in the recycling plants. Four main streams are the typical outcome of the density separation (Table 1) and have some important properties which have an impact on the quality and safety. Streams A and B can be refined towards single plastic streams. On the other hand, Streams C and D are complex streams and are considered mixed plastics. Moreover, from an early characterization work performed in NONTOX [7], Streams A and B have been found to have typical Br levels below 2000 ppm which make them categorized as non-hazardous by the current applicable EU regulations [8]. On the other hand, Streams C and D show levels of bromine much higher than 2000 ppm and are considered hazardous. Considering the previous, purification work on Streams A and B has been the focus for EXTRUCLEAN (purification with CO_2 on extruder with focus on polyolefins and styrenics). As for Streams C&D, the purification and recovery work has been done by CREASOLV (purification and recovery by selective dissolution and precipitation with solvents) combined with sensor based sorting. The main recovered polymers are HIPS, PC and ABS). Side steams of both processes as well as waste plastic streams not targeted by these fractions are treated for valorization by thermocatalytic conversion (TCC) towards monomers and pyrolysis oil (Figure 2).

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Table 1 Density sorting: practical density ranges for separation of plastics from WEEE, ELV and C&DW and NONTOX focus

Density range (g/cm³)	***Stream***	***NONTOX emphasis***		***Major polymers in the stream***	***Targets for Purification***
		EXTRUCLEAN	***CREASOLV***		
<1.0	A			**POLYOLEFINS** - PP, PE and versions with low levels of filler and reinforcing fibers	PP/PE, PE, PP
1.0-1.1	B			**STYRENICS** - ABS (low Br), PS &HIPS (low Br), filled and reinforced polyolefins	ABS, HIPS/PS
1.1-1.25	C			ABS (high Br), PS &HIPS (high Br), PC, PC/ABS, PA, soft PVC, PMMA. Filled and reinforced polyolefins and styrenics	ABS, HIPS, PC
>1.25	D			Hard PVC and other high density and highly filled polymers	

A, B: Monomaterial streams (>90% of one polymer type) (typically not hazardous)

C, D: Mixed streams

Material and product design in NONTOX

The way from waste into products starts from collection, continues by sorting and purification and is followed by the upgrading of the sorted and purified recyclates. The aim of NONTOX is to upgrade the properties of recyclates into compounds and products in high value applications such as electrical and electronic equipment, non-food packaging, consumer goods, transportation, building and infrastructure. To upgrade the recyclates, hence restore the primarily level of mechanical properties, processability in the melt (melt rheology), sensorial properties such as color and smell, and thermal and processing stability of polymers, the materials are upgraded by the incorporation of other tailoring materials such as other polymers, compatibilizers, stabilizers and other performance additives.

To support circularity from the perspective of design for recycling and design from recycling, NONTOX works in the development of materials with recycled content and products designed to fit the commercially available and economically feasible separation by density, to mitigate the formation of mixed plastic streams and secure materials that can be easily recycled again. The work focuses on monomaterial products, including multilayered products and self-

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reinforced composites with polyolefins, styrenics and polycarbonate matrices. The overview of demonstrators that NONTOX will explore are presented in (Table 2).

A unique feature of CREASOLV is the recovery and purification of PC from mixed contaminated streams. NONTOX will explore the upgrade of PC towards PC/ABS blends applied in small domestic appliances and demonstrate the circularity of the material now enabled by CREASOLV (DM2). From another perspective, cost is an important parameter of recycled materials in particular when the purification cost is transferred to the product, therefore NONTOX is studying the simultaneous purification and conversion of recyclates into products exploring scenarios where only virgin materials have been implemented. NONTOX will also advance some steps in understanding alternatives for components requiring food contact approved materials as the supply of food grade recyclates in the market is scarce and limited to PET and HDPE.

Polyolefins and styrenics are the most abundant polymer groups in the recycling streams from WEEE (mainly styrenics) and ELV (mainly polyolefins). It is therefore worth to focus on the proper design of these materials for their next life to facilitate the purification and sorting of future waste volumes. These two main families of materials are recovered from Streams A and B correspondingly for polyolefins and styrenics. One alternative are the multilayer combinations of virgin and recyclates which are useful in products made, e.g., from films and laminates in coextrusion, coextrusion blow molding and thermoforming (DM3), also attempts in rotomoulding could fit in this concept (DM4). Another alternative is also the combination of virgin and recyclates in advanced injection molding, e.g., two components injection molding, insert molding and overmoulding (DM2). A main target for this work is avoiding the modification of density by the incorporation of higher density modifiers such as other polymers, fillers and fibers that could result in the contamination of the higher density class during the sorting process. Here alternatives such as high-performance fillers in controlled amounts will be explored in addition to self-reinforced polymers. Polymers with enhanced mechanical properties by orientation and structure will be used to reinforce recyclates and limit the use of heavy reinforcements such as conventional fillers and fibers (DM1, DM7).

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Table 2 Prioritized demonstrators NONTOX: focus on circularity

DM#	***Target TRL***	***Demonstrator***	***Material Concept***	***Target application***
DM1	6	Vacuum Cleaner Base	✓ CE friendly materials ✓ SRPOs ✓ High efficiency fillers	E&E Appliances ***Also for*** *Automotive*
DM2	6	Shaving Machine Cover	✓ CE friendly materials ✓ Monomaterial multicomponent ✓ Circularity of PC/ABS enabled by CREASOLV	E&E Appliances ***Also for*** *Automotive*
DM3	6	Refrigerator Liner	✓ CE friendly materials ✓ Food contact parts from recycling ✓ Monomaterial multicomponent ✓ Multilayer ABCBA	E&E Appliances
DM4	4	Rotomoulded Item [e.g. fuel/septic tanks]	✓ CE friendly materials ✓ Monomaterial multicomponent	B&I Automotive
DM5	4	3DP Item [Multipurpose]	✓ CE friendly materials	Consumer goods
DM6	3	Purified and processed item [e.g. HP Insulation]	✓ CE friendly materials ✓ Simultaneous processing and purification	B&I
DM7	4	SRPO Item [e.g. Hockey protection equipment]	✓ CE friendly materials ✓ SRPOs	Consumer goods

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